Towards an ecological dynamics theory of flow in sport

FARROKH, David, DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123>, ARAÚJO, Duarte, STRAFFORD, Ben W <http://orcid.org/0000-0003-4506-9370>, RUMBOLD, James L and STONE, Joseph A <http://orcid.org/0000-0002-9861-4443>

Acta Psychologica 253 (2025) 104765

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Towards an ecological dynamics theory of flow in sport

David Farrokh[a,*], Keith Davids[a], Duarte Araújo[b], Ben W. Strafford[a], James L. Rumbold[a], Joseph A. Stone[a]

[a] Sheffield Hallam University, UK
[b] CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, Portugal

ARTICLE INFO

Keywords:
Ecological dynamics
Flow
Sports
Multiscale dynamics
Information

ABSTRACT

Flow is an optimal state of absorption that may be experienced in appropriately challenging and intrinsically motivating activities such as sports. Flow may be an important concept for understanding the emergence and role of sport in society, yet theoretical explanations of flow have had limited success explaining, predicting, and facilitating flow in sport. Here, we use the ecological dynamics framework, seeking to resolve foundational issues in an explanation of flow, building towards a theory of flow in sport. To address this challenge, we highlight the utility of ecological conceptualisations of experience, intention, skill, attention, information, and temporality, in explanations of flow experiences in sport, before discussing some novel empirical predictions motivated by the theory. We suggest that a multiscale ecological dynamics approach is well equipped to explore flow in performer-environment systems that display interaction-dominant dynamics and conclude by outlining avenues for future research created by an ecological dynamics theory of flow in sport.

1. Introduction

Flow states describe enjoyable experiences of complete absorption in a task which is perceived as optimally challenging (Peifer & Engeser, 2021). While flow can arise in many different domains (e.g., music, art, dance, exercise, work) sport has featured as a prominent context for flow experiences from the outset of its initial conceptualisation (Csikszentmihalyi, 1975), remaining an important part of flow research (Jackson & Csikszentmihalyi, 1999; Stoll & Ufer, 2021). The concept of flow has also gained recognition within fields such as sport psychology, performance psychology, and positive psychology (Csikszentmihalyi, 2000). Despite popularised appreciation for the concept, scientific progress in flow research has been hampered by theoretical and methodological issues (Swann et al., 2018). Farrokh et al. (2024) have recently argued that nearly all theories of flow have been constructed within the cognitive metatheoretical framework and suggested that new theories should be developed from alternative metatheoretical foundations.

Here, we seek to explicate the foundations of the ecological dynamics framework (Araújo et al., 2006), outline key implications for flow, and build towards an explanatory theory of flow in sport. Building on the metatheoretical analysis of Farrokh et al. (2024), we argue that an ecological dynamics theory of flow can resolve key impediments to the understanding of flow, framing the phenomenon in a more empirically tractable manner. Given the questions surrounding many traditional flow research frameworks such as the nine-dimension model (Swann et al., 2017), we choose not to use existing frameworks to define the explanandum. Rather, we take the opportunity to use the ecological (transactionalist (Heft, 2012)) metatheory (Gibson, 1966, 2014) to return to some questions which originally inspired the concept of flow. In our metatheoretical re-framing, we reconsider fundamental concepts such as attention, intention, adaptivity and skill, temporality, information, and experience as they relate to flow. Finally, we discuss some testable predictions this theory might motivate, and outline steps for future research.

2. Why should we study flow in sport?

Concepts in psychology tend to flicker in and out of popular awareness, often rapidly gaining prominence only to be discarded and forgotten just as quickly. The prolonged difficulty in explaining flow, as well as its potential to provoke shallow, commercialised interpretations, provide grounds for questions regarding the fundamental validity of the concept (e.g., Hassmén et al., 2016). However, we feel that flow is

* Corresponding author at: Sport and Physical Activity Research Centre, Academy of Sport and Physical Activity, Sheffield Hallam University, Collegiate Hall, Collegiate Crescent, Sheffield S10 2BP, UK.
E-mail address: d.farrokh@shu.ac.uk (D. Farrokh).

https://doi.org/10.1016/j.actpsy.2025.104765
Received 22 October 2024; Received in revised form 15 December 2024; Accepted 28 January 2025
Available online 30 January 2025

worthy of continued consideration (i.e. theoretical and empirical research) for several important reasons, outlined next.

First, flow seeks to explain highly meaningful experiences, linked to many positive life outcomes (Freire et al., 2021; Tavares & Freire, 2016). If the concept of flow is entirely dismissed, then either a similar concept must be proposed to fill this space, or we must deny the relevance of meaning itself. Therefore, ignoring or rejecting the entire area seems an odd choice unless one is committed to an extreme form of nihilism, since flow experiences are meaningful by definition. Csikszentmihalyi (1975) began his academic career by conducting a thorough study of adjacent concepts such as play, peak experiences, and intrinsic motivation, concluding that they did not sufficiently explain the phenomenon he named flow. So, it is unlikely that flow can be satisfactorily subsumed into other existing concepts.

Second, we claim that causes of the difficulty in explaining flow are not specific to flow. Rather, we propose that flow is stretched between a number of dualisms that have caused difficulty across many domains of psychology. These paradoxes or dilemmas include:

For example, flow researchers analysing the degree of automaticity or voluntary control of action in flow (e.g., Vuorre & Metcalfe, 2016) are dealing with a specific instance of a more general question about the role of intentionality in action (Juarrero, 1999, 2023). Similarly, ambiguity surrounding the loss of self-consciousness and the transformation of time in flow (Swann et al., 2018) is unsurprising, given that self-consciousness and time are complex topics that have been the subject of much philosophical study. While the proximity of flow to so many metatheoretical questions and paradoxes is certainly noteworthy, it is by no means a reason to discard the concept.

Finally, flow may be well positioned to address core questions about our motivations and experiences engaging in sport, which has developed into an economically and socially significant global phenomenon with an increasing degree of professionalisation (even at recreational levels). The positive experiences (e.g., flow) capable of emerging in sport could dovetail with current societal needs (e.g., enhance physical activity, build community, sense of agency, meaning and value in emotional and psychological experiences). In contrast, a limited understanding of the relationship between flow experiences and sport may allow other ways of defining value and meaning, such as profitability, commercial interests or spectator entertainment value, to exert a higher degree of influence on the future of sports. There may be a fundamentally and mutually significant relationship between flow and sport, such that better understanding of one may afford fundamental insight into the other.

3. The origins of flow

While many details of the original conception of flow (Csikszentmihalyi, 1975, 1990) have been questioned recently (Swann et al., 2018), several facts about the phenomenon are uncontroversial. The concept was developed by Mihalyi Csikszentmihalyi (1975) during interviews which sought to explore experiences in autotelic (self-motivating) activities. Flow necessarily refers to some subset of experience. It is also generally accepted that these experiences relate to the motivations or intentions of the participant, and result in some optimal form of absorption in the task at hand (Peifer & Engeser, 2021). According to Csikszentmihalyi (1975), flow is situated at the intersection of play, peak experience and intrinsic motivation. These core themes must be addressed by any theory of flow, regardless of the metatheoretical framework within which it is constructed.

Csikszentmihalyi (1975) emphasised the importance of first-person reports in understanding flow, which has traditionally been conceptualised as a *subjective* (private) experience (Csikszentmihalyi, 1990; Peifer & Engeser, 2021). Additionally, Csikszentmihalyi was sceptical of mechanistic explanations and questioned how much neuroscience had to offer to flow research (Beard, 2015). Despite this hesitancy, Csikszentmihalyi (1990) maintained that "whatever happens in the mind is the result of electrochemical changes in the central nervous system" (p. 26). Because descriptive accounts have a limited ability to provide a causal explanation of the phenomenon (Swann et al., 2018), contemporary theorists of flow have sought to complete the picture by investigating physiological processes during flow experiences (e.g., Harris et al., 2017). Practically, this has resulted in an expression of dualism with the bifurcation of flow research into subjective-psychological, and objective-physical branches, with difficult challenges faced in each case.

4. Naturalism redux?

Because the term flow is a "native category", emanating from descriptions of their experiences by interviewed participants during autotelic activities (see Csikszentmihalyi, 1975, p. 36), the nature of the relationship between psychological flow and the flows of energy or matter studied by physical scientists warrants consideration. Csikszentmihalyi (1971) expressed a clear view on this relationship in a paper entitled "From Thermodynamics to Values: A Transition Yet to be Accomplished". In this critical commentary, Csikszentmihalyi responds to the idea that breakthroughs in thermodynamics and dissipative systems might provide insights into the (self-)organisation of human behaviour and experience (Katchalsky, 1971) and asserts that human concerns such as symbols, meaning, and values are beyond the reach of the natural sciences. Discussing the relevance of organisation emerging in dissipative systems, Csikszentmihalyi (1971) confidently asserted that the energy flows analysed in the natural sciences hold only "the barest twinkling of an analogy" (p. 164) to human psychology and opined that:

> To understand how values affect the behaviour of men, we must recognize the unique forces and systemic characteristics that determine the motions of men. And that requires the study of the laws of consciousness and volition, two uniquely human processes which social scientists have shied away from for the exact reason that should have attracted them: consciousness and will are furthest removed from those processes that physical scientists study (pp. 166–167).

The sentiment expressed by Csikszentmihalyi (1971) is a common theme in the history of psychology. In fact, John Dewey (1929) had already summarised the issue several decades prior:

> Hence immediate qualities, being extruded from the object of science, were left thereby hanging loose from the "real" object. Since their existence could not be denied, they were gathered together into a psychic realm of being, set over against the object of physics. (p. 264)

Dewey, however, reached a different conclusion to Csikszentmihalyi:

> Given this premise, all the problems regarding the relation of mind and matter, the psychic and the bodily, necessarily follow. Change the metaphysical premise; restore, that is to say, immediate qualities to their rightful position as qualities of inclusive situations, and the problems in question cease to be epistemological problems. They become specifiable scientific problems: questions, that is to say, of how such and such an event having such and such qualities actually occurs. (pp. 264–265)

The theory presented here seeks to: (i) transcend the limitations of objective materialism and subjective idealism by restoring the "immediate quality" of flow to the inclusive situation (i.e. the multi-scaled performer-environment system), and (ii), explore how events experienced as flow may occur and may be facilitated.

