

**Ecological cognition : expert decision-making behaviour in sport**

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# 1 **Ecological cognition: Expert decision-making and action expression in sport**

## 3 **Abstract**

4 Expert decision-making can be directly assessed, if sport action is understood as  
5 an expression of embedded and embodied cognition. Here, we discuss evidence for this  
6 claim, starting with a critical review of research literature on the perceptual-cognitive  
7 basis for expertise. In reviewing how performance and underlying processes are  
8 conceived and captured in extant sport psychology, we evaluate arguments in favour of  
9 a key role for actions in decision-making, situated in a performance environment. Key  
10 assumptions of an ecological dynamics perspective are also presented, highlighting how  
11 behaviours emerge from the continuous interactions in the performer-environment  
12 system. Perception is of affordances; and action, as an expression of cognition, is the  
13 realization of an affordance and emerges under constraints. We also discuss the role of  
14 knowledge and consciousness in decision-making behaviour. Finally, we elaborate on  
15 the specificities of investigating and understanding decision-making in sport from this  
16 perspective. Specifically, decision-making concerns the choice of action modes when  
17 perceiving an affordance during a course of action, as well as the selection of a  
18 particular affordance, amongst many that exist in a landscape in a sport performance  
19 environment. We conclude by pointing to some applications for the practice of sport  
20 psychology and coaching and identifying avenues for future research.

21  
22 Keywords: Ecological cognition, action choices, expertise, affordance selection,  
23 constraints, information

24 Main text: 9305 words.

26

## Introduction

27           How expert athletes decide to do what they do is a topic that has interested  
28 scientists for several decades (e.g., Beise & Peasley, 1937), and particularly sport  
29 psychologists(e.g., Straub & Williams, 1984). It has been argued that sport is a most  
30 appropriate context for studying expert decision-making (Gilovitch, 1984, Gilovitch et al,  
31 1985). According to Gobet (2016), sport is a domain of expertise, where expertise relies  
32 on perception: “experts literally ‘see’ things differently compared to novices” and “these  
33 differences in perception and knowledge affect *problem solving* and *decision making*”  
34 (Gobet, 2016, p.7).

35           Predicated on these ideas, studies of decision-making in sport have intensively  
36 tested athletes'perception and anticipation, attention, memory, and decision-making.  
37 An important gap emerges immediately: decision-making in sport, by following trends  
38 in cognitive psychology, has neglected the important role of *action* and its constitutive  
39 role in cognition (Araújo, Ripoll & Raab, 2009; Prinz, Beisert & Herwig, 2013; Wolpert &  
40 Landy, 2012). In this article, we critically overview research on the perceptual-cognitive  
41 basis of decision-making, before we present an action-based alternative, from the  
42 ecological dynamics framework, clarifying repercussions for theory and research in  
43 sport psychology.

44

### **The perceptual-cognitive framework for the study of decision-making in sport**

46           Currently, the perceptual-cognitive view of decision-making tends to focus on  
47 use of perception, memory and decision-making tasks to capture performance and to  
48 identify mediating mechanisms (Williams & Abernethy, 2012; for previous reviews see  
49 Bar-Eli, Plessner & Raab, 2011; Cotterill & Discombe, 2016; Hodges, Huys & Starkes,  
50 2007; Raab & Helsen, 2015; Tenenbaum & Gershgoren, 2014; Williams & Ward, 2007).

51

52 ***Paradigms for capturing perceptual-cognitive performance***

53           Research in sport has purported to reveal experts' ability to use "advance cues"  
54 for anticipatory responses, or to anticipate outcomes of an immediate opponent's action,  
55 often before an action is completed (e.g., Abernethy et al., 2001; Williams et al., 2002).

56 Early research showed that expert players are better than novices at detecting  
57 deceptive moves by an opponent (e.g., Jackson et al., 2006). Also, in comparison with  
58 novices, experts display visual search strategies that tend to fixate on movements of an  
59 opponent's body segments that are more remote from an end effector when completing  
60 an action such as hitting a ball (e.g., Abernethy & Russell, 1987). Research  
61 methodologies employed allowed participants to observe, and respond to short 'sport-  
62 specific courses of action', captured in a series of video-clips (also in films, static images  
63 and point-light displays). The clips are edited to present an entire course of action,  
64 testing: (i) rapidity and accuracy in controlled response conditions (e.g., response time  
65 paradigm), or (ii), relative importance of spatial and temporal variables in decision-  
66 making by occluding specific information sources (spatial occlusion paradigm), or  
67 varying durations of each clip (temporal occlusion paradigm). Traditional explanations  
68 for these findings were similar to original proposals of de Groot (1965) studying chess  
69 players: perception in experts is better developed because they can access more refined  
70 internal representations as knowledge structures (e.g., Ericsson & Kintsch, 1995).

71           Recognition and recall have been associated with the study of memory, through  
72 identification of sequences of play. Several studies in sport have used brief  
73 presentations of domain-specific material, followed by a recall task (e.g., Allard &  
74 Starkes, 1980). In these tasks, a series of slides or video-clips are presented, and  
75 participants have to indicate verbally or on paper, as quickly as accurately as possible,

76 which slides or clips were already presented, and which were new (recognition  
77 paradigm, e.g., Smeeton et al., 2004), or to recall players' positions in a display (recall  
78 paradigm, e.g., North et al., 2011). Results showed that experts attain better recall and  
79 recognition performance than non-experts, with *structured* performance situations, but  
80 not with unstructured situations. These results have been explained with reference to  
81 chunking theory (Chase & Simon, 1973), and this and other memory-based  
82 representations are assumed to underpin experts' performance superiority, particularly  
83 with respect to decision-making (Tenenbaum & Gershgoren, 2014, see Kording &  
84 Wolpert, 2006 for a Bayesian formalization).

85         The influence of the information-processing paradigm on the study of decision-  
86 making in sport has promoted what Simon (1956) called 'bounded rationality'  
87 (including related, more contemporary, approaches, e.g., fast and frugal heuristics,  
88 naturalistic decision making): humans are rational within the limits imposed by their  
89 cognitive systems (inferring the capacity to process information). The reasoning behind  
90 the claim that rationality is bounded suggests that understanding decision-making  
91 requires studying both the environment and the decision-maker. Even if a decision-  
92 maker meticulously follows normative steps of rationalization, there is still an influence  
93 of environmental constraints to consider.

