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THE INTENDING–PERCEIVING–ACTING CYCLE IN SPORTS PERFORMANCE

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Summary
Whereas behavioural scientists have tended to emphasize the personal constraints of performers in attempting to understand perception and action in sport, from an ecological dynamics perspective, skilled behaviour consists of intentional adaptation to the constraints imposed by the environment during task performance. Ecological dynamics integrates an information-based approach to perception with a dynamical systems orientation to action. For a given task, a performer and the performance environment are treated as a pair of dynamical sub-systems that are coupled and interact mechanically and informationally. Their continuous interactions give rise to behavioural dynamics, a vector field with stable, avoided and changing system states. Sudden transitions in behaviours indicate that decisions emerge in the ‘intending–perceiving–acting cycle’. These ideas imply that there should be a strong emphasis on the specificity of the relations between the individual and the environment in designing representative settings both for experiments and for practice in sport.

Introduction
The ability of humans to select behavioural patterns that are tightly coordinated with the environment, when trying to achieve specific performance goals, has long been a concern for behavioural scientists. The production of stable yet adaptive behaviours raises two constituent issues. First, it implies the coordination of action, exemplified when the neuromusculoskeletal components of the body become temporarily organized into coordinated movement, or by the coordination patterns that emerge from the interpersonal interactions between players in sports teams. Second, it implies perception, such that information about the world and the body enables actions to be selected and adapted to environmental conditions. The problem of
intentionality and decision making is thus grounded on the problem of the coupling between sub-systems involved in perception and action (Warren, 2006).

From an ecological dynamics perspective, skilled behaviour consists of intentional adaptation to the constraints imposed by the environment during task performance (e.g. Araújo and Davids, 2009). The influential work of Kugler and Turvey (1987) drew attention to the role of information in guiding action, originally argued by Gibson (1979), but went further in modelling how human action is constrained by laws of non-linear dynamics. Gibson’s (1979) suggestion was that, rather than being localized in an internal structure, control is distributed over the performer–environment system. For Warren (2006), the structure and physics of the environment, the biomechanics of the body, perceptual information about the state of the agent–environment system and the demands of the task all serve to constrain behavioural outcomes. Adaptive behaviour, rather than being imposed by a pre-existing structure, emerges from this confluence of constraints under the boundary condition of a particular task or goal.

The link between information and action during sport performance

In ecological dynamics, perception refers to how animals, including humans, can be aware of their surroundings. For example, during locomotion, a performer can visually regulate their actions by detecting information from the optic flow. Optic flow is created by patterns of light available at a point of observation, structured by particular performer–environment interactions. In optic flow, particular reliable patterns of optical structure, called invariants, are relevant to guiding activity. Outflow and inflow are distinct forms of optic flow that inform the performer whether he/she is moving forwards or backwards. Flow is structured by the texture and objects that we encounter as we move around a performance environment (e.g. gaps, people, terrain) and allows us to discover invariants to regulate activity (Carello and Turvey, 2002). In order to effectively guide their activities, performers need to know more than just what they are approaching (i.e. perception for object identification). They also need to know how they are approaching (i.e. the spatio-temporal characteristics of how they are addressing a feature of the performance environment). Are they moving too fast? Do they need to adjust that approach? Should they slow down or speed up? Turn? Stop? For example, as a skilled rugby union player runs with the ball towards a group of defenders, he/she makes subtle adjustments to behaviour in order to control the impending collision. The player needs to maintain enough speed to engage them, but not so much that physical contact occurs. Effective performance requires that he/she knows when to adjust running-line trajectories in order to avoid being tackled.

Optical structure relevant to negotiating the environment has been identified and provides examples of quantitative invariants. The optical quantity called $\tau$ is specific to when a point of observation will contact an upcoming surface. As the performer approaches the defenders, their optical projection on the retina magnifies. The speed of approach affects this rate of retinal image expansion, regulating the change in optical area per unit of time. The quantity $\tau$ is given by the inverse of the relative rate of the retinal expansion – how long it will take until there are no units of time left (Lee, 1998). As our rugby player slows down (or speeds up), the rate at which $\tau$ approaches zero changes. The rate of this change (that is, the derivative of $\tau$) is specific to when to pass the ball to a support player or when to change running-line trajectory to avoid collision. It quantifies whether the observer’s kinetic energy is being dissipated (e.g. by braking) at a rate sufficient to stop movement before contact occurs. These descriptions of global optical structure capture situations when an observer is approaching a surface. But they are also relevant to a surface or object, such as a ball, approaching the point of observation. Local disturbances of optical structure are relevant to the guidance of interceptive behaviours and can be described in
terms of $\tau$ and its derivative, providing specific information to the performer on when and how the interception of an object, individual or surface will occur.