In our analysis of these "inclusive situations" we highlight the utility of research methods which have traditionally been used in the study of physical energy flows (e.g., the multiscale dynamics approaches discussed in Section 9) to analyse the lawful support for the real possibilities that give shape to experiences such as flow. However, we do not suggest that psychological flow be *directly* equated with the energy flows studied by physical scientists or deny that flow is experienced by a specific individual performer. The naturalistic attitude proposed here only questions the subjective conceptualisations of flow experience insofar as subjectivity has been understood as irreconcilably opposed to objectivity. Instead, we offer that "[t]he supposedly separate realms of the subjective and the objective are actually only poles of attention" (Gibson, 2014, p. 108) and discuss new possibilities for scientific inquiry into attentional processes as they fluctuate between these poles (see Sections 9 and 10). Finally, we underscore that complementarity of dynamic flows of energy and local constraints (Pattee & Rączaszek-Leonardi, 2012) can accommodate Csikszentmihalyi's (1971) concerns without requiring a rejection of naturalism.

5. Ecological dynamics

In the following, we introduce the ecological dynamics framework (Araújo et al., 2006) which underpins the subsequent theory of flow in sport. Ecological dynamics is a contemporary framework that synthesises insights from ecological psychology (Gibson, 1966, 1979/2014; Reed, 1988), dynamical systems theory (Kelso, 1995), complexity science (Mandelbrot, 1999; Rosen, 1991), and evolutionary biology (Gottlieb, 2007; Oyama, 2000) to study phenomena self-organising across multi-scaled performer-environment systems. The ecological approach diverges from mainstream cognitive science in fundamental ways which are often overlooked. The hegemonic nature of the cognitive metatheory has often resulted in (mis)interpretations which unknowingly conserve its core assumptions (Costall & Morris, 2015). We seek to avoid this outcome by highlighting key differences and the practical outcomes for flow research (see Farrokh et al. (2024) for further detail on metatheoretical issues in the explanation of flow).

The ecological approach can usefully be construed as an attempt to re-frame psychology in a manner which turns intractable, ill-posed problems into well-posed ones (Warren, 2021). The use of "intelligence loans", or ad hoc ontological addenda (e.g., mental entities) to patch over these problems is, therefore, discouraged by the ecological approach (Turvey, 2018). This position can be summarised by Gibson's (2014) insistence that "[k]nowledge of the world cannot be explained by supposing that knowledge of the world already exists" (p. 241). The ecological approach takes the ubiquity of *adaptive* behaviour (such as that observed in flow activities) as the primary explanandum for psychology. The actions of organisms across all kingdoms of life can be observed to relate to the physically extended environment with a high degree of success in tasks ranging from mundane to spectacular (e.g., Araújo et al., 2023). It should be emphasised that precise relations between the performer and the performance environment are assumed by *any* theory of flow. We anticipate that an account of the action and perceptual systems that support these precise relationships with the performance environment will be helpful in explaining flow.

Gibson (2014) recognised that philosophical assumptions common within the psychology of perception excluded the explanation of adaptive behaviour *a fortiori*. Perception conceptualised as the internal enrichment of impoverished stimulation (e.g., inference or prediction) *presupposes* knowledge about the world to explain cognition. In place of these representationally-mediated, three-term relationships between perceiver and environment, Gibson proposed a direct, two-term theory of perception (Gibson, 2014). Ecological approaches do not start with a disembodied mind trying to establish epistemic contact with an external world since organisms and environments have been ontologically co-determined through co-adaptative processes across many scales (Reed, 1988). From this perspective, organism-environment and perception-action comprise nested, interdependent systems that can only be understood in the context of their history of interactions (Gibson, 1966).

Ecological psychology holds that, affordances – defined as "what the environment *offers* the animal, what it *provides* or *furnishes*, either for good or ill" (Gibson, 2014, p. 119) can be directly perceived, and the nested structure of affordances supports direct perception even in linguistic and social interactions (Kelty-Stephen, 2024; Rączaszek-Leonardi, 2012; Stoffregen & Wagman, 2024). Affordances transcend dichotomies such as subjective-objective or physical-mental, and can only be understood as part of a broader rejection of Cartesian dualism - exemplified by Gibson's exasperated remark "Why must we seek explanation in either Body or Mind? It is a false dichotomy" (Gibson, 2014, p. xii). While this alternative metatheory dissolves many intractable problems in psychology (such as the dichotomies noted in Table 1), it also necessitates the reconceptualisation of a number of fundamental concepts and implies a broader understanding of causality (Juarrero, 1999, 2023). It is our position that the alternative accounts of core concepts such as causality, intention, attention, perception, temporality, and experience are ideally positioned to resolve the dilemmas facing flow researchers.

It should be noted that the following themes are not intended as a model of a linear temporal sequence and are only arranged with consideration for the convenience of the reader. Additionally, aspects of flow detailed here often display significant overlap or interdependence. This is to be expected within the ecological metatheory (Gibson, 2014), as the modularity of distinct cognitive faculties is called into question. The theory developed here utilises concepts from the natural sciences to understand the way in which performers and their experiences spill out and cascade across the many scales of the performance environment. The intermittent, circular, and scale-free nature of such processes do not lend themselves to "box and arrow" models describing chains of component contributions familiar to traditional psychology (Wallot & Kelty-Stephen, 2018).

6. An ecological conceptualisation of experience for flow research

Because flow is recognised to be some type of experience, we begin by discussing the conception of experience used within the theory. While flow has often been defined as a *subjective* experience (Peifer & Engeser, 2021), this is a metatheoretical preference which needs to be critically examined. Alternatively, William James (1976) illustrated that experience is not primarily subjective or objective but participates in multiple frames of reference at once. An ecological dynamics perspective builds on these Jamesian insights and holds that experiences such as flow refer to *both* the physical performance environment and the action capabilities and history of the performer (Seifert et al., 2022). Experience is, therefore, meaningful without being exclusively subjective or internal.

The *personally* meaningful nature of challenges in flow activities has often been used to support exclusively subjective conceptualisations of the experience (e.g., Csikszentmihalyi, 1990). Note, however, that this stance assumes a subject-object ontology in which the environment comprises value-free objects. The ecological approach rejects this ontological bifurcation and reconsiders the relationship between experience, value and meaning:

> The perceiving of an affordance is not a process of perceiving a value-free physical object to which meaning is somehow added in a way that no one has been able to agree upon; it is a process of perceiving a value-rich ecological object. Any substance, any surface, any layout has some affordance for benefit or injury to someone.
>
> Gibson (2014, pp. 131–132)

For example, certain snow-covered slopes may elicit feelings of

Table 1
Common dualisms implicated in flow research.

Voluntary	Involuntary/automatic
Conscious	Unconscious
Internal	External
Present/Online	Absent/offline
Top-down	Bottom-up

excitement in an individual who enjoys skiing. The *meaning* of the slope is only found in a relationship which includes both its physical properties (e.g., gradient, properties of the snow and surface) *and* the abilities and dispositions of the individual to interact with these properties. This is particularly important in flow because it is these higher-order, relational properties of the performer-environment system that underpin adaptive action. For action to succeed, the skier must be able to perceive the actionable properties (affordances) of the slope. We might expect fluctuations in experience to correspond to fluctuations in higher-order properties, very loosely characterised as "ski-down-ability".

For example, the experience evoked by a looming obstacle such as a tree is not so much a "subjective evaluation" as much as a recognition of the real possibility of injury afforded (affordances can be "for good or ill" (Gibson, 2014)). In many flow activities, the emergence and dissolution of affordances provide clear insight into the fluctuating dynamics of experience. This affordance-experience relationship is clearly evident in high-risk activities. Flow researchers would not disagree that an affordance to navigate around an obstacle and avoid a high-speed collision will result in a sense of exhilaration and relief.

From an ecological perspective, it is the meaning-laden performance environment, rather than an internal model, that is the object of experience. Because the affordances performers perceive as they adapt to the performance environment are inherently meaningful, additional processes which assign subjective value are not required. An obstacle approaching in a manner which does not afford avoidance *means* collision. The ecological conception of experience is, therefore, able to refer to both the individual performer and the performance environment through an impredicative entailment that connects wholes to parts (Chemero & Turvey, 2007; Farrokh et al., 2024; Rosen, 1991). Importantly, this conception of experience is also not reducible to verbal reports (Seifert et al., 2022). In many flow activities (e.g., sports), the meaningful fluctuations in the affordances perceived by performers are so transient, subtle, or complex that they challenge verbal description.

Consider an attacker-defender dyad in a team invasion game (e.g., football, hockey, basketball). The distance, angle, and relative velocity between the players are recognised to be important variables that describe the state of the dyadic system (Passos et al., 2008). In simple terms, an attacker who is closer to the goal, or accelerating away from a defender gains an advantage related to the objective of scoring a goal. The many scales of fluctuations which occur in these order parameters (Passos et al., 2009) are, therefore, highly meaningful to performers. Experience in all sport is filled with such fluctuating dynamics of complex variables relating to meaningful outcomes (i.e. eco-physical variables) (Araújo et al., 2021; Lopes et al., this issue). While these dynamics have been recognised as a significant gap in the understanding of flow, they are difficult to access via verbal reports or methods which require participants to be immobilised (Peifer & Tan, 2021). It is quite possible that the difficulty of describing these complex, higher-order variables verbally has contributed to the notion that flow is subjective or internal.