94         The fast and frugal heuristics framework places greater significance on the role  
95 of the environment than the information-processing approach, and is aligned with the  
96 arguments of Simon (1956). It addresses environmental variables that are  
97 representative of those in socio-cultural settings, towards which an experiment is  
98 intended to generalise, as Brunswik (1944; 1956) originally proposed. Fast and frugal  
99 heuristics are strategies for decision-making that do not involve much searching for  
100 information or computation (Gigerenzer et al., 1999). This approach has some

101 similarities with the naturalistic decision-making framework (Klein, 1998) that has  
102 investigated decision making of experts under time pressure in their domain of  
103 expertise. A significant conclusion of both frameworks is that experts tend not to  
104 deliberate between options but expediently implement the first *satisfactory* action. Raab  
105 and colleagues conducted research within the fast and frugal heuristics framework in  
106 sports contexts (see Raab, 2012 for a review). For example, they (Raab & Johnson 2007;  
107 Johnson & Raab, 2003) used video clips of team sports performance which were  
108 interrupted when a player with the ball faced several possible actions. Participants  
109 choosing better options generated fewer options. Expert players, performing under  
110 time constraints, use the 'take the first' heuristic, choosing the first alternative that  
111 emerged and better players tended to select the 'best' option. Option generation and  
112 selection were proposed to occur in an athlete's memory, from internalised knowledge  
113 representations of performance (Raab, 2012).

114         Similar knowledge structures are proposed as an explanation for how athletes  
115 generate different probabilistic expectations on how an event may evolve, such as the  
116 potential success associated with performing a certain action (e.g., a pass or dribble  
117 with a ball), or in predicting next movements of an adversary (e.g., Alain & Proteau,  
118 1980; McRobert et al., 2011). It is assumed that the mind or the brain calculates the  
119 statistical distribution of likely event probabilities, and the level of uncertainty in  
120 sensory feedback (Kording & Wolpert, 2006; Williams & Abernethy, 2012), before  
121 making a decision.

122

### 123 ***Paradigms for measuring the mediating mechanisms of decision-making***

124         The prevailing approach assumes that to understand mediating mechanisms  
125 employed by performers to make decisions, measures of behaviours like eye

126 movements, verbal reports, as well as imaging of neurophysiological and  
127 neuroanatomical function, should be undertaken (Williams & Abernethy, 2012).  
128 Recently, neuroscientific evidence has been proposed to support theoretical arguments  
129 of cognitive sport psychologists (e.g., Tenenbaum, Hatfield et al., 2009), highlighting  
130 brain activity putatively “underlying” processes of perceptual-cognitive performance  
131 (e.g., Williams & Abernethy, 2012; Yarrow, Brown & Krakauer, 2009). Although using  
132 highly restricted micro-movements (e.g., button-pressing, blinking, pointing), research  
133 related to sport performance has postulated that experts tend to display more  
134 consistent brain behaviours during preparatory periods before initiating movement  
135 (Hatfield & Hillman, 2001). These include: (i) more efficient organization of brain  
136 regions (Milton et al., 2007), or (ii), specific brain areas displaying greater 'activation  
137 levels', (Aglioti et al., 2008; Wright et al., 2011), in experts compared to novices. These  
138 findings have been interpreted as support for a mirror neuron system (Rizzolatti &  
139 Sinigaglia, 2016), which is proposed to transform internal sensory representations of  
140 the behaviours of other performers into motor representations of an observed  
141 behaviour. Later in this chapter we argue that the prevalent idea of 'brain activity', as  
142 the underlying mechanism of perceptual-cognitive performance, is a fallacy. Brain  
143 activity does not constitute proof of the presence of representations, and it should not  
144 be misconstrued as action or cognition (e.g., as if activity level is indicative of the brain  
145 'deciding for' an individual).

146         Eye movement recording has also been used to assess how performers visually  
147 search a displayed image or scene during decision-making (Ripoll et al., 1995; Vickers,  
148 2016; Williams et al., 2004). Expert players tend to exhibit fewer fixations of longer  
149 durations and focus for a longer time on areas of free space that could be exploited or  
150 exposed (e.g., Vaeyens et al., 2007). Again, these findings are explained as revealing the

151 underlying neural structure (Vickers, 2016), for example, as explained by mirror neuron  
152 theory (Rizzolatti & Sinigaglia, 2016). Additionally, verbal protocols, as described by  
153 Ericsson and Simon (1993), have also been used, either concurrently or retrospectively,  
154 as a way to evaluate thought processes that mediate action (e.g., McPherson & Kernodle,  
155 2007; Kannekens et al. 2009). Regardless of the discrepancies between 'what we say,  
156 what we do' (Araújo et al., 2010), verbal reports are interpreted as responses to  
157 “situation prototypes”, represented in long-term memory (MacMahon & McPherson,  
158 2009; Ericsson & Kintsch, 1995).

159

### 160 **Criticisms of representational approaches to decision-making in sports**

161 Previous research on perception, action and cognition has typically been  
162 grounded on theories of memory enrichment through representations (i.e., schemas,  
163 scripts, schematas, programs and the like), which consider stimuli in the environment  
164 to be impoverished for individuals. The role of internalised knowledge structures is to  
165 enhance meaning and richness of stimuli. Stimuli need encoding, and transformation by  
166 internal mechanisms that transform meaningless stimuli into meaningful  
167 representations, in order to interpret the environment and program the body to  
168 implement actions during performance (Kording & Wolpert, 2006).

169 Alternatively, non-representational approaches (e.g., ecological dynamics, Araújo  
170 et al., 2006; for a discussion among different approaches see Araújo & Bourbousson,  
171 2016) are predicated on the idea that perception and cognition are embedded and  
172 embodied, emphasising the study of the performer-environment relationship as an  
173 appropriate scale of analysis. We elaborate some criticisms of the representational  
174 approach to cognition, where cognition is seen as information processing that results in  
175 representations in the mind or brain (Rowlands, 2009). In interpreting these criticisms,



176 we discuss ecological dynamics as an important *action-based*, non-representational  
177 approach to cognition. From this perspective, cognition is the on-going, active  
178 maintenance of a robust performer–environment system, achieved by closely  
179 coordinated perception and action (Araújo et al., 2006; Stepp et al., 2011).

180

### 181 ***Theoretical criticisms: The world is its best model***

182         The representational approach to human performance considers  
183 representations as containing meanings of symbols (i.e., perceptual encoding of stimuli  
184 in the brain, motor programs decoding intentions from brain, through the nervous  
185 system, to physical apparatus for coordinating actions, e.g., muscles, joints, limbs,  
186 bones)(see Araújo, 2007, Shaw, 2003). Representations are assumed to ‘stand for’  
187 things in the world and things in the body. However, the mechanisms typically  
188 proposed for associative memory, or generally, knowledge structures are *epistemic*  
189 *mediators*. They provide contact with the world for an individual athlete.  
190 Computationally, this process of making contact requires conventional rules of  
191 reference that specify what symbols refer to, as well as rules of common usage that  
192 specify symbol meaning in actual contexts. The conventional connection of symbols to  
193 what they represent necessarily involves establishing common conventions through  
194 perceptual means (Shaw, 2003). Currently, little, if anything, is known about how the  
195 vital computational processes of symbolic encoding, decoding, and respective rules, are  
196 biologically implemented. In contrast, the ecological dynamics approach holds that  
197 ambient energy distributions are necessarily specific to the facts of the environment  
198 and of a performer’s actions relative to the environment (Gibson, 1979; Turvey & Shaw,  
199 1995). As Warren (2006, p.361) asked, if perceptual and cognitive states are

200 representations, how is it possible for an agent to know what they stand for, without  
201 presuming some other direct access to the world?

