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Understanding sport skills through the theories of visual perception: Contrasting indirect and direct approaches

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ABBREVIATIONS

τ	optical variable tau
Dideal	ideal deceleration
Dmax	maximum deceleration

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BACKGROUND: Understanding sport skills through the theories of visual perception brings the debate to the level of basic and applied components of science, characterizing contributions from the most relevant approaches in the field of Motor Behavior about the indirect and the direct paradigms.
AIM AND FINDINGS: The first section of this article emphasizes theoretical assumptions of visual perception from indirect and direct approaches; the notion of the relative utility of these perspectives in explaining vision is discussed, which includes analysis of the goals of explanation, prediction, and simplicity. The second section is devoted to demonstrating the critical insufficiencies of indirect perspective. The third and final section focus on the ecological dynamics account applied to sports, emphasizing the elements of decision-making and motor control. Ecological dynamics is shown as an interesting alternative to understand sport skills, accounting for involved complexities of perception, decision-making, and action.

Vision is essential to motor behavior in everyday life and sports contexts. Athletes are dependent on a constant supply of accurate and reliable information from the environment while performing complex movements.[1,2] This article describes theoretical assumptions of visual perception from indirect (i.e., information processing and computational vision) and direct (i.e., direct perception, ecological psychology) approaches; then, it is followed by identifying the relative utility of these perspectives in explaining the visual phenomenon. Secondly, we compare these representational and dynamical views into the sport context, showing criticisms of an indirect perspective in sports. As a third and final step, we present the ecological dynamics account in sports, emphasizing elements of decision-making and motor control. Ecological dynamics seem an interesting alternative to understanding sport skills, accounting for perception-action connections, motor action complexities, attunement to the environment, and cognitive functioning.

MAIN CONCEPTS OF DIRECT AND INDIRECT THEORIES

The terms direct and indirect will be used for clarity of comparison between these two approaches, although considerable variance can be observed in each point of view. The following topics were selected to represent relevant theoretical differences. Readers should be aware that each perspective has its assumptions and logical reasoning, which implies that each of these comparisons is not trivial or straightforward, as these topics may suggest. However, they were expected to support the following analysis of relative utility.

Optic array vs. retinal image

What are the implications of defining the retinal image or the optic array as the starting point for visual perception? Although the optic array and retinal image concepts may be interchangeable for many practical reasons, they are associated with distinct approaches.[3] According to the indirect approach, the retinal image is the point of origin for visual perception studies. As photo-receptors do not map the optic nerve fibers in a one-to-one relationship, the retinal image itself cannot represent the external world simply and accurately.[4] The retinal information that leaves the retina to the optic nerve contains only an approximation of light intensities that initially reaches the retina.[5,6] Because this correspondence is not complete, indirect perspective researchers argue that pure (i.e., before central processing) information carried out by the optic nerve needs to be detailed in order to specify objects and events in the external world. A substantial improvement and mediations into the visual cortex based on complex computational processes are required in this view.[7,8]

Alternatively, Gibson's[9,10] optic array leads to a different conception of the information available in light to a perceiver.

> *The optic array may be thought of as a bundle of narrow cones of light with their apices at the point of observation, each cone having as its base a distinct environmental texture element and thus being optically differentiable from its neighbors in terms of the intensity and/or spectral composition of the light it contains. At each point of observation there is a unique optic array. It is the passage of the eye through successive points of observation that gives rise to the optic flow field at the eye ([11], p. 282).*

The ecological concept of information is based on the idea that the richness of perceptual experience is present in the stimulation itself, and it does not depend on constructive processes. An accurate specification of the nature of objects, places, and events is available to the organism at stimulation.[7,12–14] Gibson[10] has criticized the indirect notion of information, "information that can be extracted from ambient light is not the kind of information transmitted over a channel. There is no sender outside the head and no receiver inside the head" (p. 64). In this instance, information, which is the structure that specifies an environment to an animal,[9,10] is understood as a bi-directional arrow, with one side pointing to the environment and the other side pointing to the animal. Information-about objects, scenes, events, and information-for the perceiver are two linked aspects that compose information analysis.[7]
The indirect perspective of a mosaic of point-light intensities on the retina describes the input for a perceiver in the same terms as the input for a single photoreceptor. The input for a receptor is a stream of photons, but the input for a perceiver is a pattern of light extended over space and time.[13] Gibson[9,10] described this pattern as gradients and rates of optic texture flow, which emphasize the changes in the temporal pattern of light.