We have outlined how an ecological dynamics theory of flow in sport begins with a fundamentally different conception of experience that cannot be understood within a subject-object framework. Crucially, this conceptualisation of experience is able to support explanations of precise performer-environment relations and the meaningful nature of flow states. Given the significant challenges faced by theories underpinned by dualistic ontologies (Farrokh et al., 2024), we consider this alternative metatheory utilised by the ecological dynamics framework essential to scientific progress in the understanding of flow. In the following, we use the ecological understanding of experience to consider the *subset* of experience described by the concept of flow.

7. Intentionality and the role of constraints in shaping flow experiences

Intention is implicated in two of the original dimensions of flow (clear goals, autotelic experience) (Csikszentmihalyi, 1990) and remains an important aspect of any theory of flow. In flow, performers engage with a task under certain intentional conditions. Flow experiences are only plausible for agents capable of *caring* about the tasks they engage with. This intentional dimension of caring about a task is fundamental to all sports and also creates the epistemic conditions for an explanation of flow. Here, we construe intention broadly to capture multiple scales such as motivation, goals, and the prospective (future-oriented) quality of behaviour within flow activities. Generally, intentional behaviour is understood to have the quality of *aboutness* (being directed towards objects) (Turvey, 2018).

Csikszentmihalyi (1975) was unconvinced by the prevalent narratives which construed behaviour as the logical outcome of some external factor such as reward or punishment and left no role for the intentions of the individual. As noted previously, the tension between internal and external or subjective and objective is a repeating theme in current flow research. As has generally been the case in flow research, the observed limitations of exclusively objective explanations have been understood to necessitate subjective explanations of intentions in flow. Accordingly, Csikszentmihalyi's (1990) account construes intention as a mental representation of a desired outcome.

Traditional explanations of intentionality (e.g., mental representation of an outcome) have faced significant challenges finding their place in scientific theories (Juarrero, 1999). If the prevailing framings of intention and causality are conserved, theorists are forced to choose between a deterministic physical science and the insertion of an immaterial self or 'ghost in the machine' (Ryle, 2009; see also Juarrero, 1999). Further, approaches that locate the origin of intentions in a mental realm have struggled to explain how these immaterial entities are able to cause the action of physical bodies (Kloos & Van Orden, 2010; Kugler et al., 1990) and lead to a muddled dichotomy between voluntary and involuntary actions (Van Orden & Holden, 2002). While discussions around the nature of intention will no doubt continue, flow researchers could adopt a metatheoretical framework which propose radically different responses to the problem posed by intentional behaviour (Dixon et al., 2016; Shaw & Kinsella-Shaw, 1988).

The ecological perspective on intention in flow rejects the assumption that intentions are mental entities exerting *efficient* cause on a linear chain of contiguous reactions (Juarrero, 1999). Rather, intentional contents exemplify a form of *circular* causality in which longer timescales of behaviour *constrain* (Umerez & Mossio, 2013) system degrees of freedom at shorter timescales in a continually evolving hierarchy (Kloos & Van Orden, 2010; Van Orden & Holden, 2002). Notably for flow research, the view of intentions as constraints dissolves the distinct categories of voluntary and automatic actions. Indeed, Kugler et al. (1990) considered intentions as, perhaps, the primary (specific) system control parameter, a significant source of information used to organise order parameters (collective variables used to organise coordination in a dynamical system). The vertical coupling between scales (as opposed to vertical separation required by the efficient causality account, see Van Orden & Holden, 2002) that underpins the ecological conceptualisation of intention also motivates specific empirical predictions discussed in Section 11.

From this perspective, the nestedness and relatedness of constraints play an important role in the explanation of skilled behaviour and the experiences therein (Balagué et al., 2019). The interaction between these nested scales (Kelty-Stephen & Wallot, 2017) is characterised by impredicative entailments that define complex systems (Rosen, 1991) and signifies the irreducibly embedded nature of performance (Araújo, Davids, & McGivern, 2019). In practical terms this means that a set of constraints governing a flow activity can both arise out of interactions and serve to constrain behaviours emerging at shorter timescales.

7.1. The integrated model and evolving task constraints

An ecological dynamics perspective on the nested nature of constraints may also provide additional insight into the recent distinction between flow and clutch states in the context of sport (Swann et al., 2017). The integrated model of flow (Swann et al., 2017) considered flow states and clutch states as overlapping, but distinct, experiences arising due to the openness of goals, among other contextual factors. An ecological dynamics approach could provide the tools to explore the intentional dynamics of behaviour emerging under these differing networks of constraints. More precisely, empirical analyses of the variability of movement in potential flow and clutch states could quantify potential differences in the use of perceptual information (e.g., Kelty-Stephen & Dixon, 2014).

More generally, an ecological dynamics approach seeks to shed light on the relationship between flow and the continually evolving structure of flow activities or sports considered as sets of replicable task constraints (Rączaszek-Leonardi, 2012). Such a relationship is suggested in Massimini et al.'s (1988) paper on the role of flow in biocultural evolution, but the framing of a mimetic process operating in a subjective landscape has not supported further research, thus far. We expect that flow plays a significant role in the constraint selection process defining the genesis and subsequent evolution of a sport. For example, it is intuitively apparent that children at play adapt the constraints of their activities to foster certain (perhaps flow) experiences.

Returning briefly to the relationship between physical energy flows and psychological flow discussed in Section 4, the role of selected constraints in flow activities enables flow experiences to be situated socially and historically and qualify as a psychological phenomenon. For example, catching a fly ball means something in the context of a baseball game because of the constraints which have been selected, but the constraints of the game only acquire meaning when they constrain dynamic flows of energy (e.g., participating athletes). As such constraints and dynamics shape experiences, such as flow, collectively rather than independently (Pattee & Rączaszek-Leonardi, 2012).

8. Adaptivity and skill in flow activities

It is uncontroversial that flow involves skilled performance. While passive activities such as watching a movie or enjoying a sunset may generate some features of flow, they are not considered to be flow experiences due to the lack of skilled performance and activity on the part of the participant (Barthelmäs & Keller, 2021). The way in which skills and activity challenges are construed is, therefore, an important part of any theory of flow. While the relationship between skills and challenges were originally considered to be orthogonal dimensions, Barthelmäs and Keller (2021) have questioned this framing, as skills and challenges are inherently relative to one another. However, from an ecological dynamics perspective, a deeper critical investigation into the concept of skill used in flow theories is still required. Empirical research in ecological dynamics has revolutionised the contemporary understanding of skill acquisition (e.g. Araújo et al., 2006; Davids et al., 2008; Hristovski et al., 2006; Passos et al., 2008). Here, we emphasise the aspects of that body of work with the greatest relevance for flow in sport.

Theories of flow developed within the cognitive metatheory have traditionally conceptualised skills as some form of mental representations, neurally encoding actions (e.g., Dietrich, 2004; Gold & Ciorciari, 2021). These may be referred to as representations, programmes, scripts or schemata. Regardless, all posit some local organising entity that is stored within the organism and then executed. Such explanations of skilful behaviour have been termed *component-dominant* views and can be contrasted with the ecological view that behaviour is not generated by centralised components, but rather dominated by interactions connecting many scales of events (Balagué et al., 2013; Van Orden et al., 2005).

Ecological dynamics, therefore, conceptualises skilled performance as a functional, *adaptive* relationship with a performance environment, rather than originating in a stored representation of an ideal technique (Davids et al., 1994). Skill is not a "thing" that can be "acquired" and "possessed" by someone, but rather is contextually defined, providing an "adaptive", functional relationship between an organism and its environment (Araújo & Davids, 2011, p. 18). It is stressed that behaviour can be "regular without being regulated" (Gibson, 2014, p. 215) due to the natural laws that govern self-organisation (Kelso, 1995) and the degeneracy inherent to neurobiological systems (Seifert, Komar, et al., 2016). The emphasis on soft-assembled coordinative structures in ecological dynamics is well summarised by the proposal that, "[d]exterity is the ability to create a perfect key for any emerging lock" (Bernstein, 1996, p. 215). The ecological understanding of skill as adaptivity-in-context also suggests reconsideration of the commonly utilised concept of automaticity.

8.1. Issues with the concept of automaticity

The word automatic is commonly invoked to describe a sense of control and effortlessness experienced in flow (Csikszentmihalyi, 1990). However, explanation via automaticity creates several problems. First, if the actions performed in flow are truly automatic programs executed from within, intense concentration would not be required and the link between action and perception is severed. Second, it is unclear how skills conceptualised as pre-existing and automated programs might be able to deal with the unique contextualised challenges likely to be encountered in each flow activity (Van Orden et al., 2011), or effectively constrain the abundant degrees of freedom available to the movement system (Latash, 2012). The emphasis on automaticity of skills in flow may create an unhelpful organismic asymmetry (Seifert et al., 2022) in which the decontextualised movement patterns are analysed, rather than the movement-context relationships that hold consequences for performance outcomes. When intentions are not expected to exert efficient cause, the dichotomy between automatic and consciously controlled movement is resolved.

8.2. The dynamics of adaptive action in flow

We have, thus far, discussed general differences between ecological and cognitive approaches to skills in flow. In the following, we explore the nature of skills in flow implied by an ecological dynamics rationale. We believe that rejecting the narrative of automatically executed motor programmes will enable a more nuanced discussion of both the phenomenology and dynamics of skills in flow. An ecological dynamics account emphasises that control of action cannot be localised in either the performer or environment alone but is co-determined by the emerging relationship between them (Araújo, Hristovski, et al., 2019).

We anticipate that the experience of fluid adaptation in flow is likely to emerge in metastable performer-environment systems (Kelso, 1995, 2012) which remain open to multiple latent patterns of coordination by hovering close to regions where multiple affordances are present (Hristovski et al., 2006, 2011) and multiple scales of events are tightly linked by multiplicative cascades (Kello et al., 2008; Kelty-Stephen, 2017). For example, as an attacker-defender dyad in a football/soccer match draws closer to system reorganisation (e.g., tackle or successful dribble), surrounding attackers and defenders influence the affordances available to players in the 1v1 system. However, the surrounding players are also influenced by the unfolding 1v1 as they hover between continuing to attack/defend or transitioning to defence/attack. These "extended critical transitions" (Longo & Montévil, 2014) reflect continual symmetry breaking of the system and indicate emerging new forms of order (Kelso, 1995).