202         In sport, the majority of decision-making studies follow the assumption that  
203 decision-making and perceptual judgements are predicated on internalised knowledge  
204 structures operating as inference engines to deliberate on 'the' best decision, or the  
205 decision that 'best fits' the task. In this process, the same assembly of stimuli is assumed  
206 to be perceived and commonly represented in the mind of every observer of a situation.  
207 These stimuli are viewed as always constraining similar decisions and actions (the  
208 “correct” decisions made by experts, for example). Thus, it is believed that some people  
209 decide well and other people decide poorly. The problem is that, in open, dynamic  
210 systems there is no “best decision”, since the most functional decision at any moment  
211 may compromise future decisions (Araújo et al., 2006; Davids & Araújo, 2010). During  
212 the act of perceiving, the limbs, ears or eyes of a performer explores available  
213 information in an environment. Complex, structured energy fields of ambient, patterned  
214 energy (i.e., information), such as light reflected from objects, are an environmental  
215 resource to be sought and exploited by individuals, who continuously modulate their  
216 interactions with the world, i.e., exerting their agency (Withagen et al., 2017).  
217 Information is the basis for maintaining contact with the environment because it is  
218 specific to its sources. Thus, various exploratory actions of perceptual systems are  
219 required for perception to occur. For the ecological dynamics approach, meaning in  
220 perception is not derived from any form of mental association, or labelling, but only  
221 from information detected by an observer. Therefore, perceptual learning, for example  
222 due to training and experience, is the process of becoming *attuned*, i.e., better able to  
223 differentiate more and more kinds of information, increasing the range and economy of  
224 the information detection process (Reed, 1993).

225           These arguments suggest that an individual's regulation of behaviour can be  
226 explained without the postulation of mental representations. Decisions are expressed  
227 by actions (Beer, 2003). Planning an action before acting (denoted as "strategical" in  
228 sports science) can influence the course of decisions (e.g., where to explore), but  
229 behaviour is always dependent on circumstances (action is not a mechanical outcome,  
230 but it is "tactical", i.e. an intentional exploration for an efficient solution). In this respect,  
231 decision-making is an *emergent* behaviour (Araújo et al., 2006). As the individual moves  
232 with respect to her/his surroundings, there are opportunities for action (affordances,  
233 Gibson, 1979) that persist, arise, and disappear, even though the surroundings remain  
234 the same. Changes of action can give rise to multiple variations in opportunities for  
235 subsequent actions. To exemplify, in team games, two defenders may face an attacker  
236 with the ball, but the gap between the defenders may vary momentarily, inviting  
237 different actions of the attacker, depending on his/her capacities (e.g., speed of  
238 movement), amongst other things. Perception of *affordances* (opportunities for action)  
239 is the basis for performers controlling her/his behaviours *prospectively*, i.e., regulating  
240 future behaviors (Gibson, 1979; Turvey, 1992). An important aspect of expert  
241 performance involves acting in a manner that is consistent with ways that are socio-  
242 culturally endorsed (Barab & Plucker, 2002, van Dijk & Rietveld, 2017), such as those  
243 valued in different sports. Experience in acting in a performance context attunes  
244 performers to perceptual variables that reliably specify the state of the environment  
245 relevant to performance in a specific task (Araújo & Davids, 2011). In this way, athletes  
246 can use the situation as its own best model, actively exploring and scanning it in detail  
247 at specific locations according to particular needs in the moment. This idea was  
248 elegantly described by Rodney Brooks, a prominent scientist in robotics as 'the world as  
249 its best model' (Brooks, 1991). Accordingly, robotics and other areas (e.g.,

250 computational neuroscience) are actively searching for embodied and embedded  
251 explanations for cognition (including perception and action) (see Clark, 2015) for a  
252 recent review). If social, historical, and possibly other external processes, are to be  
253 taken as integral constraints on skilled action, then traditional notions of expert  
254 performance (which relegate these processes to an individual's internal environment)  
255 should be re-examined: focusing on contexts and relations channelling expert  
256 performance

257

### 258 ***Methodological criticisms: Variables that are beyond immediate observation***

259         How scientific findings from laboratory experiments can provide effective  
260 interventions in society (Ericsson & Williams, 2007) has become a major concern within  
261 sport psychology. A critical issue is that disregard for the need to study *functional*  
262 behaviours in traditional empirical designs has led to a decoupling of perceptual  
263 processes from actions on relevant external objects and events (Fajen, Riley, & Turvey,  
264 2009; van der Kamp et al., 2008). Neisser (1976) recognised this weakness, in his  
265 seminal treatise on cognitive psychology, arguing that laboratory settings with  
266 contrived and trivial tasks, rather than everyday situations in life, can lead to the  
267 emergence of artificial decisions and behaviours. Examples abound in sport, perhaps  
268 best exemplified with reference to research methodologies in which film and video  
269 presentations have been used to simulate sport performance contexts. Discrepancies  
270 between these task constraints and performance in sport contexts have long been well-  
271 documented (Williams et al., 1999; Williams & Abernethy, 2012). These concerns were  
272 endorsed by a recent meta-analysis (Travassos e al., 2013) which clarified how  
273 expertise effects on decision-making in sport were moderated by ubiquitous response  
274 modes (verbal reports, button pressing, performance of micro-movements) and

275 methods of stimuli presentation (slides, images, video presentations, *in situ*) in research.  
276 Moderating effects on decisions and actions were most obvious when participants were  
277 required to move in highly controlled laboratory conditions, rather than when actually  
278 performing sporting actions under *in situ* task constraints (Travassos et al., 2013).

279         For example, evidence has revealed that, when cricketers bat against a bowler,  
280 ball projection machine or a video simulation of a bowler with a projection machine,  
281 significant variations in timing of movement initiation and downswing initiation arise  
282 under the different task constraints (Pinder et al., 2011). Similar findings have emerged  
283 in studies of catching behaviours (Stone et al., 2015). Such findings indicate the  
284 relevance of *representing* in investigations, the key constraints of performance  
285 environments (see Brunswik, 1956). The *representativeness* of a particular situation  
286 helps participants to achieve performance goals cyclically, by acting to perceive  
287 information to guide further actions (Araújo & Davids, 2015). There needs to be a clear  
288 correspondence between behaviours in one context (an experiment or a training  
289 session) and behaviours in another context (a performance environment) (for detailed  
290 arguments see Araújo & Davids, 2015). The concept of correspondence is of great  
291 importance in decision-making, because, among other things, it is linked to our ability to  
292 perceive similarities between contexts. Recently, Seifert and colleagues (Seifert et al.,  
293 2013, 2016) showed how training on an indoor climbing wall might facilitate climbing  
294 on a frozen waterfall. Correspondence between behaviours in these contexts resulted in  
295 emergence of the use of quadrupedal locomotion, facilitating use of limb extremities  
296 and control of gravitational forces due to the vertical support needed for locomotion.