The indirect view of visual input is not concerned with the environment as perception is centered on the perceiver.[3,15] The direct approach emphasizes the relationship between the environment surrounding a perceiver and the optic array that specifies the environment.[10] The aspect to be discussed in the next section is, in direct view terms, the environment's specification by the optic array, or in indirect view terms, the relationship between stimuli and percept.

Immediate vs. mediate perception

The existence and necessity of cognitive mediation in visual perception is a topic of intense debate.[13,14,16–20] Indirect perspective researchers have argued that perception requires inference processes to supplement the supposedly impoverished nature of the flat, static retinal image.[3,7] Gibson, on the other hand, argued that since the structure of light directly specifies surface layout, mediating cognitive and/or computational processes are not necessary for perception.[9,10,21]

The indirect approach to visual perception maintains that the objects and surfaces' world must be reconstructed by piecing together more primitive elements such as edges and blobs.[22] Knowledge of the world is needed in order to create these reconstructions. Indirect theories have proposed various kinds of knowledge, for example, the knowledge that natural objects approximate to general cones.[23] The ecological approach maintains that objects are not perceived by adding up a set of features and using knowledge of the world. Instead, the information in higher-order invariants is directly perceived. In this case, it is not necessary or possible to decompose these processes into more primitive operations or computations.[13,24]

Given the assumptions of indirect theories of visual perception, research orientation has been on the nature of computational stages, types of representations, and storage necessary for vision. Marr[18] suggested that a consolidated theory of vision should focus on three levels of explanation and analysis. At the computational level, the most conceptual one, a theory should specify the task the visual system needs to complete, including a description of the available sources of pure information to support this task. At the algorithmic level, it is determined how the information available on the retinal image can be processed to find the task's computational requirements. At this point, specific algorithms, processing mechanisms, and representations should solve the computational task to be discovered and tested. The implementational level aims to find out possible neural, physiologic mechanisms that put algorithms to function.

The direct perception perspective only effectively recognizes two levels of vision: an ecological level (equivalent to Marr's computational level) and a physiological level (equivalent to Marr's implementational level). Usually, the direct perception perspective focus on the ecological level. The algorithmic level, the level where any representational processes would exist, is eliminated from the direct perception view.[7,10,13]

Bruce and Green[3] put forward an attempt to overcome disagreements from these two theories. These authors were in line with the direct notion that properties of the world can be detected without cognitive processes. However, such processes of detection would have to rely on computation. Bruce and Green used Fodor and Pylyshyn's[16] notions of cognitively impenetrable processes (which cannot be influenced by beliefs and expectations) and compiled detectors (which run in an autonomous, data-driven manner) to suggest some common ground between the two opposite approaches with respect to cognitive mediation.

> *At a higher level of analysis, compiled detectors can be regarded as detecting properties of the world directly, but at a lower level of analysis their*

> *operations can be unpacked. At a behavioral level, it does not matter whether one argues that τ [the optical variable that specifies time-to-contact information (Lee, 1976, 1980)], for example, is perceived directly, or whether it is computed by compiled detectors. What does matter is that its detection needs not to rely on inferences of the hypothesis-testing variety ([3], p. 381).*

In summary, the direct approach emphasizes no need for mediation between light structure and visual perception, while indirect approaches assume information processing of stimuli features as essential to perception. The subsequent section will focus on the necessity of mediation at more abstract levels. The meaningfulness of visual information and memory-related constructs will be discussed.

Affordances vs. representations

The indirect theory also regards perception as a mediated process when discussing how the world's knowledge is represented in more abstract levels. The term representation is used in various senses, and it generally refers to any symbolic description of the world.[13,20] Newell, Rosenbloon, and Laird[25], when describing the functions of the cognitive architecture, identified memory, symbols, operations, and interpretation as capable of being a symbol system. However, none of these functions represent the external world; such representation is a function of the computational system as a whole.