These theoretical ideas have been exemplified in research by Correia et al. (2011), who analysed time series positional data of rugby union players from video footage of competitive performance. The $\tau$ value of the distance–motion gap between an attacker (first receiver) and his closest defender was calculated, along with the duration of the next pass made by that attacker to a teammate (second receiver). Results revealed that the initial $\tau$ value predicted 64 per cent of the variance observed in pass duration. A qualitative distinction of $\tau$ dynamics between two periods of the approach between the attacker and the defender was also observed (Figure 3.1).

The degree of variability or dispersion in the entire time series of $\tau$ data (inter-trial variability) was compared between the period up until the first receiver got the ball (i.e. approach ‘Without ball’ – left-hand side of Figure 3.1) and after receiving the ball from the onset of the second phase of play (i.e. approach ‘With ball’ – right-hand side of Figure 3.1). To clarify, time zero refers to the time when an attacker who will perform a pass received the ball. The phase before time zero is termed ‘Without ball’, since the attacker whose pass is under analysis is without the ball during this initial period. Before the attacker receives the ball at time zero, both players are approaching each other. Then, during the phase ‘With ball’ (when the attacker has received the ball), the players continue approaching until the attacker releases the ball (i.e. makes the pass). Results showed that the point-by-point mean $\tau$ values computed were greater for the first period of approach than for the second phase. These data suggested that the time-to-contact values between the attacker and the defender may provide information about future pass possibilities. Moreover, these periods displayed dissimilarities in the point-by-point mean and standard deviation bands. The higher inter-trial variability during the approach ‘Without ball’, compared to a low variability in the approach ‘With ball’ indicates that these $\tau$ data points tend to be much closer to the mean $\tau$ in the approach ‘With ball’. Correia et al. (2011) argued that the informational fields constraining attacker–defender interaction may be viewed as a convergent channelling of possibilities towards a single pass solution (Figure 3.1).

While all performers need to perceive information on openings and obstacles to locomotion, what counts as an ‘opening’ on field necessarily differs between individual performers. How perception is ‘individualized’ is addressed next, together with the concept of affordance.

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**Figure 3.1** Point-by-point $\tau$ average band (M±SD) of the distance–motion gap between the 1st receiver and the defender. The mean is the black line, and the standard deviations are the grey lines. $X = 0$ marks the instance the 1st receiver receives the ball from the onset of the second phase of play, i.e. beginning the part of the approach ‘With ball’. (From Correia et al., 2011.) See text for further details.
The intending–perceiving–acting cycle

**Affordances**

Affordances are possibilities for action in a particular performer–environment setting (Gibson, 1979); they are what an arrangement of surfaces/textures/objects offers to a performer. Whether a hurdle, for example, is a ‘running over’ place or a ‘jumping off’ place is not determined by its absolute size or shape but how it relates to a particular performer, including that individual’s size and agility and style of locomotion. The assumptions central to Gibson’s (1979) theory of affordances are that: (a) actor-scaled properties of the environment afford a given behaviour to a performer; (b) informational invariants in energy arrays specify an individual-specific action; and (c) provided observers have perceptual machinery sensitive to this information, they are able to perceive an affordance (Gibson, 1979; Withagen and Michaels, 2005). The theory of affordances is based on the dual interdependence of perception and action, where affordances are the primary objects of perception, and action is the realization of affordances.

These ideas were exemplified by Esteves et al. (2011), who studied 1 vs 1 basketball sub-phases and showed that decisions made by an attacker to drive to the left or right of a defender were affordance-based. These investigators showed that the specific posture adopted by a defender guided the decisional behaviour of the attacker. Both novice and intermediate attackers made the same affordance-based decisions by driving to the side of the defender’s most advanced foot, but only at small values of interpersonal distances. Leftward drives emerged at smaller angles, which corresponded to the defender having his right foot advanced. Rightward drives occurred at larger angles, which corresponded to the defender having his left foot advanced. The use of this posture information by attackers trying to dribble towards the basket was not specific to expertise levels. This observation indicates how contextual information (e.g. posture of defender) directly helped to guide decisional behaviours – a finding in line with data from other studies (e.g. Cordovil et al., 2009). Decisions on drive direction when dribbling, in both skill groups, was based on transient postures emerging from immediate defenders. By acting on an affordance related to the information available in a performance context, performers can rely on information about a future state of the player–environment system, a functional way to control ongoing actions and achieve task goals. The perception of affordances depends on the level of attunement of an individual to relevant properties of the environment, acquired through experience and learning (Fajen et al., 2009). The fact that both groups acted on the posture information in a similar way indicates that novices may have been attuned to the relevant information sources even before the coupling of their perceptions and actions was fine-tuned.