Metastability not only maximises each performer's sensitivity to the demands of context, but it has also been recognised as a bridging point between phenomenology and dynamics of skilled action (Bruineberg et al., 2021) since first-person experiences can be used to help identify meaningful variables (i.e., eco-physical variables). Because an ecological dynamics approach posits an entangled relationship between action and perception, we next discuss the type of perceptual information needed to support this account of adaptive action, and its implications for attention in flow.

9. Information for action and attention in flow

Some of the difficulty explaining flow may relate to its proximity to the concept of 'attention'. While attention is intuitively accessible, it has proven to be a difficult phenomenon to study empirically (Hommel et al., 2019). Despite frequently mentioning the close relationship between flow and attention, Csikszentmihalyi (1978) expressed dissatisfaction with extant theories of attention and suggested that a new conceptual paradigm might be required for scientific progress. It is imperative, therefore, that an account of attention in flow goes beyond the relatively trivial statement that attention is focused on the task at hand, or that it is not directed elsewhere.

The ecological approach situates attention as "an adaptive relationship between performing and procuring information to guide and support that performance" (Gibson & Rader, 1979, p. 6). A central question, therefore, concerns the process by which performers in flow attend to information for action. The ecological definition of attention makes three important claims. First, effective attention cannot be defined in isolation from the demands of the task (e.g., as a larger general reservoir or stronger spotlight). The effective structure of the attentional process reflects the structure of the information needed to support successful performance in a given task. Second, procuring information is considered to be, itself, an active process. Finally, and more subtly, the instantaneous present moment and trichotomy of past, present, and future are rejected; perceiving is continuous. We claim that the ecological information that enables performers to perceive affordances (Wagman & Blau, 2019) will clarify the nature of attention in flow.

Information, as conceptualised by the ecological approach, exists in the relationship between a performer's exploratory movement and the lawful structure of the ambient energy arrays (e.g., light structured by surfaces) (Gibson, 2014; Kugler & Turvey, 1987). Transformations created by exploratory movement reveal invariant properties of the performer-environment system. For example, as an individual approaches an object, the centre of optical expansion is lawfully related to heading direction and the rate of optical expansion specifies the time to contact (Lee & Reddish, 1981; Silva et al., 2019). Because the information perceived is generated actively, the regulation of action is explained without the need for additional steps or intermediary mental processes. The information variables used in the prospective control of action have been the subject of a robust and fruitful empirical research programme both in sport (Davids et al., 2005; Fajen et al., 2009; Jacobson et al., 2021) and psychology (Kelty-Stephen & Dixon, 2014; Kugler & Turvey, 1987; Lee & Reddish, 1981).

At this point, it is worth reflecting on what this extant body of research implies for the study of attention in flow. First, the adaptivity of a given attentional process depends on the way it is situated within a longer timescale of events, denoting an impredicative entailment (Chemero & Turvey, 2007; Rosen, 1991). For instance, the same sidewards glance at a doorway provides information that guides and supports performance when one proceeds to exit the room, but functions as a distraction if one remains in the room and maintains a conversation; the longer sequence of events contextualises the shorter. As such, attention can be observed in the manner in which the action-perception process relates to itself as it unfolds over many nested timescales. Second, the ecological emphasis on multiscale dynamics provides a general framework for the empirical study of information use across different cognitive phenomena (for an overview, see Dixon et al., 2011).

The multiscale dynamics approaches motivated by an ecological perspective have already shed light on attention (Avelar et al., 2019), anticipation (Stephen et al., 2008; 2011), executive function (Anastas et al., 2014), task engagement (Bennett et al., 2022), adaptivity (Nonaka & Bril, 2014), and insight (Stephen et al., 2009), offering a compelling account of the general prospective or future-facing nature of intentional behaviour. We propose that understanding attention in flow may be supported by the concept of "strong anticipation" (Dubois, 2003; Stephen & Dixon, 2011; Stepp & Turvey, 2010) in which performers couple to long-range temporal correlations that give lawful structure to seemingly chaotic events (e.g., evasive opponents). Additionally, fractal fluctuations in gaze behaviour have been shown to accelerate visual search (Stephen & Anastas, 2011), suggesting further study of the multiscale structure of gaze behaviour in the context of flow in sport. Empirical research on multiscale dynamics in flow has already made a promising start with Montull et al.'s (2020) study which found that ecological information describing the stability of the performer-environment system reliably co-varied with measures of flow experiences in a slackline task.

The multiscale dynamics of information use may also offer a parsimonious explanation of selective attention, a key aspect of flow. Expert performers may stay close to the jagged edges of system reorganisation in order to maintain flexibility (Hristovski et al., 2006). In these critical regions, extremely small fluctuations may be sufficient to break the symmetry of the delicately poised system, however, only events related to the relevant opportunities for action (i.e., affordances) can perturb the organisation of the system (Kloos & Van Orden, 2010). Thus, Csikszentmihalyi's (1990) recognition that flow increases as performers become able to make "finer and finer distinctions in the challenges involved in the activity" (p. 97) may have much to do with the fact that affordances are exquisitely nested and contain further affordances (Stoffregen & Wagman, 2024). Esteves et al. (2011) found that basketball players differentiated between dribbling affordances that allowed them to beat a defender with enough time to take a shot and those that did not also afford shooting. Hence, highly focussed attention in flow may be the result of nested systems that hover close to the edges of reorganisation.

To summarise so far, we have argued the explanations of information and attention espoused by ecological dynamics enable flow to be more than an efficient internal process. On the present account, flow in sport reflects the infinite richness of the environment and the real possibilities for action created when "perceiving gets wider and finer and longer and richer and fuller" (Gibson, 2014, p. 244).

10. Temporality and self-consciousness reconsidered

The original nine-dimension model of flow (Nakamura & Csikszentmihalyi, 2014) includes transformation of time (i.e., speeding up or slowing down) and the loss of self-consciousness as characteristics of the flow experience. More recently, however, limited support has been found for these dimensions (Swann et al., 2018). While we make no commitment to the nine-dimension model, we comment briefly on these two dimensions in order to illustrate the manner in which metatheoretical stances have directly constrained flow research and demonstrate the utility of an ecological dynamics approach.

The nature of time and (self-)consciousness have been the subject of philosophical musings for millennia. Participants offering verbal reports on the transformation of time or loss of self-consciousness in flow are situated within the history of these terms and will likely reflect received views that are culturally pervasive. At issue in both temporality and self-consciousness is the question of unit. A unit gives a system a characteristic scale and separates above (embedding context) from below (subcomponents). However, the ecological approach raises important questions about the nature of units:

> There are forms within forms both up and down the scale of size. Units are nested within larger units. Things are components of other things. They would constitute a hierarchy except that this hierarchy is not categorical but full of transitions and overlaps. Hence, for the terrestrial environment, there is no special proper unit in terms of which it can be analysed once and for all. There are no atomic units of the world considered as an environment. Instead, there are subordinate and superordinate units.

Gibson (2014, p. 5)

These insights about nesting hold important implications for understanding both temporality and self-consciousness.

An ontologically distinct self (i.e., unit as "one") requires an unchanging atomic unit that reliably divides the subjective internal world from the objective external world. Systems that display nested structure (of either objects or events) may not have a *single* appropriate unit. At one extreme, an idealised self-similar (fractal) structure completely obscures the notion of unit; the same pattern stretches to infinity in both directions of scale. By contrast, a classical Euclidean object (e.g., a triangle) has a single, obvious level of wholeness that defines its characteristic scale. The ecological approach does not expect the units of time and self in flow to be limited to either of these extremes. Rather, multiple scaling laws (i.e., multifractality) are needed to reflect the coexistence of scale-invariant natural laws and scale-dependent constraints (Kelty-Stephen, 2024; Mandelbrot, 1999; Stoffregen & Wagman, 2024).

From this perspective, the loss of self-consciousness would not be expected to be a binary phenomenon where the absolute unit of self is either present or absent. Rather, the unit of self may shift fluidly as performers couple and de-couple from the task context. For example, a hockey player's stick may be experienced functionally as part of the "self" during play. Alternatively, an athlete directing their intention towards their own body (e.g., stretching a stiff muscle or massaging a bruise) sub-divides their own body into "subjective" and "objective" parts, demonstrating the fluidity of unit (Gibson, 2014). Similarly, nested events provide the basis for any conception of time (Gibson, 1975). Because perception is necessarily extended in time, the distinction between present and past or perception and memory cannot be made rigorously (Gibson, 1975). In both cases, the structure of events in potential flow activities can be investigated empirically (Kelty-Stephen, Lane, et al., 2023) and the need for participants to verbally interpret complex philosophical topics is avoided.

In conclusion, an ecological perspective holds that consciousness only exists at the level of the performer-environment relation. Research cannot reduce such a relation – or else only matter exists, nor only focus on the relation - or else only idealisation exists. (Physical) performers can directly perceive their (physical) situation and themselves in that situation without needing a 'consciousness copy' of the environment, nor a 'consciousness copy' of themselves. (Shaw & Kinsella-Shaw, 2007). As Gibson (2014) put it " [perception] involves awareness-of instead of just awareness. It may be awareness of something in the environment or something in the observer or both at once, but there is no content of awareness independent of that of which one is aware" (p. 228).

11. Implications for empirical research

For a theory of flow in sport to be maximally impactful, it should have consequential implications for empirical research. Here, we outline some empirical expectations our theory motivates.