297         Performance in sport contexts involves actions, in which perceptual judgements  
298 and decisions are embodied (Araújo et al., 2006; Beer, 2003). Much previous research  
299 has linked perception to verbal responses, eye movements or neuroanatomical parts of

300 the body supposed to express variables beyond immediate observation (i.e., decisions,  
301 judgments). However, actions by which cognition is expressed require that information  
302 be available in the patterned ambient energy for behaving with respect to  
303 environmental constraints. In this regard, actions, not their surrogates, are true  
304 cognitive behaviours.

305

306 ***Hidden reductionism: Expert decision-making is not that which happens in a body***  
307 ***location***

308 Gobet (2016) has proposed that 'the jury is out' with regard to whether  
309 neuroscience has “really taught us anything surprising and critical” (p.184) concerning  
310 expert anticipation and decision-making. Gobet (2016) also suggested that studying the  
311 nervous system at the level of brain regions is the wrong level of analysis for  
312 understanding such processes. To exemplify, the mirror neuron hypothesis (Rizzolatti &  
313 Sinigaglia, 2016) is a theory grounded on representations, located in the CNS, which are  
314 considered to have just the right type of organization needed to produce behaviours  
315 (Churchland & Sejnowski, 1989).

316 This type of reductionist explanation of decision-making, as an internalised  
317 neurophysiological process, seems to endorse psychological attributes as specific  
318 anatomical substrates, and not as emerging from interactions of the *individual-*  
319 *environment system*. This is an organism-centred view of behaviour which misses a  
320 central point: the reciprocity between an organism and environment (Davids & Araújo,  
321 2010). Such a neurophysiological perspective is predicated on a conceptualisation of a  
322 CNS that perceives, executes, conceives and constructs an action for the organism. For  
323 this reason some neuroscientists have argued that sport represents a valuable natural  
324 context which challenges the brain (Walsh, 2014). However, it is the performer, who

325 actually perceives and acts during dynamical interactions with sport environments, not  
326 separate parts of his/her body (e.g., components of a nervous system), (Araújo & Kirlik,  
327 2008). Athletes act to perceive and perceive to act (Gibson, 1979), with many more  
328 subsystems engaged in the emergence of behaviours than simply the CNS. Evidence for  
329 this view is abundant in the literature, traced back to Dewey (1896) (but see recent  
330 reviews of empirical evidence from Reed, 1982; 1996; Richardson et al., 2008; Seifert et  
331 al., 2016b; Teques et al, in press). Sport experts are active performers engaged in  
332 dynamical transactions with their functionally defined environments. Thus, expert  
333 performance is not possessed by the brain of a performer, but rather it is best captured  
334 as an ongoing, dynamically varying relationship that has emerged (and continues to  
335 emerge) between the constraints imposed by the environment and the capabilities of a  
336 performer (Araújo & Davids, 2011).

337         This conceptualisation does not mean that the role of neurophysiological  
338 systems in these continuous interactions should not be considered (Teques et al., in  
339 press). After studying the emergent interactions of environment-athlete systems under  
340 the specific constraints of sport tasks, researchers can investigate what affordances  
341 (opportunities for action) are relevant, how they channel action, what the structure of  
342 such actions are and how the entire process involves the contributions of many  
343 individual sub-systems such as the nervous or the cardiovascular sub-systems. In  
344 ecological analyses of neural processes underlying behavioural regulation (Järvilehto,  
345 1998), a basic principle of nervous system functioning is the self-organisation  
346 *tendencies* of neuronal assemblies. Neuroanatomical organizations are temporary, only  
347 relatively stable and self-organizing to capture the embeddedness of individuals in their  
348 environments, dependent on what Gibson (1966a, 1966b) called the *resonance* of a  
349 perceptual system to ecological information. Gibson proposed that “The brain is a self-

350 tuning resonator” (Gibson, 1966b, p. 146) and achieving resonance implies that the  
351 perceiver learns to become 'tuned' to specific patterns of ambient energy (e.g., sound  
352 from the steps of an approaching opponent or vision of an approaching ball). Such  
353 structured information specifies features of a particular substance, surface, object, or  
354 event in relation to a particular individual. Resonance is not something that a brain  
355 achieves in isolation, but involves all the body (sub)systems involved in perceiving and  
356 acting in the environment (Gibson, 1966a). Resonance captures how the brain-body-  
357 environment system is embedded and embodied (Teques et al., in press).

358         Similar reasoning can be applied to use of eye movements or verbal protocols as  
359 explanatory mechanisms in expert decision-making. Like neurophysiological processes,  
360 eye movements and concurrent verbalizations may be related to performance. But they  
361 also may not, although performance may still be maintained (e.g., high levels of  
362 performance achieved by Paralympic athletes such as blind or deaf-mute performers). A  
363 key point is that partial (neural or eye activity) or surrogate processes (verbalizations)  
364 are not different aspects of decision making in sport (Cotterill & Discolombe, 2019);  
365 more importantly they are not the phenomenon of interest. The embeddedness of a  
366 performer within the performance environment during action is the phenomenon of  
367 interest. Why study the behaviour of the eye if what one really wants to study is the  
368 exploratory behaviours of a player or of a team? Why not move directly to the study of  
369 actions, and how it reveals the performer's exploration, problem solving or reasoning in  
370 a performance task?

371         It is worth noting that researchers can actually test hypotheses about action and  
372 cognition directly. Different kinds of activities and different kinds of information  
373 produce various cognitive functions. All of them have their basis in perceptually-guided  
374 actions. Investigators can modify ambient information in addition to modifying task



375 demands when they seek to study cognition. Since action is an expression of cognitive  
376 processes, it is possible to look at organizational and functional aspects of  
377 contextualized action in testing hypotheses about cognitions in behaviour (Araújo et al.,  
378 2006, Correia et al., 2013).

379

### 380 **An ecological dynamics account of decision-making in sport**

381

382 Ecological dynamics can be traced to areas of science tangential to sport  
383 performance. Two seminal researchers were instrumental in its origin: the ecological  
384 psychologist James J. Gibson (1966, 1979) and the physicist and biomechanist, Nikolai A.  
385 Bernstein (1967, 1996). Turvey (1977) first highlighted the relevance of their work for  
386 understanding of perception and action, further elaborated by Kugler, Kelso and Turvey  
387 (e.g., 1980) by introducing the language of complex systems from physicists such as  
388 Prigogine (Prigogine & Nicolis, 1971), Haken (1977), and Iberall (1977). A  
389 comprehensive exposition of these ideas, and their implications for sport scientists, was  
390 provided by Davids and colleagues (Davids et al., 1994; Williams et al., 1992).  
391 Importantly, Davids et al.'s (1994) paper was influential for indicating the  
392 interdisciplinary relevance of their insights for the sport sciences (especially motor  
393 learning, biomechanics, sport psychology, sport pedagogy, performance analysis). A  
394 further important impact in the sport sciences was made in developing an ecological  
395 dynamics rationale for decision-making by Araújo et al. (2006), where the link to  
396 Brunswik's (1944, 1956) concept of *representative design* was firmly established. There  
397 are three important assumptions of the ecological dynamics approach, which are worth  
398 emphasizing in discussions of decision-making: i) behaviour emerges from the

399 performer-environment system; ii) perception is of affordances (opportunities for  
400 action); and iii), action, therefore cognition, emerges under interacting constraints.