Direct theories of perception reject all such representations. This rejection is based on the notion that objects and surfaces in the environment are specified by high-level invariant properties of optic flow patterns. Consequently, there is no need for any processes of construction or matching representations.[15,26] In addition, the invariants to which the perceiver is attuned specify the actions that can be performed. Gibson called this relationship affordance. The affordance of something is the specific combination of its properties of substance with its surfaces related to the animal.[10,21] It is anything within the environment that contributes to this kind of interaction.[15,27,28] The fact that affordances are perceived is important because this provides meaning to perception. To detect affordances of the ambient is to detect meaningful, available information that is unique, personal, and specific to species.[7,29]

Fodor and Pylyshyn[16] strongly disagree with how the gibsonian theory avoids the use of representation and implies a problem of trivialization.

> *How do people perceive that something is a shoe? There is a certain (invariant) property that all and only shoes have - namely, the property of being a shoe. Perceiving that something is a shoe consists in the pick up of this property (p. 142).*

Fodor and Pylyshyn's[16] main criticism was that the terms invariant and direct detection are left so unconstrained that they are meaningless. They defend a “sufficiency criterion” expressed in the following two constraints: 1) the only thing that can be picked up is a restricted class of properties of ambient light, and 2) spatio-temporal limits on these properties are determined by what stimuli turn out to be efficient to cause perceptual judgments. The consequence of these restrictions is that visual perception must involve inferences based on those directly detected light properties. This inference occurs because the causally effective stimulus for perception usually underdetermines what is seen. For example, one art expert detecting the fact that Da Vinci executed a painting would rely on inferences because the sample of light reflected from the painting is not sufficient to cause recognition of it. It is argued that information about the properties of Da Vinci's paintings represented in memory is necessary for such perception.[16]

To summarize the concepts discussed above, an example of how a soccer goalkeeper perceives an approaching ball is illustrative to differentiate the two approaches. Let's assume that goalkeepers perceive the remaining time the ball has to arrive and contact their hands through the variable time-to-contact. The indirect view of perception is based on the idea that our visual system uses a sequence of static snapshots (retinal images), comparing one to the next, in order to detect changes and movement, which requires that each image be stored, represented, and retrieved from a memory system, as well as the participation of higher-order cognitive processes, such as inference. An "indirect goalkeeper" is expected to mentally calculate the time-to-contact, dividing the distance to the ball by velocity of the ball[4] or more complex variations of this type of mental processing.[30] The direct view of perception is based on the notion that an optic array continuously changing, named optic flow, is visually available and contains invariant properties of the environment, including the rate of expansion of the ball image on the retina. A "direct goalkeeper" is expected to directly perceive time-to-contact information from the optic flow, without the need for mental calculations or representations[31,32] Both of our imaginary indirect and direct goalkeepers are capable of perceiving time-to-contact of a ball approaching to allow preparation and regulation of arm and body movements.

The arguments presented on the nature of visual input, cognitive mediation, and representations/affordances briefly described antagonistic aspects of direct and indirect theories. Many counterarguments from both sides were not mentioned due to the scope of the present study. In sum, on the indirect view side, the notion of retinal image as the starting point to visual perception is tightly associated with some computational or cognitive mediation between stimuli and percept, which includes the necessity of memory-related processes. On the direct view side, the richness of information present on optic array notion allows a lawful relation between environment and perceiver, which favors meaningful actions based on optic flow.

RELATIVE UTILITY OF DIRECT AND INDIRECT THEORIES

An evaluation of the relative utility of these two theories includes an analysis of the goals of explanation, prediction, and simplicity expected in science. Such inspection requires the understanding of individual assumptions and contexts of research. Also, practical definitions of the scientific aims and some criteria normalization are necessary to keep fairness when comparing distinct theories.

Science attempts to obtain a comprehensive account of the universe and its contents designating relationships between investigation phenomena.[33–35] Emphases on aspects of parsimony, explanation, and prediction are cognitively expected in science. The extent to which different theories succeed in pursuing these aims can be represented by the degree of utility of these theories. To compare their relative utility, mean parsimony, explanatory

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power, and predictive capability will be used as criteria. The overview elaborated on optic array topics vs. retinal image, immediate vs. mediate perception, and affordances vs. representations will support the following comparison.