11.1. Interaction-dominant dynamics will be pervasive in flow activities

A key hypothesis that emerges from an ecological dynamics theory of flow in sport is the expectation that interaction-dominant dynamics (Ihlen & Vereijken, 2010; Kelty-Stephen, Lane, et al., 2023) will be pervasive in flow activities. Current research in flow typically seeks to identify the *components* responsible for generating flow experiences. By contrast, the current account seeks to identify the *interactions* responsible for flow. Component-dominant and interaction-dominant systems have empirical signatures that can be clearly distinguished (Kelty-Stephen & Wallot, 2017; Mangalam, Likens, & Kelty-Stephen, 2023). We do not expect flow to exhibit a simple, monotonic relationship with the degree of cross-scale interactivity in all activities. Rather, the multiplicative cascades modelled by multiscale dynamics approaches (Kelty-Stephen, Lane, et al., 2023) may support differing demands on context-sensitivity under different task constraints (Kelty-Stephen, Similton, et al., 2023).

11.2. Intermittency of flow experiences and context-sensitivity

Intermittency is entailed by the cross-scale interactivity and multiplicative cascades found in interaction-dominant systems. The difficulty of predicting or controlling flow is a well-noted issue in flow research (Swann et al., 2012). Intuitively, if the antecedents of flow were well understood, they could be manipulated to induce flow experiences. However, the present theory predicts that no *single* scale of analysis will be adequate to provide necessary and sufficient conditions for flow. Not only are the multiple scales of the performer-environment system considered necessary conditions for flow, but multiplicative cascades across these scales may have important implications for when flow occurs.

Processes involving multiplicative cascades are typically marked by *intermittent* patterns (Mandelbrot, 1999). Because an ecological dynamics theory of flow in sport predicts that these cascades support context-sensitivity and adaptation in many activities, we expect that flow will arise intermittently. Dormant periods reflect the product of small multipliers, while sudden spikes arise from large multipliers (Ihlen & Vereijken, 2010). The difficulty predicting and controlling flow is, therefore, understood to result from the broad range of scales likely implicated in flow and the nonlinear interactions between them.

11.3. Non-ergodicity: the distribution and markers of flow experiences

Because the symmetry-breaking transitions and multiplicative cascades (see Section 8.2) we expect to find in flow activities often break ergodicity (Kelty-Stephen & Mangalam, 2023; Longo & Montévil, 2014), we find it likely that flow may be non-ergodic. A process is ergodic when variability between individuals (i.e., ensemble data) is equivalent to variability within an individual across time (i.e., time-series data; Mangalam & Kelty-Stephen, 2021; Molenaar & Campbell, 2009). For example, ten fair dice cast once should result in similar outcome distributions to one fair die cast ten times. We find the question of ergodicity to have great practical significance for research on flow in sport. The successful identification of reliable psychophysiological correlates of flow (Peifer & Tan, 2021) in inter-individual trends would likely require flow to meet the ergodic assumptions (for a review of ergodicity in psychological research, see Meyer-Lindenberg, 2023). The absence of such correlates indicates that flow might not meet such assumptions. This question has already been raised in the study of flow at work (Ceja & Navarro, 2017), and we expect that flow in sport will also be non-ergodic. Evidence of ergodicity-breaking in flow activities would also suggest the limitation of internal predictive models which require a constrained form of variation (Mangalam, Kelty-Stephen, et al., 2023). Non-ergodic processes will likely benefit from intra-individual forms of analysis that can assess continuous fluctuations in time (e.g., Correia et al., 2013; Molenaar & Campbell, 2009) and nonlinear descriptors that are, themselves, ergodic (see Kelty-Stephen & Mangalam, 2023).

12. Avenues for future research

In the following, we make several general suggestions for future research on flow in sport.

12.1. Enhancing understanding of constraints on co-adaptation in flow experiences

A comprehensive theory of flow should utilise general concepts to explain how the domain-specific conditions for flow (e.g., flow in sport) are created. Presently, we consider constraints (Umerez & Mossio, 2013) and co-adaptation (Kauffman & Johnsen, 1991; Passos et al., 2016) to be key scientific concepts for future research into how flow experiences are shaped in the context of sport. When athletes participate in a sport, they abide by a set of task constraints that limits the use and availability of system degrees of freedom. For example, football/soccer players are constrained to not control the ball with their hands, while basketball players may not control the ball with their feet. While the laws of nature do not change from sport to sport, these specific constraints provide exceptional boundary conditions that complement the natural laws governing the self-organisation of behaviour (Pattee & Rączaszek-Leonardi, 2012).

While task constraints comprising an official format of a sport appear fixed at the short timescales (e.g., a single game), they change over longer timescales and can also be manipulated to create a wide range of training activities (Davids et al., 2008). While constraint manipulation has typically been considered in the context of skill acquisition (Button et al., 2020), it can also be used to shape experience. However, the effective manipulation of constraints on experience in sport requires an understanding of *what* is constrained, and the manner in which constraints exert influence.

To understand what is constrained in sport, we refer to the concept of co-adaptation (Kauffman & Johnsen, 1991). Co-adaptation refers to bi-directionally coupled relationships in which the adaptive movements of one agent transforms the affordances available to another agent (Passos et al., 2016). Co-adaptation spans both competition and cooperation. The relevance of co-adaptation is most obvious in sports that feature direct competition between athletes (e.g., invasion games, net sports, martial arts), but actions in individual sports are also co-adaptive in nature. We propose that constraints on co-adaptation (e.g., Torrents et al., 2016) will be most relevant for studying flow in sport.

A key tendency observed in co-adapting systems is attraction to critical or metastable regions in which the organisation of the system fluctuates as it approaches a transition to a different state of organisation (Passos et al., 2009). As noted in Section 9, we theorise that this delicate balance is related to the nature of attentional processes in flow in sport. The manner in which constraints influence these tightly coupled interactions (e.g., the 1v1 sub-phase of invasion games) may, therefore, be central to the study (and facilitation) of flow in sport. Constraints do not exert efficient causality (Juarrero, 1999). For example, the presence of a basketball hoop does not force a player to take a shot. Rather, it is one of many conditions *supporting* this possibility (Turvey, 2018). Suppose the diameter of the hoop is doubled. The immediately obvious effect is an increase in affordances to shoot. However, this constraint manipulation will ripple throughout the entire structure of the nested affordances available to the athletes as they co-adapt. An affordance to shoot can nest within it a region in which a performer may choose to shoot or fake a shot and dribble.

The effect a given constraint will exert on a system cannot be determined a priori because the value and meaning of a constraint is always relative to the dynamic flow of action it constrains (Pattee & Rączaszek-Leonardi, 2012). While this makes it difficult (if not impossible) to suggest constraints that will necessarily result in flow experiences in all contexts, multiscale dynamics are well positioned to analyse the relationship between specific cascading flows (e.g., co-adapting athletes) and constraint manipulations. Constraints may be likened to stones placed in a small stream while building a dam. We may expect that a given stone will fill a gap in the dam, but this is contingent on the flow of the water and the co-positioning of the other stones. The role of a specific stone may change if these other factors change. The context-dependent nature of the stone does not hinder children from building dams in streams, and neither does the context-dependent nature of constraints on co-adaptation (Balagué et al., 2019) hinder practitioners from manipulating constraints conducive to flow experiences.

12.2. *The role of eco-physical variables in future research on flow*

Because flow emerges in skilled, intentional performance, the identification of the variables that are meaningful to performers is crucial. Eco-physical variables “express the fit between the environment and the performer's adaptations” (Araújo et al., 2021, p. 76). For example, a football/soccer player approaching the ball in the run-up to a penalty kick may experience rapid fluctuations in experience as the higher-order relationship between their body position (e.g., angle of hips, timing of steps) and momentum (constraining the possible trajectories of the shot) and the movement of the goalkeeper (constraining the shots they can block) tilts the system towards a goal or a miss/save. In short, there are eco-physical variables (perhaps relative phase between both player-ball-goal angles over time) that can describe the rapidly unfolding shooter-goalkeeper relationship as it teeters between outcomes. We would expect the identification of eco-physical variables in such a task to provide insights into the dynamic contours of experience to the extent that the performer is invested in the task.

12.2.1. *Avoiding a symbol-dynamics dualism*

The uncrossable divide between symbols and dynamics posited by cognitive-computational approaches (see Pylyshyn, 1980, p. 111) has had a clear influence on psychological research methods. When symbolic and dynamic processes are assumed to be different in kind, ecological dynamics might be mistakenly associated with only the dynamic side of this presumed divide, while psychological processes are considered to be symbolic operations. We note that this proposed division of labour is, itself, situated within the cognitive metatheory and rests on the questionable assumption of near-decomposability (see Wallot & Kelty-Stephen, 2018). Additionally, the restriction of (sport) psychology to non-dynamic processes would render it largely useless for assessing the experiences during the dynamic flow of action.

Because ecological dynamics rejects symbol-dynamics dualism, we assert that it can support a thoroughgoing psychology (e.g., Carvalho & Araújo, 2022). Eco-physical variables, therefore, do not oppose subjective-qualitative and objective-quantitative approaches, and have employed mixed-methods research designs to good effect (Seifert, Adé, et al., 2016). Verbal reports or other qualitative methods are not discouraged by an ecological dynamics perspective (see Seifert et al., 2022) and can be an important part of identifying eco-physical variables in flow activities (Jackman et al., 2023). We only suggest that verbal reports are poorly prepared to support advances in flow research when situated as reports on subjective internal processes (Seifert et al., 2022).

12.3. *Flow research could benefit from ecologically empowering tasks*

One of the most important outcomes of an ecological dynamics theory of flow in sport is the relationship between events and experiences:

> The basic assumption of this approach is that ecologically significant events will be accompanied by ecologically significant experiences. By an ecologically significant event or experience we mean those events or experiences which possess sufficient efficacy to significantly modify the adaptive lifestyle of the organism if they are but occur or are omitted. The sign or value of such events and experiences can, of course, be either positive (supportive) or negative (damaging), such as the event of falling off a cliff or the experience of vertigo that prompts a hasty retreat from the cliffs edge.
>
> Shaw et al. (1974, p. 280)

The implications for flow research are clear: the ecological significance of an event cannot be faked. The difficulty of inducing flow in the laboratory (Moller et al., 2010) is likely the result of the limited situational significance many common research tasks hold for the participants. The holistic context must be considered in the design of the study. We should not be surprised when the actions of a participant who stops by the laboratory to participate in an unfamiliar or highly constrained task in order to receive extra credit in a class does not provide deep insights into the nature of flow (Durcan et al., 2024).