401

### 402 ***Behaviour emerges from the performer-environment system***

403 Behaviour is defined at the ecological level of analysis: the level of interactions  
404 between an organism and its environment, both continuously shaping each other  
405 (Gibson, 1979; Richardson et al., 2008). A consequence of this idea is that behaviour can  
406 only be understood, not simply according to the characteristics of a performer, but  
407 symmetrically according to the characteristics of a performance environment. If sport  
408 psychologists seek to generalize behaviours from one context (e.g., experimental  
409 laboratory, training session) to another context (competition, a performance  
410 environment), there should be clear theoretical guidance on establishing behavioural  
411 correspondence between contexts. This guidance is available in ecological psychology  
412 (e.g., Brunswik, 1956), where it has been demonstrated how athlete behavioural  
413 patterns are generated from the tight coordination emerging between a performer and  
414 a performance environment in the service of achieving specific performance goal (e.g.,  
415 coupling limb movements when climbing a vertical surface, Seifert et al., 2014; for a  
416 review, see Araújo & Davids, 2015).

417 A tight performer-environment relationship seems to be a 'common-sense' view  
418 proposed in traditional sport psychology. However, a misconception is that the  
419 performer is typically regarded as *the* active agent, with the environment acting as a  
420 passive 'backdrop' that merely supports an individual's selection of actions, providing  
421 sources of stimuli to control behaviours (Araújo & Davids, 2011). The separation of  
422 organism and environment leads to theorising in which the most significant explanatory  
423 factors in behaviour are located *within* the organism. The upshot is that causes for

424 behavioural disturbances are located in disturbances of brain function or in lack of  
425 sensitivity to 'cues to control' performance (e.g., O'Brien & Ahmed 2015; Wolpert &  
426 Landy, 2012; Yarrow et al., 2009). In ecological dynamics, there is no internal  
427 knowledge structure or central pattern generator inside the organism responsible for  
428 controlling action. Rather, all parts of the system (brain, body, environment) are  
429 dynamically integrated during action regulation, just as both hands in the air are needed  
430 for the task of clapping. Contemporary research has clarified this misconception  
431 through the identification and analysis of eco-biophysical variables that capture the  
432 embedded relations between a performer and his/her environment (Araújo et al., 2006,  
433 Correia et al., 2013).

434

### 435 ***Perception is of affordances***

436 In ecological psychology, environmental properties can directly inform an  
437 individual performer about what he/she can and cannot do in a performance  
438 environment (Gibson, 1966a, 1979; Michaels, 2000). For example, the rate of dilation of  
439 an image of an approaching object on an individual's retina can provide time-to-  
440 collision information without mental computations of distance or speed of an object to  
441 intercept it (Lee, Young, Reddish, Lough, & Clayton, 1983; Craig & Watson, 2011). By  
442 calibrating information of their own action capabilities, individuals directly perceive  
443 *opportunities to act* in the environment (i.e., affordances) (Gibson, 1979). The concept of  
444 affordances captures the fit between the constraints on each performer and the  
445 properties of the environment. Cognition emerges during such continuous interactions  
446 at the ecological scale of analysis, i.e., the performer-environment system (Turvey,  
447 1992), not from an internalised model of the world (the world is its own best model).  
448 Affordances, as possibilities for action in a particular performance setting, are what an

449 arrangement of surfaces, texture and objects *offers* to a performer. Whether a gap  
450 between two defenders, for example, is passable or not is not determined by its  
451 absolute size (whether measured in cms, metres or feet and inches), but how it relates  
452 to particularities of an individual performer, including size, speed and agility. The  
453 concept of affordance presupposes that the environment is directly perceived in terms  
454 of what *actions* a performer can achieve within a performance environment (i.e., it is not  
455 dependent on a perceiver's expectations, Richardson et al., 2008). Affordances are  
456 dynamic, changing across continuous performer-environment interactions (Fajen et al.,  
457 2009) and are not representational properties of mind. Perceiving an affordance is to  
458 perceive how one can act in a particular set of performance conditions. Affordances  
459 capture the dynamics of the continuous interactions among individuals and their  
460 environment (Araújo & Davids, 2016).

461 Performers can anticipate or prospectively control their actions by producing  
462 movements guided by information about future states of affairs in a performance  
463 environment (Beek et al., 2003; Montagne, 2005; Turvey & Shaw, 1995). Gibson (1966a,  
464 1979) termed this direct perception, or "knowledge of" the environment. This type of  
465 knowledge is not formulated in pictures, symbols or words, because it is the knowledge  
466 that makes the formulation of pictures and words possible. Knowledge of the  
467 environment obtained through direct perception is not subjective or private.  
468 Information is available in the environment, and many performers can detect it. On the  
469 other hand, Gibson conceived another type of knowledge: "images, pictures, and  
470 written-on surfaces afford a special kind of knowledge that I call mediated or indirect,  
471 knowledge at second hand" (Gibson, 1979, p. 42). This kind of knowledge, or indirect  
472 perception, is intrinsically shared, because it involves the displaying of information to  
473 others. In these cases the information on which direct perception can be based is

474 selectively adapted and modified in a display, for example as a schematic presentation  
475 of the co-positioning of players in two handball teams. They consolidate gains of  
476 perception by mediating knowledge through communication. The role of indirect forms  
477 of knowledge is to make others aware and to articulate shared knowledge (Reed, 1991).  
478 Thus, contradicting some unfortunate misinterpretations in sport psychology (e.g.,  
479 Ripoll, 2009; Sutton & McIlwain, 2015; Williams & Ward, 2007), the ecological dynamics  
480 approach is deeply concerned with knowledge and considers cognition to play an  
481 important role in theoretical explanations of human behaviour (Araújo et al., 2009a).