The first difficulty in this analysis is the difference in the investigation phenomenon that each theory defines. Although the phenomenon could be simply defined as visual perception, each theory has a different answer to what visual perception is. Direct perception theory is basically interested in the ecological level of analysis[9,10,21,] and the research in this area is directed to describe and explain the ambient-perceiver relationship. The indirect view includes the work on computational/representational processes as a research topic, as shown by Marr[18]. As a result, each approach has its own goal. For practical purposes, the direct perception theory seems as adequate as the indirect theories to explain visual perception.

The conception of parsimony holds that the simplest of a group of theories, which account for equal adequacy for phenomena, is the most acceptable theory in science, other aspects being equal. Simplicity refers to the economy in the use of unverified assumptions in developing explanations. The minimum number of unverified notions and hypothetical constructs should be used for postulating theories.[34] Bunge[36] defines epistemological simplicity as the closeness to sense experience and, in particular, to observation.

Regarding parsimony, it seems clear that the notion of direct perception is simpler than indirect perception. The theory of visual perception, as described by Gibson[9,10], is more economical in developing explanations, and it does not use a series of complex abstract representations, as in the case of the indirect theories. The concepts of optic array and affordance reduce the number of logical links involved in visual perception.

Also, the notion of mean parsimony asks how close to observation the theories are. In general, the ecological concepts are based on the light's structure, which seems, in principle, more verifiable than an abstract mental representation. This does not imply that direct view concepts are easier to test than indirect view ones. For example, the strongest shreds of evidence for optic flow were obtained in animal studies, and more investigation in humans could strengthen the concept.[37] One could correctly argue, in agreement with Bunge[36], that simplicity, in this case, does not account for the complex characteristics of the phenomenon if ones' assumptions include internal representations. Another possible argument is that cognitive processes are perfectly testable in visual perception, as shown by the enormous amount of experimental research produced in psychological and physiological studies.[5,6]

Bunge[36] defines explanatory power as an epistemological requirement, implying ambiguity of the demand for simplicity.

> *Explanatory power = Range X Accuracy: the greater the range of the theory, the less properties involved; but the greater the accuracy, the more complex the theory will be…. Consequently the demand for simplicity is ambiguously relevant to the demand for a large explanatory power (p. 102).*

The conception of explanatory power considers the relation between the amplitude and complexity of an explanation. The indirect approach may take advantage of complexity due to the inclusion of computational/representational mechanisms in their explanations, suggesting that the indirect view of visual perception is closer to neurophysiology. Findings from this area help the statement of possible mechanisms into computational/representational models. Neurophysiological studies investigate how neurons connect to each other to transmit information from the eyes to the brain's visual areas and how different areas have different functions in vision. For example, with the use of sophisticated techniques, it is possible to explain, within the cognitive framework, how the damage in some areas of the brain may influence visual attention mechanisms during specific tasks.[38] It is worthy of noting that, although there is a historical lack of emphasis on nervous systems directly, there are recent advances available (e.g., [39]).

Another aspect that can be considered in the discussion of explanatory power is the ecological validity. Overall, indirect perception studies have a lower ecological validity than direct perception studies. If it is assumed that low ecological validity negatively affects the range of explanation and vice-versa, the direct perception approach would have its explanatory power relatively increased.

The ecological approach seems to face limitations regarding the range of explanation due to its high specificity of some concepts. Affordance and optic array, for example, describe relationships specific to the perceivers' point of observation, specific to objects and scenes, and specific to the task. Although invariants' notion should represent the system's metric across aspects of specificity, such invariants are not easily identifiable. On the other hand, the indirect view approach focuses on understanding the underlying process, which, in principle, could generically explain a variety of other situations.