Two boxers engaged in a friendly sparring match may execute similar movements to two strangers engaged in a physical altercation, but the ecological significance of the events could not be more different. The dynamics are not differentiated by contrasting subjective evaluations, but by the differing consequences that become apparent when the longer scales of nested events are considered. The necessity of considering multiple scales aligns with our suggestion that flow is better studied through "vertical" relationships linking nested events than "horizontal" chains exerting efficient cause at a single scale (Farrokh et al., 2024). An empowering task needs to present affordances that solicit participants' actions, implying perceptual and action variability that draws individuals to become, and remain, physically, psychologically and/or emotionally embedded in activity (Araújo, Brymer, et al., 2019). Future research should explore how sports can be situated as positive ecologically-empowering (significant) experiences.

13. Conclusion

The ecological dynamics framework can provide a parsimonious account of existing descriptions of the flow experience while resolving problems that have been intractable thus far within the traditional cognitive psychology framework. While exact claims about the antecedents or causal mechanisms of flow cannot be made without further empirical support, we feel there is sufficient evidence to posit the ecological dynamics framework as well positioned to guide this empirical research. An ecological dynamics rationale significantly reconceptualises some aspects of flow, which may appeal to Csikszentmihalyi's (1978) hope that "a new conceptual paradigm will be able to inspire new research, direct it along the most promising paths, and then relate findings to each other and explain them in a meaningful context" (p. 356).

Ultimately, it is argued that flow must be more than an internal process if it is to be remain a meaningful concept in psychology. Internal subjective framings of flow may motivate the search for "hacks" presumed to enable the direct manipulation of experience once some central control panel is found. We feel this perspective is antithetical to an understanding of flow that would promote meaning in life through earnest engagement with the world we share. The ecological approach identifies "the constraints on action as the fundamental basis for the reality of experience" (Flach & Holden, 1998, p. 93). In sport, we are presented with many opportunities to confront this reality in a direct and courageous manner.

CRediT authorship contribution statement

David Farrokh: Writing – original draft, Conceptualization. **Keith Davids:** Writing – review & editing, Supervision. **Duarte Araújo:** Writing – review & editing. **Ben W. Strafford:** Writing – review & editing, Supervision. **James L. Rumbold:** Writing – review & editing, Supervision. **Joseph A. Stone:** Writing – review & editing, Supervision.

Declaration of competing interest

No sources of funding from any funding agency in the public, commercial, or not for profit sectors were used to assist in the preparation of this article. We have no known conflict of interests.

Data availability

No data was used for the research described in the article.

References

Anastas, J. R., Kelty-Stephen, D. G., & Dixon, J. A. (2014). Executive function as an interaction-dominant process. *Ecological Psychology, 26*(4), 262–282. https://doi.org/10.1080/10407413.2014.957985

Araújo, D., Brymer, E., Brito, H., Withagen, R., & Davids, K. (2019). The empowering variability of affordances of nature: Why do exercisers feel better after performing the same exercise in natural environments than in indoor environments? *Psychology of Sport and Exercise, 42*, 138–145. https://doi.org/10.1016/j.psychsport.2018.12.020

Araújo, D., Couceiro, M., Seifert, L., Sarmento, H., & Davids, K. (2021). *Artificial intelligence in sport performance analysis* (1st ed.). Routledge (doi:kv24).

Araújo, D., & Davids, K. (2011). What exactly is acquired during skill acquisition? *Journal of Consciousness Studies, 18*(3–4), 7–23. https://www.ingentaconnect.com/contentone/imp/jcs/2011/00000018/f0020003/art00001.

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise, 7*(6), 653–676. https://doi.org/10.1016/j.psychsport.2006.07.002

Araújo, D., Davids, K., & McGivern, P. (2019). The irreducible embeddedness of action choice in sport. In M. Cappuccio (Ed.), *Handbook of embodied cognition and sport psychology* (pp. 537–555). MIT Press. https://mitpress.mit.edu/books/handbook-embodied-cognition-and-sport-psychology.

Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., & Davids, K. (2019). Ecological cognition: Expert decision-making behaviour in sport. *International Review of Sport and Exercise Psychology, 12*(1), 1–25. https://doi.org/10.1080/1750984X.2017.1349826

Araújo, D., Roquette, J., & Davids, K. (2023). Ubiquitous skill opens opportunities for talent and expertise development. *Frontiers in Sports and Active Living, 5*. https://doi.org/10.3389/fspor.2023.1181752

Avelar, B. S., Mancini, M. C., Fonseca, S. T., Kelty-Stephen, D. G., de Miranda, D. M., Romano-Silva, M. A., de Araújo, P. A., & Silva, P. L. (2019). Fractal fluctuations in exploratory movements predict differences in dynamic touch capabilities between children with Attention-Deficit Hyperactivity Disorder and typical development. *PLoS One, 14*(5), Article e0217200. https://doi.org/10.1371/journal.pone.0217200

Balagué, N., Pol, R., Torrents, C., Ric, A., & Hristovski, R. (2019). On the relatedness and nestedness of constraints. *Sports Medicine - Open, 5*(1), 1–10. https://doi.org/10.1186/s40798-019-0178-z

Balagué, N., Torrents, C., Hristovski, R., Davids, K., & Araújo, D. (2013). Overview of complex systems in sport. *Journal of Systems Science and Complexity, 26*, 4–13. https://doi.org/10.1007/s11424-013-2285-0

Barthelmäs, M., & Keller, J. (2021). Antecedents, boundary conditions and consequences of flow. In C. Peifer, & S. Engeser (Eds.), *Advances in flow research* (pp. 71–107). Springer. https://doi.org/10.1007/978-3-030-53468-4_3.

Beard, K. S. (2015). Theoretically speaking: An interview with Mihaly Csikszentmihalyi on flow theory development and its usefulness in addressing contemporary challenges in education. *Educational Psychology Review, 27*(2), 353–364. https://doi.org/10.1007/s10648-014-9291-1

Bennett, D., Roudaut, A., & Metatla, O. (2022, April). Multifractal mice: Operationalising dimensions of readiness-to-hand via a feature of hand movement. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (pp. 1–18). https://doi.org/10.1145/3491102.3517601

Bernstein, N. (1996). On dexterity and its development. In M. Latash, & M. T. Turvey (Eds.), *Dexterity and its development* (pp. 3–244). Lawrence Erlbaum.

Bruineberg, J., Seifert, L., Rietveld, E., & Kiverstein, J. (2021). Metastable attunement and real-life skilled behavior. *Synthese, 199*(5), 12819–12842. https://doi.org/10.1007/s11229-021-03355-6

Button, C., Seifert, L., Chow, J. Y., Davids, K., & Araújo, D. (2020). *Dynamics of skill acquisition: An ecological dynamics approach*. Human Kinetics Publishers.

Carvalho, A., & Araújo, D. (2022). Self-regulation of learning in sport practices: An ecological dynamics approach. *Asian Journal of Sport and Exercise Psychology, 2*(1), 3–7. https://doi.org/10.1016/j.ajsep.2022.03.003

Ceja, L., & Navarro, J. (2017). Redefining flow at work. In C. J. Fullagar, & A. Delle Fave (Eds.), *Flow at work: Measurement and implications* (pp. 81–105). Routledge.

Chemero, A., & Turvey, M. T. (2007). Complexity, hypersets, and the ecological perspective on perception-action. *Biological Theory, 2*, 23–36 (doi:bz78kz).

Correia, V., Araújo, D., Vilar, L., & Davids, K. (2013). From recording discrete actions to studying continuous goal-directed behaviours in team sports. *Journal of Sports Sciences, 31*(5), 546–553. https://doi.org/10.1080/02640414.2012.738926

Costall, A., & Morris, P. (2015). The "textbook Gibson": The assimilation of dissidence. *History of Psychology, 18*(1), 1–14. https://doi.org/10.1037/a0038398

Csikszentmihalyi, M. (1971). From thermodynamics to values: A transition yet to be accomplished. *Zygon, 6*, 163–167. https://doi.org/10.1111/j.1467-9744.1971.tb00713.x

Csikszentmihalyi, M. (1975). *Beyond boredom and anxiety: Experience of play in work and games*. Jossey-Bass.

Csikszentmihalyi, M. (1978). Attention and the holistic approach to behavior. In K. S. Pope, & J. L. Singer (Eds.), *The stream of consciousness: Emotions, personality, and psychotherapy* (pp. 335–358). Springer. https://doi.org/10.1007/978-1-4684-2466-9_13.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. Harper & Row.

Csikszentmihalyi, M. (2000). The contribution of flow to positive psychology. In J. E. Gillham (Ed.), *The science of optimism and hope: Research essays in honor of Martin E. P. Seligman* (pp. 387–395). Templeton Foundation Press. https://psycnet.apa.org/record/2001-16094-023.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: A constraints-led approach*. Human Kinetics, ISBN 978-0736036863.

Davids, K., Handford, C., & Williams, M. (1994). The natural physical alternative to cognitive theories of motor behaviour: An invitation for interdisciplinary research in sports science? *Journal of Sports Sciences, 12*(6), 495–528. https://doi.org/10.1080/02640419408732202

Davids, K., Williams, A. M., & Williams, J. G. (2005). *Visual perception and action in sport*. Routledge.

Dewey, J. (1929). Experience and nature. In *Paul Carus lectures*. Open Court Publishing Company.