482         A recurrent question to ecological psychologists is “what about consciousness?”.  
483 Scientists and philosophers have argued about the nature of consciousness, whether it  
484 exists or can be verified, without reaching a consensus about the involvement of mind–  
485 body dualism, physical reductionism, or epiphenomenalism (Shaw and Kinsella-Shaw,  
486 2007). Specifically in psychology, Wilhelm Wundt and William James conceived  
487 consciousness without separating inner and outer experiences. Chalmers (1996)  
488 identified the 'easy' and 'hard' problems in defining consciousness. The solution to the  
489 easy problem involves discovering the alignment between behaviours and their  
490 neurological correlates. The 'hard' problem implies moving beyond mere correlation to  
491 show how the nature of experience (behaviours) superimposes on the nature of  
492 physiological events. Merely correlating inner and outer events, avoids questions of  
493 how experience arises and where its content comes from (Shaw & Kinsella-Shaw, 2007).  
494 Correlation between two data series says nothing about the nature of the items  
495 correlated.

496         For Shaw and Kinsella-Shaw (2007) consciousness facilitates the detection and  
497 use of information. It can improve its integration, specification, interpretation, and  
498 generalization, as well as making movement control more flexible and coordinated over

499 a wider range of tasks. Consciousness contributes to the adaptive value of being aware  
500 of one's needs, preferences, and intentions with respect to actual or potential  
501 performance situations. However, the greater the ecological significance of what one  
502 needs to be aware of, the more likely it will be attended to. As Gibson put it:

503         "Perceiving is an achievement of the individual, not an appearance in the  
504         theater of his consciousness. It is a keeping-in-touch with the world, an  
505         experiencing of things rather than a having of experiences. It involves  
506         awareness-of instead of just awareness. It may be awareness of something in  
507         the environment or something in the observer or both at once, but there is no  
508         content of awareness independent of that of which one is aware (Gibson, 1979,  
509         p.239)."

510         With this understanding of perception, Gibson advanced the holistic view of  
511         consciousness of Wundt and James, by eliminating the need for solving the "easy-hard"  
512         problems of consciousness. Within this view these problems do not even arise: mental  
513         and material have equal status (Shaw & Kinsella-Shaw, 2007). Gibson followed James  
514         and Holt in rejecting the mind-matter dualism in that consciousness needs to be capable  
515         of physical characterization. For example, the experience of observing a goal scored  
516         when a football is curved through the air, implies a particular way of kicking the ball by  
517         a soccer player, in relation to a specific position related to the goal, and to the specific  
518         angle of the observer. These physical relations are needed for this experience to occur.  
519         Consciousness is a physical relation that only exists at the level of the individual-  
520         environment system. If one subtracts such relations, only matter exists. Individuals can  
521         directly perceive their situation and themselves in that situation without needing a  
522         'consciousness copy' of it:

523 Grounded situational awareness emerges when the performer notices what  
524 surrounds her/him, what is changing, and what is emerging (Shaw, 2003). Importantly,  
525 to be aware of an affordance is not to have some kind of belief about the world (e.g.,  
526 beliefs about cause and effect; Reed, 1996). Informed awareness is not just information  
527 about the environment, but of information about oneself in relation to that surrounding  
528 environment as well (Shaw & Kinsella-Shaw, 2007).

529 Recently, Seifert, Cordier and colleagues (2017), in a study about decision-  
530 making in climbing, showed that, during previewing, climbers do not necessarily make  
531 plans based on mental representations for programming their actions. Rather previews  
532 help them become aware of functional properties of the environment. They perceive  
533 opportunities for action rather than neutral physical properties (metrics such as  
534 distance (in cms or inches) to reach a hold). By capturing gaze behaviours during route  
535 previewing, and by relating those behaviours to actual climbing actions, Seifert and  
536 colleagues (2017) demonstrated that previewing allowed climbers to become  
537 perceptually attuned to affordances. Once acted upon they implied adjustments and  
538 revealed new information that, in turn, implied further adjustments and so on towards  
539 goal achievement (see Araújo, Dicks, & Davids. in press). Previewing (attuning to  
540 specific affordances) can be considered a strategical behaviour (changing at a slower  
541 timescale without relying on mental representations and motor programming). The  
542 explorations, adjustments and choices actually made during the implementation of this  
543 strategy in climbing (faster changing) tactical behaviours. These continuous  
544 interactions in person-environment relations during performance do not require a role  
545 for non-observable concepts such as mental representations and motor programs.

546

547 ***Action, therefore cognition, emerges under constraints***

548           One consequence of the performer–environment system assumption is that  
549 behaviour can be understood as self-organized under constraints, in contrast to  
550 organization being imposed from inside (e.g., the mind) or outside (e.g., reinforcement  
551 contingencies, or the instructions of a coach). Performance is not prescribed by internal  
552 or external structures, yet within existing constraints, there are typically a limited  
553 number of stable solutions that can achieve specific desired outcomes (Araújo et al,  
554 2006). An athlete’s task is to exploit physical (e.g., rule-determined performance area  
555 characteristics) and informational (e.g., characteristics like surface features to be used  
556 in vertical ascent or distances to angles between co-positioning other players)  
557 constraints to stabilize performance behaviours. Constraints have the effect of reducing  
558 the number of configurations available to an athlete at any instance. In a performance  
559 environment, behaviour patterns emerge under constraints as less functional states of  
560 organization are dissipated. Athletes can exploit this tendency to enhance their  
561 adaptability and even to maintain performance stability under perturbations from the  
562 environment. Importantly, changes in performance constraints can lead a system  
563 towards bifurcation points where choices emerge as more specific information becomes  
564 available, constraining the environment-athlete system to switch to more functional  
565 paths of behaviour (such as performing a half volley on court in tennis, rather than a  
566 volley, as ball trajectory changes due to top spin on the ball). Measurement of the  
567 dynamics of eco-biophysical variables (e.g., the angle between an attacker-defender-  
568 goal) enables understanding of how the cognitive functioning might be predicated on  
569 emergent, on-going performer-environment interactions in sport (Araújo et al., 2006;  
570 Correia et al, 2013).

571

572           *Choice of action modes while perceiving an affordance*



573           When a performer changes from one action mode (walking towards a ball) to  
574 another (running after catching it), transitions among stable behavioural states (i.e.,  
575 action modes) emerge from dynamic instabilities in the athlete-environment system.  
576 Transitioning provides a universal decision-making process for switching between  
577 distinct behavioural patterns (Kelso, 1995). Such stabilities and instabilities do not exist  
578 *a priori* in the (internalised) memorial structure of a performer, nor are pre-determined  
579 in the structure of the environment. Rather they are co-determined by the confluence of  
580 constraints and information, exemplifying how control lies in the emerging relations of  
581 the individual–environment system. This is a key point for sport psychologists to  
582 understand when they engage with athletes to help improve their decision-making  
583 behaviours. Emergent behavioural patterns have been formally modelled using  
584 differential equations and potential functions to describe the dynamical interactions of  
585 system components (e.g., Haken, Kelso, & Bunz, 1985; Scholz, Kelso, & Schöner, 1987).  
586 The landscape changes as attractors disappear or emerge. Athletes can exploit system  
587 multi-stability, transiting between different action modes.