The aspect of prediction also represents the utility of a theory. Bunge[36] defines predictive power (that will be used as synonymous of capability) as follows:

> *Predictive power = (Range explainable ex post facto + Unexpected range) X Accuracy: simplicity is ambiguously favorable to predictability not only because it is incompatible with accuracy and compatible with manifest range, but also because the unexpected range of a theory … is greater as the theory is richer (p. 103).*

If the relation between ecological validity and explanatory power proposed above is appropriate, it could be extended to predictability as well. In this case, the predictive capability of each theory would differ according to the situation. The direct view seems to have a higher predictive capability in natural situations. For example, visual perception characteristics during locomotion are well predicted by ecological theories based on the notion of optic flow.[40] Indirect view, however, could predict properly the situations more dependent on representation, such as visual illusions[20] or artistic evaluation of paintings.[16]

The utility is a topic that emerges when the characteristics of basic and applied types of science are discussed.[41–43] Theories with higher utility seem to be more indicated to application. Hoffman and Deffenbacker[42] proposed a more analytical categorization of applied and basic science including distinct dimensions (validity, relevance, salience, representativeness) for ecological and epistemological aspects based on characteristics of a proposed research. They also considered the importance of implications of the experiment's results and divided the cognitive notion of generalizability into utility, novelty, and generality.

The epistemological utility was defined as the extent to which the results lead to refinements in hypotheses and theories.[42]

Comparing the relative utility in terms of mean parsimony, explanatory power, and predictive capability between direct and indirect views seems constrained by distinct levels of analyses utilized in each approach. This relative utility analysis does not provide an output of clear advantage to one of the perspectives (direct or indirect view); the utility comparison's main conclusion is that indirect and direct approach are similar, according to the referred criteria. Nevertheless, we argue in favor of the direct approach, suggesting that there are additional aspects to be considered regarding the context of sports; the developed comparison above was exclusively based upon the phenomenon of visual perception, which is certainly crucial to success in sports performance. However, the action itself and intricate perception-action connections have a central role in motor behavior theories; the ecological dynamics perspective has been fruitful in the literature, as compared to the indirect view, searching for new explanations and providing methodological advances to account for complexities and specificities of sports context. To expand these ideas, we now turn into considering the difficulties of indirect perspective in explaining visual perception and action during sports. Particularly, how cognition orchestrate perception and action in the decision-making process will be focused on in the next section, showing that understanding cognition is certainly not a privilege of the indirect perspective.

CRITICISMS OF INDIRECT PERSPECTIVE IN SPORTS

Based on the foundations of visual perception according to direct and indirect approaches, we now advance how visual perception understood in the ecological viewpoint supports athletes in making decisions and producing movements in sport contexts. We present some particular criticisms of representational approaches and summarize aspects of the ecological dynamics account of decision-making in sport.

Sport is an expression of expertise, which strongly relies on perception; athletes see things differently compared to novices, and such differences and respective knowledge affect how athletes make decisions, plan their movements, and use their best strategies in sports.[44,45] Based on these assumptions and following the trends in indirect perspective, sports studies have focused on athletes' perception and anticipation, attention, memory, and decision-making; the central role of action and its participation in cognition has been neglected.[46,47] Research on perception, action, and cognition has been traditionally based on memory enrichment through representations of various types, such as programs and schemas, which assume stimuli in the environment is impoverished; internal knowledge structures are responsible for enhancing meaning and richness of stimuli, allowing interpretation of the environment and movement programming.[48] Ecological dynamics is an action-based, non-representational approach grounded on the notion that perception and cognition are embedded and embodied, emphasizing the performer-environment relationship as an appropriate scale of analysis.[47]

The representational approach to human performance assumes that representations contain the meaning of symbols, which are responsible for connecting an individual to the world and its own body; representations are considered knowledge structures able to make these mediations. However, very little is known about how these computational processes of symbolic coding, decoding, and the involved rules are biologically implemented. In a distinct vein, the ecological dynamics approach holds that ambient energy distributions are necessarily specific to the facts of the environment and of a performer's actions relative to the environment[10,28]; information is the basis for keeping contact with the environment since it is specific to its sources. Using sport context as an example, athletes use different exploratory actions of their perceptual systems (movements of eyes, head, trunk, and whole-body locomotion) for perceiving things around. In terms of the ecological dynamics approach, meaning in perception does not come from any form of mental association but only from information detected by an observer. Due to practice, athletes are better able to difference increasing types of information, amplifying the amplitude and economy involved in information detection; this is perceptual learning, a process of attunement to the environment properties. These arguments strongly suggest that motor behavior control can be explained without postulating mental representations.[45,47]