Dietrich, A. (2004). Neurocognitive mechanisms underlying the experience of flow. *Consciousness and Cognition, 13*(4), 746–761. https://doi.org/10.1016/j.concog.2004.07.002

Dixon, J. A., Holden, J. G., Mirman, D., & Stephen, D. G. (2011). Multifractal dynamics in the emergence of cognitive structure. *Topics in Cognitive Science, 4*(1), 51–62. https://doi.org/10.1111/j.1756-8765.2011.01162.x

Dixon, J. A., Kay, B. A., Davis, T. J., & Kondepudi, D. (2016). End-directedness and context in nonliving dissipative systems. In *Contextuality from quantum physics to psychology* (pp. 185–208). https://doi.org/10.1142/9789814730617_0009

Dubois, D. M. (2003). Mathematical foundations of discrete and functional systems with strong and weak anticipations. In M. V. Butz, O. Sigaud, & P. Gérard (Eds.), *Anticipatory behavior in adaptive learning systems: Foundations, theories, and systems* (pp. 110–132). Springer. https://doi.org/10.1007/978-3-540-45002-3_7.

Durcan, O., Holland, P., & Bhattacharya, J. (2024). A framework for neurophysiological experiments on flow states. *Communications Psychology, 2*(1), 66. https://doi.org/10.1038/s44271-024-00115-3

Esteves, P. T., de Oliveira, R. F., & Araújo, D. (2011). Posture-related affordances guide attacks in basketball. *Psychology of Sport and Exercise, 12*(6), 639–644. https://doi.org/10.1016/j.psychsport.2011.06.007

Fajen, B. R., Riley, M. A., & Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*(1), 79–107. https://psycnet.apa.org/record/2009-04771-005.

Farrokh, D., Stone, J. A., Davids, K., Strafford, B. W., & Rumbold, J. L. (2024). Why isn't flow flowing? Metatheoretical issues in explanations of flow. *Theory & Psychology, 34* (2), 257–276. https://doi.org/10.1177/09593543241237492

Flach, J. M., & Holden, J. G. (1998). The reality of experience: Gibson's way. *Presence, 7* (1), 90–95. https://doi.org/10.1162/105474698565550

Freire, T., Gissubel, K., Tavares, D., & Teixeira, A. (2021). Flow experience in human development: Understanding optimal functioning along the lifespan. In C. Peifer, & S. Engeser (Eds.), *Advances in flow research* (pp. 323–349). Springer (doi:kv3b).

Gibson, E., & Rader, N. (1979). Attention: The perceiver as performer. In G. A. Hale, & M. Lewis (Eds.), *Attention and cognitive development* (pp. 1–21). Springer. https://doi.org/10.1007/978-1-4613-2985-5_1.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Houghton Mifflin.

Gibson, J. J. (1975). Events are perceivable but time is not. In J. T. Fraser, & N. Lawrence (Eds.), *The study of time II*. Springer. https://doi.org/10.1007/978-3-642-50121-0_22.

Gibson, J. J. (2014). *The ecological approach to visual perception: Classic edition*. Psychology Press (doi:gkzqbm).

Gold, J., & Ciorciari, J. (2021). A neurocognitive model of flow states and the role of cerebellar internal models. *Behavioural Brain Research, 407*, Article 113244. https://doi.org/10.1016/j.bbr.2021.113244

Gottlieb, G. (2007). Probabilistic epigenesis. *Developmental Science, 10*, 1–11. https://doi.org/10.1111/j.1467-7687.2007.00556.x

Harris, D. J., Vine, S. J., & Wilson, M. R. (2017). Neurocognitive mechanisms of the flow state. *Progress in Brain Research, 234*, 221–243 (doi:kv3d).

Hassmén, P., Keegan, R., & Piggott, D. (2016). *Rethinking sport and exercise psychology research: Past, present and future*. Springer.

Heft, H. (2012). Foundations of an ecological approach to psychology. In S. D. Clayton (Ed.), *The Oxford handbook of environmental and conservation psychology* (pp. 11–40). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199733026.013.0002.

Hommel, B., Chapman, C. S., Cisek, P., Neyedli, H. F., Song, J. H., & Welsh, T. N. (2019). No one knows what attention is. *Attention, Perception, & Psychophysics, 81*(7), 2288–2303. https://doi.org/10.3758/s13414-019-01846-w

Hristovski, R., Davids, K., & Araújo, D. (2006). Affordance-controlled bifurcations of action patterns in martial arts. *Nonlinear Dynamics, Psychology, and Life Sciences, 10* (4), 409–444.

Hristovski, R., Davids, K., Araújo, D., & Passos, P. (2011). Constraints-induced emergence of functional novelty in complex neurobiological systems: A basis for creativity in sport. *Nonlinear Dynamics, Psychology, and Life Sciences, 15*(2), 175–206. https://www.ncbi.nlm.nih.gov/pubmed/21382260.

Ihlen, E. A., & Vereijken, B. (2010). Interaction-dominant dynamics in human cognition: Beyond 1/fα fluctuation. *Journal of Experimental Psychology: General, 139*(3), 436. https://doi.org/10.1037/a0019098

Jackman, P. C., Allen-Collinson, J., Ronkainen, N., & Brick, N. E. (2023). Feeling good, sensory engagements, and time out: Embodied pleasures of running. *Qualitative Research in Sport, Exercise and Health, 15*(4), 467–480. https://doi.org/10.1080/2159676X.2022.2150674

Jackson, S. A., & Csikszentmihalyi, M. (1999). *Flow in sports*. Human Kinetics.

Jacobson, N., Berleman-Paul, Q., Mangalam, M., Kelty-Stephen, D. G., & Ralston, C. (2021). Multifractality in postural sway supports quiet eye training in aiming tasks: A study of golf putting. *Human Movement Science, 76*, Article 102752. https://doi.org/10.1016/j.humov.2020.102752

James, W. (1976). *Essays in radical empiricism*. Harvard University Press (Original work published 1912).

Juarrero, A. (1999). *Dynamics in action: Intentional behavior as a complex system*. MIT Press.

Juarrero, A. (2023). *Context changes everything: The path to coherence*. MIT Press.

Katchalsky, A. (1971). Thermodynamics of flow and biological organization. *Zygon: Journal of Religion and Science, 6*(2), 99–125. https://doi.org/10.1111/j.1467-9744.1971.tb00707.x

Kauffman, S. A., & Johnsen, S. (1991). Coevolution to the edge of chaos: Coupled fitness landscapes, poised states, and coevolutionary avalanches. *Journal of Theoretical Biology, 149*(4), 467–505. https://doi.org/10.1016/S0022-5193(05)80094-3

Kello, C. T., Anderson, G. G., Holden, J. G., & Van Orden, G. C. (2008). The pervasiveness of 1/f scaling in speech reflects the metastable basis of cognition. *Cognitive Science, 32*, 1217–1231. https://doi.org/10.1080/03640210801944898

Kelso, J. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. MIT Press.

Kelso, J. S. (2012). Multistability and metastability: Understanding dynamic coordination in the brain. *Philosophical Transactions of the Royal Society, B: Biological Sciences, 367*(1591), 906–918. https://doi.org/10.1098/rstb.2011.0351

Kelty-Stephen, D., Similton, O. D., Rabinowitz, E., & Allen, M. (2023). Multifractal auditory stimulation promotes the effect of multifractal torso sway on spatial perception: Evidence from distance perception by blindwalking. *Ecological Psychology, 35*(4), 136–182. https://doi.org/10.1080/10407413.2023.2287752

Kelty-Stephen, D. G. (2017). Threading a multifractal social psychology through within-organism coordination to within-group interactions: A tale of coordination in three acts. *Chaos, Solitons & Fractals, 104*, 363–370. https://doi.org/10.1016/j.chaos.2017.08.037

Kelty-Stephen, D. G. (2024). Scaling up: Lawfulness of affordances requires independence from any single "scale of behavior". In *The modern legacy of Gibson's affordances for the sciences of organisms* (pp. 176–195). Routledge.

Kelty-Stephen, D. G., & Dixon, J. A. (2014). Interwoven fluctuations during intermodal perception: Fractality in head sway supports the use of visual feedback in haptic perceptual judgments by manual wielding. *Journal of Experimental Psychology: Human Perception and Performance, 40*(6), 2289–2309. https://doi.org/10.1037/a0038159

Kelty-Stephen, D. G., Lane, E., Bloomfield, L., & Mangalam, M. (2023). Multifractal test for nonlinearity of interactions across scales in time series. *Behavior Research Methods, 55*(5), 2249–2282. https://doi.org/10.3758/s13428-022-01866-9

Kelty-Stephen, D. G., & Mangalam, M. (2023). Multifractal descriptors ergodically characterize non-ergodic multiplicative cascade processes. *Physica A: Statistical Mechanics and its Applications, 617*, Article 128651. https://doi.org/10.1016/j.physa.2023.128651

Kelty-Stephen, D. G., & Wallot, S. (2017). Multifractality versus (mono-) fractality as evidence of nonlinear interactions across timescales: Disentangling the belief in nonlinearity from the diagnosis of nonlinearity in empirical data. *Ecological Psychology, 29*(4), 259–299. https://doi.org/10.1080/10407413.2017.1368355

Kloos, H., & Van Orden, G. (2010). Voluntary behavior in cognitive and motor tasks. *Mind and Matter, 8*(1), 19–43. https://philpapers.org/rec/KLOVBI.

Kugler, P. N., Shaw, R. E., Vincente, K. J., & Kinsella-Shaw, J. (1990). Inquiry into intentional systems I: Issues in ecological physics. *Psychological Research, 52*, 98–121. https://doi.org/10.1007/BF00877518

Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement*. Lawrence Erlbaum.

Latash, M. L. (2012). The bliss (not the problem) of motor abundance (not redundancy). *Experimental Brain Research, 217*, 1–5. https://doi.org/10.1007/s00221-012-3000-4

Lee, D. N., & Reddish, P. E. (1981). Plummeting gannets: A paradigm of ecological optics. *Nature, 293*(5830), 293–294. https://doi.org/10.1038/293293a0

Longo, G., & Montévil, M. (2014). Perspectives on organisms: Biological time, symmetries and singularities. In *Lecture notes in morphogenesis*. Springer. https://doi.org/10.1007/978-3-642-35938-5.