Affordances exist on a continuum of action. For example, Pepping and Li (2005) showed that, for a performer, the distinction between two affordances for a standing reach and reach-and-jump action is not obvious: in the case of overhead reaching, as the required reach height approaches the maximum standing reach height, performers begin to exploit additional degrees of freedom until finally a critical boundary value is met at which an alternative reach-and-jump action emerges. As van der Kamp et al. (1998: 352) argued, action-scaled or ‘body-scaled ratios can be used as a critical determinant of action choice – a change beyond the critical ratio value demands a new class of action’. Van der Kamp et al. (1998) highlighted that this process of switching between movement patterns emerges from changes in the constraints imposed upon action for each individual. This explanation clarifies that individuals do not engage in conscious and rational mental calculations, comparing the current body ‘object-to-reach’ ratios with an internal representation of a critical ratio, and deciding on the basis of this comparison which action to execute. Rather, action may be considered an emergent process, under constraints, which harnesses intrinsic self-organization processes.
Action self-organization

Inspired by Gibson’s (1979) ecological psychology and the work of Bernstein (Bernstein, 1967), Reed (1996) argued that skilled behaviour requires subtle resource usage, asserting that behaviour is not intrinsically mechanical, but functional. He argued that, in the course of evolution, selection pressures gave rise to different action systems, enabling performers to establish new functional relationships with their performance environments. Whereas Gibson’s theorizing on affordances was primarily concerned with how they are perceived, Reed addressed how affordances are utilized. During performance in sport, resources can emerge from the performer (e.g. height, velocity) or from the environment (e.g. adherent floor, jumpable obstacle). Thus an action should not be considered as a simple displacement of anatomical parts of the body because complex biological systems exhibit the capacity for stable and unstable patterned relationships to emerge between system parts through self-organization (Davids et al., 2001). In the example of reaching and jumping, at the point of bifurcation (i.e. the critical ratio), the probability of using overhead reach and reach-and-jump actions is the same. An accidental fluctuation or perturbation to the system constrains the decision to use one or other action mode. Bifurcations show how open systems (e.g. biological systems which are sensitive to energy exchanges with the surrounding environment) often have several options in particular environmental conditions (Araújo et al., 2006). For example, when an athlete is running to gain possession of a ball in soccer, and suddenly slips, self-organized inter-limb coordination can occur, to compensate for the effects of gravity and to re-equilibrate the performer vertically.

In nonlinear dynamical movement systems, this type of re-organization process can occur in several functionally appropriate ways. Non-linear dynamics is a branch of physics that provides a formal treatment of any system which is continually evolving over time, and which can be formally modelled as a numerical system with its own equations of motion (Araújo et al., 2006). Within this framework, the behaviour of any living system can be plotted as a trajectory in a state space: the set of all states attainable by the system, together with the paths to them. Resting states of the system are attractors. A physical system can have one or more attractors. The number and layout of these attractors influence the overall functioning and behaviour of the system (Kugler et al., 1990). In human movement systems, attractors are roughly equivalent to functional states of coordination of system degrees of freedom (Kelso, 1995). For example, when dribbling in ball sports, this idea can be captured by the relative positioning of an attacker with the ball faced by a defender. When the defender matches an opponent’s movements and remains in position between an attacker and the goal, the form of this dyadic system remains stable (despite changes in specific variables describing its organization).

Self-organization processes emerge from the dynamics of open systems that intrinsically and autonomously create and destroy such stable system states. Transitions between states of organization (order–order transitions) occur at the timescale of perception and action, exemplifying interactions between athletes and the environment. These interactions initiate system trajectories from one marginally stable dynamic mode to another, providing the basis for athletes to select functional coordination modes. Structurally stable states of ordered behaviour are created or destroyed with reference to changes in the perceptual field (e.g. optic flow), allowing a performer to switch between different stable modes of behaviour. For example, a player who dribbles past an opponent near a goal area in hockey creates a transition region. In order to facilitate a transition, the attacker has to de-stabilize a stable state of system organization such as not approaching the goal until he/she can dribble past the defender, changing the dyadic system to a new state where he/she is approaching the goal.
The constant (re)structuring of system organization and behaviour emerges under the influence of constraints, which can simultaneously limit and enlarge the system’s range of behavioural possibilities. Bottom-up constraints are responsible for the initial formation of macroscopic order among system microcomponents (e.g. physiological processes of the athlete). While this is occurring, top-down constraints can ‘enslave’ the microcomponents into the macroscopic whole (e.g. competing at altitude). In this way, human behaviour can be constrained by the specific performance context in such a way that states that emerge are those that contribute to the performer–environment system’s desired behavioural goal. When microcomponents interact and bottom-up constraints produce macroscopic wholes, these large-scale patterned entities use top-down constraints (e.g. intentions) to regulate the organization of system microcomponents (e.g. motor system degrees-of-freedom) (Kelso and Engstrom, 2006).