ECOLOGICAL DYNAMICS AS THE BASIS OF EXPERT DECISION-MAKING AND MOTOR CONTROL IN SPORT

The ecological dynamics account applied to sports combines the previously referred work of Gibson[9,10] with that of Bernstein[49]; these ideas regarding perception and action have been discussed and amplified by Turvey and colleagues[48], bringing language and principles from the dynamical systems approach. A relevant impact was provided by Araujo et al.[46], developing an ecological dynamics rationale for decision-making in sports. According to Araujo et al.[47], three important assumptions of this approach are the following: First, behavior emerges from the performer-environment system. So, actions during sports events must be understood according to the performer's characteristics and, necessarily, to the performance environment. For instance, generalization from laboratory or training session context to competition environment requires rigorous behavioral correspondence between these contexts because athletes' motor patterns are generated from the tight coordination emerging between athlete and sport environment towards a specific goal. Second, perception is of affordances[15,47]; athletes calibrate informational of their own action capabilities to directly perceive opportunities to act in the environment.[50] This notion of affordances captures the link between constraints on each athlete and the environment's characteristics. Decision-making in sport involves selecting among affordances; once an affordance is perceived, its selection embodies an action mode (i.e., the action mode is chosen simultaneously), but this action mode can change to other action modes guided by the information conveyed by the affordance. Importantly, it is understood that cognition emerges during these continuous interactions between performer and environment, not from a mental representation of the world.[19,50] Third, action (and therefore cognition) emerges under constraints. Behavior is understood as resulting from a self-organization process under constraints.[46] According to this perspective, as constraints have the effect of reducing the number of configurations available to an athlete at any moment, the task of each athlete is to exploit physical and informational constraints to stabilize performance.[51]

As a sample of research conducted on sports skills such as auto racing and cycling, we now summarize advances in ecological dynamics on braking and steering to avoid obstacles. Visually guided actions such as braking and steering are behaviors that involve continuous and prospective control guided by the visual information from optic flow.[9,10,51,52] For instance, to be able to cycle safely in a competition, good steering, looking ahead, controlling speed, and braking are essential skills. Crucial visual information for braking regulation is potentially related to the actors' action capabilities, which has become a topic of investigation. Based on ecological psychology, the perceptual process is deeply linked to action once that not only visual information is used to modulate action, but the perceiver's action affects the information that is available for perception in a perception-action cycle.[9,10] Within the ecological perspective, braking's visual control has been traditionally investigated through an information-based approach (i.e., tau-dot).[51,53] Lee[31] proposed that in visually guided braking to avoid a collision, the optical variable tau (τ) specifies the time remaining until collision (i.e., time-to-contact). Particularly, the first temporal derivate of τ (tau-dot) specifies braking intensity regulation over time and should be hold at a constant value (approximately - 0.5) to bring the actor to stop safely.[31] Brake adjustments control deceleration to null the difference between the current value of tau-dot (current state) and the ideal margin value of tau-dot (i.e., - 0.5, ideal state). The tau-dot model, as well as other error-nulling models (Deceleration Error Model, Constant Deceleration Model), has been widely accepted as a formal description of visually guided braking[31,54,55] because it evidences the invariant relationship between the use of optical variables and the sufficiency of the actor's current rate of deceleration. The use of τ information to safely stop before collision has been investigated in simulated car driving,[31,55–57,] but evidence for cycling in natural context is also available.[58,59] Although these approaches are aligned to the ecological theory of visual perception regarding stimuli invariants properties,[10] the hypothesis that visually guided braking is information-based ignores the role of affordances perception on the movement guidance.