588           Araújo and colleagues (e.g., Araújo et al., 2006; Davids & Araújo, 2010) have  
589 previously explained that decision-making behaviours during performance emerge in  
590 such a landscape of attractors (stable system states), as *potential* task solutions. In  
591 contrast to the traditional view of arriving at a putative 'single best solution', athletes  
592 modulate their interactions with the environment until the performer-environment  
593 system arrives at a stable, functional solution. A viable option selected is the *strongest*  
594 attractor for an individual-environment system at any given moment, with other  
595 options having less strength of attraction. Decision-making is explained through an  
596 integration of intentions, actions and perceptions, since selected behaviours are the  
597 realization of affordances. This selection only emerges from the continuous interactions

598 of an individual and a performance environment. Ignoring other options is a  
599 consequence of the dynamical (athlete-environment) system relaxing to one stable state,  
600 concomitantly ignoring remaining options (attractors). The presence of a stronger  
601 attractor does not eliminate the influence of other attractors in the dynamic landscape  
602 of action possibilities (e.g., Araújo et al. 2014). Under dynamic performance conditions,  
603 other attractors (i.e., as options) may emerge and exert their attraction. Dynamical  
604 models can explain different decisions through the same underlying process of  
605 originating and decaying attractors. A model initially proposed by Tuller, and colleagues  
606 (Tuller et al., 1994), for judging between pronounced words accounted for decision-  
607 making behaviours in other tasks such as the walk-run transition (Diedrich & Warren,  
608 1998), or the decision to start from right or left positions in a sailing regatta (Araújo et  
609 al., 2015). In the model of Tuller et al. (1994), it is assumed that the system's state  
610 changes over time influenced by the dynamics of the attractor landscape. In the study of  
611 Araújo et al. (2015), the system's state was the decision, expressed by ecological  
612 constraints such as the sailors' place on the starting line and the angle between the  
613 wind direction and the starting line. In agreement with predictions of Tuller et al.'s  
614 (1994) model, Araújo et al. (2006, 2015) observed properties such as qualitative  
615 changes, abrupt jumps, critical fluctuations and multi-stability. In the crucial pre-start  
616 period, there was no single "valid" course for each boat to follow, so the boats engaged  
617 in an intensive pre-start competition, with each continuously trying to gain a positional  
618 advantage over opponents. Analysis of the pre-start period revealed that, although  
619 decisions regarding the discrete 'most favourable starting place' could be made in  
620 advance, this tactic was inherently misleading. There is a need to consider and interact  
621 with instantaneously changing task (e.g., movements of opposing boats) and  
622 environmental constraints (e.g., ocean currents) (Araújo et al., 2005, Pluijms et al.,

623 2013). This particular process of decision-making (the selection of a path to an  
624 advantageous starting point) clearly cannot be based on mental comparisons between  
625 optimal and actual states mentally represented, because they emerge under the  
626 interaction of emerging constraints including an adversary's actions, wind changes,  
627 ocean currents, and boat manoeuvring skills. Due to high computation loads required,  
628 this level of action programming would be highly infeasible, perhaps needless. It would  
629 be impossible to precisely calculate the exact relational state of each source of  
630 constraint such as opponent manoeuvres, winds, tides and currents, and personal/boat  
631 movements, and predict their changes, and plan how to act accordingly, on a  
632 momentary basis (see also Araújo et al., 2014 for a model in decision-making in Rugby  
633 Union).

634         Rather, action modes are chosen when affordances are selected, but they can  
635 change, guided by appearance and disappearance of affordances in the performance  
636 landscape. As Turvey and Shaw put it “to see the distance-to-contact is to see the work  
637 required, to see the time-to-contact is to see the impulse forces required, to see the  
638 direction to-contact is to see the torques required” (Turvey & Shaw, 1995, p. 158).  
639 During performance, an athlete's actions generate perceptual information, which, in  
640 turn, constrains the emergence of further movements. For example, in ice climbing,  
641 Seifert and colleagues (2014) observed how skilled climbers perceived different  
642 properties of ice surface structures to adapt their inter-limb coordination patterns with  
643 ice tools and crampons. When they detected holes in the ice surface left by previous  
644 climbers, hooking actions emerged. Conversely, when the ice was smooth and dense,  
645 climbers used swinging actions to create holes needed for a safe and rapid traversal. In  
646 turn, a climber's movements continuously change his/her relationship with the ice  
647 surface. Decision-making in this climbing task is facilitated by multi-stability of the

648 perception-action system. Multistability refers to the principle of “functional  
649 equivalence” (Kelso, 2012, p.907), also known as “degeneracy” (Edelman & Gally, 2001).  
650 Degeneracy corresponds to “the ability of elements that are structurally different to  
651 perform the same function or yield the same output” (Edelman and Gally, 2001, p.  
652 13763). It signifies that an individual can vary action-perception without compromising  
653 function (Mason, 2010; Price & Friston, 2002), as an expression of the adaptive and  
654 functional role of coordination pattern variability in order to satisfy interacting  
655 constraints (Seifert et al., 2016b). A higher level of skill reflects greater adaptive  
656 capacity to achieve similar performance outcomes with different movements and  
657 coordination patterns, rather than relying on a single (programmed, represented)  
658 ready-made solution. The presence of degeneracy in sport actions increases an athlete's  
659 complexity and robustness against perturbations and ensures a functional ongoing  
660 engagement (decision-making) with a dynamic environment.

661

### 662 ***Selecting an affordance in a world full of affordances***

663 Behaviours can be sustained by simultaneous and successive affordances, and  
664 not necessarily by a hierarchical plan or representation capturing a sequence of  
665 performance operations (Araújo, Dicks, Davids, in press). Reed (1993) argued that these  
666 patterns of behavioral organization emerge in situations in which different affordances  
667 can be utilized to enhance performance in contexts like sport. This performer-  
668 environment basis of conceptualizing behaviour indicates that affordances can be used,  
669 motivating an organism to act, but they are not to be viewed as unique causes for  
670 behaviour because a person may not act on a perceived affordance. Affordances favour  
671 certain behaviours and select against others (Withagen et al., 2012). The factors  
672 underlying the tendency for favoured behaviours to be realized are multiple. For

673 example, in climbing, a rock surface may be traversable for an individual climber in a  
674 specific way, depending on the availability and spatial organization of surface texture  
675 properties (holes shape, size and orientation, offering more or less stability) (Seifert et  
676 al 2015). Indeed, each surface property has many affordances, and it is from this  
677 selection of which affordance to act upon that it is possible to understand behavioural  
678 dynamics in different climbers. Whether the individual takes up these possibilities or  
679 not is a separate matter since affordances are not deterministic causes, i.e., one can  
680 decline or accept an invitation to act in a specific way (Withagen et al. 2012, 2017).  
681 Since affordances do not select themselves, the intention to use an affordance, as Reed  
682 (1993) put it, like other biological phenomena, emerges out of a process of variation and  
683 selection. In this way, people are 'drawn into' interactions with affordances offered by a  
684 performance environment (Withagen et al., 2017).