Intentionality and sport behaviour

The perceptual control of action and the enhancement of the quality of perception by exploratory activity are specified by initial conditions and constraints that are bounded by the goals aimed by the performer. Intentional constraints may be seen as goal-state attractors arising through the dynamic interplay of constant energy exchanges between a performer and the environment (Kugler et al., 1990). According to Kugler and Turvey (1987), internally stored energy flows provide a source of force that can be controlled by the performer in sport and which can actively utilize or compete against external forces (e.g. a runner using or braking against gravitational forces when running downhill). With the capacity to delay the use of energy flows, a movement system becomes less reactive in a mechanical sense, but more active in biological purpose. Thus, internal forces can be directed to compete actively with external forces in achieving specific goals. The intentional dynamics that emerge during performance are the consequence of a movement system’s ability to use energy tactically, to anticipate outcomes, and to choose among options. Some aspects of intentional behaviour refer to an interior frame of reference (e.g. the biological systems of the attacker), and others refer to an exterior frame (e.g. the situation confronting an attacker, which includes the position of the net/goal and defender). To intend a performance goal, a performer needs to select an initial condition that permits attainment of a specified final condition under the laws of physics. With each step closer to the goal, the information must become ever more specific, narrowing the range of possible action paths, until ultimately, at the final moments of goal accomplishment, an emergent performance path becomes uniquely defined.

The individual can use his or her internal potential only at choice points (Kugler et al., 1990). Decisions arise at those points along a trajectory at which the system must expend internal energy to keep moving in the same mode towards the same target, or where it can counter the work done on it by an external gradient. Structurally, these choice points in the field are bifurcation points that act as attractors. They imply choices because there is insufficient information in the field to define uniquely a future path. In a one-on-one dribbling situation in sport, the defender seeks to maintain system symmetry, but the attacker is looking for a way to achieve his or her goal (of scoring), thus needing to choose a different path than desired by the defender. Due to the existing symmetry of a dyadic system in which a defender confronts an attacker, there is not enough information to select a path in advance. Consequently, the selection of a goal path for the attacker is an emergent process.

In order to achieve a final goal, nonlinear behaviours will result if there is a competition between attractors (i.e. if there are multiple sub-goals to be satisfied). The player–environment system that is established during dribbling in ball sports can facilitate our understanding of
how the selected actions that emerge from player–environment interactions can contribute to achievement of an intended goal. With this approach, predicting a given behaviour requires precise and complete specification of a performer’s initial conditions (including historical context), current (and largely private) mental states and the environmental context. Because these factors interact non-linearly to constrain behaviour, incomplete knowledge of even a small detail may be enough to impair the ability to precisely predict emergent behaviour. However, it is clearly important to consider the dynamics of athlete–environment interactions in order to understand decision-making processes in sport (Araújo et al., 2006).

For example, Cordovil et al. (2009) studied effects of task and individual constraints on decision-making processes in basketball. When specific instructions were manipulated, they observed effects on emergent behaviour of the dyadic system. Moreover, when body-scaling of participants was manipulated by creating dyads with different height and arm span relations, results indicated that height had a greater effect on emergent dynamics of decision making in dyads. When attackers were considerably taller than defenders, there were fewer symmetry-breaking opportunities than in other combinations (see Figure 3.2).

![Graphs](image)

*Figure 3.2* Example of situations with symmetry-breaking (graphs on the left) and without symmetry-breaking (graphs on the right). Graphs A and B show the players’ distance to the basket over time, and graphs C and D show variations in the ‘relative’ interpersonal distance (RIPD) values in the same situations. To identify symmetry-breaking, one should look for a crossing of the lines that represent the trajectories of an attacker and defender on the graph of the players’ distance to the basket, or for a negative value for ‘relative’ interpersonal distance. (From Cordovil et al., 2009.)
The ecological dynamics of behaviour in sport