Affordances are possibilities of action available in the environment and specific to the actor.[9,51,60]. The perception of affordances captures the reciprocity of the perception and action coupling.[10] Along the years, it has been understood the role of affordances on motor performance in terms of action selection. For instance, the affordances of a roughly horizontal dense surface relative to the actor's mass inform the actor on the walkability to perform the task of walking. However, recent ecological theorists have proposed an ultimate perspective of understanding movement control as affordance-based.[51,52] According to the Affordance-based model,[52,53,61,62] movement control is scaled to the actor's action capabilities. In driving, actors brake in such a way that their deceleration will always be within the limits of their maximum capabilities, i.e., maximum deceleration (Dmax) they can achieve.[53,61,62] The braking is then only (or especially) adjusted if they threaten to get close to that maximum. This means that actors must appropriately calibrate their braking adjustments to their maximum braking ability. In a series of experiments,[53,61,62] Fajen asked drivers to watch a video of self-motion approaching stop signs and regulate a joystick to control deceleration for stopping the car smoothly and as close as possible to the obstacles.[61,62] Braking onset and the magnitude of braking adjustments were influenced when information about speed was manipulated (optic flow and eye height). Drivers were more likely to increase brake adjustments when the ideal deceleration (Dideal - information from the optic flow that indicates to the actor the rate of constant deceleration to stop at the intended location) was close to Dmax.[62] Drivers performed the braking task under weak brake conditions (lower Dmax), medium brake, and strong brake (higher Dmax). When Dideal at braking onset is analyzed in extrinsic metrics (m/s^2), drivers showed higher values of Dideal at braking onset during strong brake compared to medium and weak brakes. However, no differences were observed when Dideal at braking onset was analyzed in Dmax units (% of Dmax). The author argued that drivers calibrated their perceptual-motor system to different brake strengths by scaling information about Dideal in units of their action capabilities (Dmax).[61] This perceptual-motor calibration (or scaling) has been observed in several other visually guided actions such as baseball batting simulation,[63] performing a reaching task,[64] and others (for details see the systematic review[65]). In short, it has been shown that changes in action capabilities influence visually guided braking of drivers, which is an example of how fruitful the ecological dynamics perspective has been to investigate sport-related skills.

In addition to focusing on affordance-based control during braking and steering, captivating aspects of gaze behavior and learning process have been explored by researchers. The interest in describing the visual-motor behavior of cyclists during steering control is increasing over the years.[66–68] In general, performers pick-up visual information from two regions during cycling: the “near” region for stability and/or online control and the “far” region for guidance and hazard perception. The requirement to allocate gaze in the near region has been proposed to increase with greater immediate task complexity (e.g., cycling in a high-intensity traffic metropolis) and decreases with improvements in performer’s skill level (e.g., experienced cyclists when compared with beginners).[66,67] Moreover, gaze towards the far region increases with greater travel speed and situation unpredictability.[66] In this case, an increase in the demands of both online control (e.g., narrow paths) and situational information (e.g., unpredictable pedestrian behavior) could lead to an increase in attentional demand and cognitive workload. Higher levels of attentional demand have been associated with a greater probability of accident[69], and therefore the ability to brake on time is crucial to prevent accidents. Also, performance on visually guided braking improves with the learning process.[53,70] Fajen[70] asked participants to stop as close as possible to the obstacles in a simulated braking task over 11 blocks of trials. At the early stages of practice, participants stopped further away from the obstacle when the obstacle size was larger and showed braking onset earlier when the approaching speed was slower; however, both size and speed effects were reduced after practice. The author argued that perceptual attunement resulting from practice contributed to improvement in performance. Perceptual attunement (or education of attention) is the progress from the use of non-specifying to specifying information for controlling the actions.[53,70,71] Although the learning process seems to improve the perceptual ability of picking-up the useful information, the perceptual-motor calibration process of more experienced vs. beginners may vary as a function of task experience.

In summary, ecological dynamics seems an interesting alternative to the tradition of indirect views of perception and action in sports study. Although the previous analysis of the relative utility of indirect and direct perspectives has shown global similarities and specificities of theoretical assumptions of each view, the sports application based on direct perception reasoning, through the more recent proposal of ecological dynamics, brought to the debate relevant theoretical novelties, emphasizing the fundamental role of motor action to the domains of perception and cognition. The perspective that assumes the dynamical emergence of motor patterns as expression of cognition, resulting from organism, environment, and task constraints also reveal the importance of considering the foundations of visual perception previously discussed.

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