685         Relatedly, Kiverstein and Rietveld (2015) defined skilled intentionality as “the  
686 individual’s selective openness and responsiveness to a rich landscape of affordances”  
687 (p.701). This notion indicates that the everyday environment offers a range of more or  
688 less inviting affordances (Withagen et al. 2012). However, these affordances are  
689 relational: accessible to individuals with necessary skills (e.g., developed through  
690 previous experiences) to act on them. For example, where one tennis player with an  
691 excellent backhand shot may perceive an opportunity to force cross-court shots when  
692 using it, another player who is highly-skilled at volleying may perceive every ball as an  
693 opportunity to approach the net. Thus, sports people interact with a surrounding  
694 environment through skilled engagement with the concrete affordances that a specific  
695 environment offers them. because of their unique skill set. From this viewpoint  
696 perceptual attunement developed through experience brings an 'openness' to

697 affordances that, without skill, would not be accessible, since it is skill that opens up  
698 possibilities for action to an individual.

699         Moreover, individuals act relative to multiple relevant affordances  
700 simultaneously, or to what Rietveld and colleagues (Kiverstein & Rietveld, 2015; van  
701 Dijk & Rietveld, 2017) call a “field of affordances”, each of which is of greater or lesser  
702 significance to the performer. For example, the field of affordances of significance for a  
703 goalkeeper in hockey or football only marginally overlaps with the field of affordances  
704 for an attacking player in these invasion games. This idea justifies why an individual is  
705 open to and ready to act on multiple affordances at the same time,, which needs to  
706 underpin practice design in sport. Through experience, training and practice,  
707 individuals can display tendencies towards a specific link with the environment in a  
708 field of affordances. Additionally, the existence of *constellations of constraints*,  
709 maximizing the availability of affordances, has been identified in different sports  
710 settings (e.g., Barsingerhorn et al.2013; Pepping et al, 2011; Hristovski et al, 2006, Paulo  
711 et al, 2016). These regions of 'hyper-link' in a field of affordances may be important in  
712 sensitizing performers to subtle differences in an opponent's actions, and thus in the  
713 process of calibration to a perceived affordance. In learning design, the perception of a  
714 new affordance in a landscape of temporally nested affordances (Hristovski et al., 2011;  
715 Torrents et al, 2015) can bring about higher adaptive capacities of performers.

716         We recently suggested that one important way to explain how affordances are  
717 selected is based on information for the next affordance (Araújo, Dicks & Davids, in  
718 press). This is the informational basis for the selection of affordances in multi-scale  
719 dynamics (Keijzer, 2001). This means that affordances are conditionally-coupled (van  
720 Geert 1994), allowing a dynamic assembly of overall behavioural sequences. In tennis,  
721 Carvalho and colleagues (2014) studied how sequential behaviours, expressed as

722 successive strokes in a rally, was based on conditionally-coupled affordances. The *goal-*  
723 *directed displacement index*, was developed as a measure to simultaneously consider the  
724 distance of competing players in relation to two on-court reference points –the central  
725 line of the court and the net- during competitive performance. This eco-biophysical  
726 variable reflects the state of the individual-environment system. This study showed that  
727 different functional relations could be established between skilled players attuned,  
728 open, and responsive to match affordances. A player with an advantage is perceiving  
729 and creating affordances for the other (see Fajen, et al, 2009), where the other is invited  
730 (pressured) to act upon such affordances, since he/she is open and responsive to play in  
731 the rally. The stability of the interactions between players is highly constrained by the  
732 co-adaptations (co-positioning) of the players (near or away from the central line of the  
733 court, or from the net) and the pattern of interactions developed during play (cross-  
734 court or down-the-line rallies). In such a field of affordances, a player with an advantage  
735 tries to create a successively more unstable situation for the other player, stroke after  
736 stroke, in an effort to de-stabilize the existing spatial-temporal coordination between  
737 them. The advantage in a rally is a process that is developed through successive actions,  
738 where nested affordances are dynamically assembled and imply perceptual attunement  
739 of skilled players to information for the next affordance.

740

## 741 **Conclusion**

742 In sport, coordination of whole body actions emerges with events, objects and  
743 surfaces and other athletes in the environment, is a requisite of performance. In other  
744 social-cultural activities, such as chess or playing piano, expert action tends to reside in  
745 micro-movements. A generalized interest of the scientific community on the topic of  
746 action has been around for no more than two decades (Herwig et al., 2013). However,

747 sport performance is not typically predicated on performance of micro- or simple  
748 movements. It is a phenomenon that capitalises on detailed interactions between an  
749 individual and a performance environment. This is why the structure of action, during  
750 ongoing interactions of a performer in a performance environment, is a key issue for  
751 understanding expert cognition in sport.

752         From this viewpoint, the study of decision-making in sport involves selecting  
753 among affordances. However, once an affordance is perceived, its selection embodies an  
754 action mode, i.e., the action mode is chosen in the perception of an affordance.  
755 Interestingly, this action mode can change to other action modes guided by the  
756 information conveyed by the affordance (e.g., from walking to running when fielding in  
757 cricket or baseball if a ball's trajectory is perceived as falling to ground earlier). A few  
758 models of decision making already exist in ecological dynamics (e.g., Araújo et al., 2014;  
759 2015). But there are many other courses of action, competition sub-phases and sports  
760 to address. Moreover, action modes bring about new affordances among which new  
761 selections may emerge. Therefore, the two instances of decision-making are intimately  
762 connected and future research is needed to investigate this relationship.

763         Ecological dynamics is focused in the performer-environment system as an  
764 explanatory level of analysis, not on inferred internal variables. Ecological dynamics  
765 research is needed to understand how environmental manipulations (e.g., match status  
766 in competition, effects of differences in heights between a competing attacker and  
767 defender or the influence on performance of variations in holds designed into a  
768 climbing wall) influence the behavioral dynamics of the participants (Cordovil et al.,  
769 2009).

770



771           The understanding of action, and therefore cognition, as an emergent process  
772 under individual, environmental and task constraints has consequences for how  
773 decision-making behaviour is understood and enhanced by experience and training  
774 (Araújo et al., 2009b) by sport psychologists and sport practitioners. Also, such an  
775 approach has consequences for understanding of cognition and agency (Withagen et al.,  
776 2017), and creativity (Hristovski et al. 2011), in general psychology, as well as  
777 performance analysis in sport (Passos et al., 2017), sport pedagogy (Chow et al., 2015;  
778 Renshaw et al., 2015), team sport expertise (Araújo, Silva & Davids, 2015) and talent  
779 development (Araújo et al., 2010; Davids et al., 2017). Indeed, sport psychology is  
780 located in an exciting position, to reveal how action is not a ready-made implementation  
781 selected 'off the shelf', but a true choice behaviour emerging from a range of  
782 opportunities.

783

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