The key to studying a performer–environment system in sport then is to make the dynamics underlying the system’s behaviour observable. Araújo, Davids and colleagues, in conjunction with others, have used this approach to study performance in sport (e.g. Araújo et al., 2006; Davids et al., 1994, 2001; Handford et al., 1997; McGarry et al., 2002; Palut and Zanone, 2005; Passos et al., 2006; Schmidt et al., 1999). An attraction of dynamic models is that they can explain different decisions by means of the same underlying process of emerging and decaying attractors. The behaviour of an identified system collective variable over time can often be described by a gradient equation. More precisely, if the system variable of interest (i.e. a collective or coordination variable or order parameter) is denoted by ‘x’ and the potential function is denoted by ‘V’, then the evolution of ‘x’ over time can be expressed by the differential equation (3.1).

\[
\frac{dx}{dt} = -\frac{dV}{dx}
\]  

A value of ‘x’ for which the derivative ‘dx/dt’ is equal to zero is an equilibrium point and corresponds to a steady state of the system. If that value is a minimum of ‘V’, then it is a stable region (i.e. an attractor); if the value is a maximum of ‘V’, then it is an unstable region (i.e. a repellor). A simple interpretation of equation (3.1) consists of identifying ‘x’ with the coordinate of a small ball which moves in the potential landscape. In line with this principle, a model proposed by Tuller et al. (1994) was established to study speech perception, namely the discrimination between the words ‘say’ and ‘stay’, when an acoustic parameter was varied. Listeners perceive the word ‘say’ at short silent gaps after the ‘s’ noise and they perceive the word ‘stay’ at long silent gaps, implying the presence of two attractors (say and stay). If ‘x’ is a variable characterizing the perceptual form, then the potential function ‘V’ can be written as equation (3.2).

\[
V(x) = k x - (x^2)/2 + (x^4)/4
\]

where ‘k’ is a control parameter (gap duration). Equation (3.3) follows from equations (3.1) and (3.2).

\[
\frac{dx}{dt} = -k + x - (x^3)
\]

This model has since been used in studying transition behaviours in other movement tasks, such as shifting between walking and running (Diedrich and Warren, 1995), selecting to start on the right or left in a sailing regatta (Araújo et al., 2003, 2006) and in action selection in rugby union (Araújo et al., 2009). The characteristic nature of the attractor states for V(x) is such that for all states within an attractor well, the system will tend to be pulled towards the minimum of the well. Once the system is caught in an attractor well, it will tend to drift towards the minimum (where V(x) = 0), and then meander (stochastically) around this minimum. The system is considered to have settled when this situation occurs (i.e. when the system is caught in an attractor well). It is assumed that a decision has been made (i.e. a new behavioural pattern initiated) as soon as the system has settled. The system is assumed to start in some initial state, x₀ and stochastically change over time until it settles and a new pattern is initiated.

Building on the notion of a potential landscape, Schöner et al. (1992) modelled the acquisition of an intrinsically unstable coordination mode by introducing the complementary concept of intrinsic dynamics. Intrinsic dynamics reflect the learner’s inherent coordination tendencies.
(resulting from a mix of innate biological constraints, development and previous learning) as he/she starts out to learn a new coordination pattern.

The conceptualization of learning as a modification of an individual’s intrinsic dynamics implies that learning a new coordination pattern not only leads to improved performance of the learned pattern, but may affect the performance of other patterns as well. In other words, learning a particular coordination pattern may have both positive and negative transfer effects. Although more needs to be understood about such transfer processes in the context of learning sport skills, coaches should be aware that such effects may occur, especially when athletes engage in skills or activities involving topologically similar coordination patterns (e.g. badminton and tennis; rugby union and Australian Rules Football). Moreover, all learning processes emanate from existing intrinsic coordination tendencies, never from a ‘blank slate’. Although one can measure those coordination tendencies only under special circumstances, they always affect the dynamics of learning. As a consequence, some coordination patterns are easy to acquire by some individuals, but hard for others.

Concluding remarks

The production of stable yet adaptive behaviours implies the coordination of action, where the individual selects action modes, and it implies perception, where information is selected (picked up) from the environment in order to guide action. The problem of intentionality and decision making is, thus, grounded on perception and action cycles (Araújo et al., 2006). From an ecological dynamics perspective, skilled behaviour consists of continuous intentional adaptations to the constraints imposed by the environment during task performance (e.g. Araújo and Davids, 2009). The implication is that the structure of the environment, the biomechanics of the body, perceptual information about the state of the performer–environment system and the demands of the task all serve to continuously constrain behaviours. Adaptive behaviours, rather than being imposed by a pre-existing structure (e.g. memory), emerge from this confluence of constraints under the boundary condition of a particular task.

References