Lopes, H., Carrilho, D., Brito, H., Vaz de Carvalho, M., Carvalho, A., & Araujo, D. (2024). *The role of eco-physical variables for analyzing and modeling goal-directed behavior in sport* (manuscript in preparation).

Mandelbrot, B. B. (1999). *Multifractals and 1/f noise: Wild self-affinity in physics (1963–1976)*. Springer (doi:kv3m).

Mangalam, M., & Kelty-Stephen, D. G. (2021). Point estimates, Simpson's paradox, and nonergodicity in biological sciences. *Neuroscience & Biobehavioral Reviews, 125*, 98–107. https://doi.org/10.1016/j.neubiorev.2021.02.017

Mangalam, M., Kelty-Stephen, D. G., Sommerfeld, J. H., Stergiou, N., & Likens, A. D. (2023). Temporal organization of stride-to-stride variations contradicts predictive models for sensorimotor control of footfalls during walking. *PLoS One, 18*(8), Article e0290324. https://doi.org/10.1371/journal.pone.0290324

Mangalam, M., Likens, A. D., & Kelty-Stephen, D. G. (2023). *Multifractal nonlinearity as a robust estimator of multiplicative cascade dynamics*. arXiv preprint. https://doi.org/10.48550/arXiv.2312.05653. arXiv:2312.05653

Massimini, F., Csikszentmihalyi, M., & Fave, A. D. (1988). Flow and biocultural evolution. In M. Csikszentmihalyi, & I. S. Csikszentmihalyi (Eds.), *Optimal experience: Psychological studies of flow in consciousness* (pp. 60–81). Cambridge University Press.

Meyer-Lindenberg, A. (2023). The non-ergodic nature of mental health and psychiatric disorders: Implications for biomarker and diagnostic research. *World Psychiatry, 22* (2), 272–274. https://doi.org/10.1002/wps.21086

Molenaar, P. C. M., & Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current Directions in Psychological Science, 18*(2), 112–117. https://doi.org/10.1111/j.1467-8721.2009.01619.x

Moller, A. C., Meier, B. P., & Wall, R. D. (2010). Developing an experimental induction of flow: Effortless action in the lab. In B. Bruya (Ed.), *Effortless attention: A new perspective in the cognitive science of attention and action*. The MIT Press. https://doi.org/10.7551/mitpress/8602.003.0010.

Montull, L., Vázquez, P., Rocas, L., Hristovski, R., & Balagué, N. (2020). Flow as an embodied state. Informed awareness of slackline walking. *Frontiers in Psychology, 2993*. https://doi.org/10.3389/fpsyg.2019.02993

Nakamura, J., & Csikszentmihalyi, M. (2014). The concept of flow. In M. Csikszentmihalyi (Ed.), *Flow and the foundations of positive psychology* (pp. 239–263). Springer. https://doi.org/10.1007/978-94-017-9088-8_16.

Nonaka, T., & Bril, B. (2014). Fractal dynamics in dexterous tool use: The case of hammering behavior of bead craftsmen. *Journal of Experimental Psychology: Human Perception and Performance, 40*(1), 218–231. https://doi.org/10.1037/a0033277

Oyama, S. (2000). The ontogeny of information: Developmental systems and evolution. Duke University Press.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Milho, J., & Serpa, S. (2008). Information-governing dynamics of attacker–defender interactions in youth rugby union. *Journal of Sports Sciences, 26*(13), 1421–1429. https://doi.org/10.1080/02640410802208986

Passos, P., Araújo, D., Davids, K., Milho, J., & Gouveia, L. (2009). Power law distributions in pattern dynamics of attacker-defender dyads in the team sport of rugby union: Phenomena in a region of self-organized criticality. *Emergence: Complexity and Organization, 11*(2), 37–45. http://hdl.handle.net/10451/21715.

Passos, P., Davids, K., & Chow, J. Y. (Eds.). (2016). *Interpersonal coordination and performance in social systems*. Routledge.

Pattee, H. H., & Rączaszek-Leonardi, J. (2012). *Laws, language and life: Howard Pattee's classic papers on the physics of symbols with contemporary commentary* (Vol. 7). Springer Science & Business Media.

Peifer, C., & Engeser, S. (2021). Theoretical integration and future lines of flow research. In C. Peifer, & S. Engeser (Eds.), *Advances in flow research* (pp. 417–439). Springer. https://doi.org/10.1007/978-3-030-53468-4_16.

Peifer, C., & Tan, J. (2021). The psychophysiology of flow experience. In C. Peifer, & S. Engeser (Eds.), *Advances in flow research* (pp. 191–230). Springer (doi:kjt2).

Pylyshyn, Z. W. (1980). Computation and cognition: Issues in the foundations of cognitive science. *Behavioral and Brain Sciences, 3*(1), 111–132. https://doi.org/10.1017/S0140525X00002053

Rączaszek-Leonardi, J. (2012). Language as a system of replicable constraints. In H. H. Pattee, & J. Rączaszek-Leonardi (Eds.), *LAWS, LANGUAGE and LIFE: Howard Pattee's classic papers on the physics of symbols with contemporary commentary* (pp. 295–333). Springer. https://doi.org/10.1007/978-94-007-5161-3_19.

Reed, E. S. (1988). *James J. Gibson and the psychology of perception*. Yale University Press.

Rosen, R. (1991). *Life itself: A comprehensive inquiry into the nature, origin, and fabrication of life*. Columbia University Press.

Ryle, G. (2009). *The concept of mind: 60th anniversary edition* (1st ed.). Routledge. https://doi.org/10.4324/9780203875858

Seifert, L., Adé, D., Saury, J., Bourbousson, J., & Thouvarecq, R. (2016). Mix of phenomenological and behavioural data to explore interpersonal coordination in outdoor activities: Example in rowing and orienteering. In P. Passos, K. Davids, & J. Y. Chow (Eds.), *Interpersonal coordination and performance in social systems* (pp. 104–125). Routledge.

Seifert, L., Araújo, D., & Davids, K. (2022). Avoiding organismic asymmetries in ecological cognition: Analysis of agent-environment couplings with eco-physical variables. *Adaptive Behavior, 31*(2), 163–168 (doi:kv4z).

Seifert, L., Komar, J., Araújo, D., & Davids, K. (2016). Neurobiological degeneracy: A key property for functional adaptations of perception and action to constraints. *Neuroscience & Biobehavioral Reviews, 69*, 159–165. https://doi.org/10.1016/j.neubiorev.2016.08.006

Shaw, R., & Kinsella-Shaw, J. (1988). Ecological mechanics: A physical geometry for intentional constraints. *Human Movement Science, 7*(2–4), 155–200. https://doi.org/10.1016/0167-9457(88)90011-5

Shaw, R., & Kinsella-Shaw, J. (2007). The survival value of informed awareness. *Journal of Consciousness Studies, 14*, 137–154.

Shaw, R., McIntyre, M., & Mace, W. (1974). The role of symmetry in event perception. In R. B. MacLeod & H. L. Pick (Eds.), Perception: Essays in honor of James J. Gibson. Cornell University Press.

Silva, P., Kiefer, A., Riley, M. A., & Chemero, A. (2019). Trading perception and action for complex cognition: Application of theoretical principles from ecological psychology to the design of interventions for skill learning. In M. Cappuccio (Ed.), *Handbook of embodied cognition and sport psychology* (pp. 47–74). The MIT Press. https://mitpress.mit.edu/books/handbook-embodied-cognition-and-sport-psychology.

Stephen, D. G., & Anastas, J. (2011). Fractal fluctuations in gaze speed visual search. *Attention, Perception, & Psychophysics, 73*, 666–677. https://doi.org/10.3758/s13414-010-0069-3

Stephen, D. G., Boncoddo, R. A., Magnuson, J. S., & Dixon, J. A. (2009). The dynamics of insight: Mathematical discovery as a phase transition. *Memory & Cognition, 37*, 1132–1149. https://doi.org/10.3758/MC.37.8.1132

Stephen, D. G., & Dixon, J. A. (2011). Strong anticipation: Multifractal cascade dynamics modulate scaling in synchronization behaviors. *Chaos, Solitons & Fractals, 44*(1–3), 160–168. https://doi.org/10.1016/j.chaos.2011.01.005

Stephen, D. G., Stepp, N., Dixon, J. A., & Turvey, M. T. (2008). Strong anticipation: Sensitivity to long-range correlations in synchronization behavior. *Physica A: Statistical Mechanics and its Applications, 387*(21), 5271–5278. https://doi.org/10.1016/j.physa.2008.05.015

Stepp, N., & Turvey, M. T. (2010). *On strong anticipation. Cognitive Systems Research, 11* (2), 148–164. https://doi.org/10.1016/j.cogsys.2009.03.003

Stoffregen, T. A., & Wagman, J. B. (2024). Higher order affordances. *Psychonomic Bulletin & Review*, 1–30. https://doi.org/10.3758/s13423-024-02535-y

Stoll, O., & Ufer, M. (2021). Flow in sports and exercise: A historical overview. In C. Peifer, & S. Engeser (Eds.), *Advances in flow research* (pp. 351–375). Springer. https://doi.org/10.1007/978-3-030-53468-4_13.

Swann, C., Crust, L., Jackman, P., Vella, S. A., Allen, M. S., & Keegan, R. (2017). Psychological states underlying excellent performance in sport: Toward an integrated model of flow and clutch states. *Journal of Applied Sport Psychology, 29*(4), 375–401 (doi:gdj4wq).

Swann, C., Keegan, R. J., Piggott, D., & Crust, L. (2012). A systematic review of the experience, occurrence, and controllability of flow states in elite sport. *Psychology of Sport and Exercise, 13*(6), 807–819. https://doi.org/10.1016/j.psychsport.2012.05.006

Swann, C., Piggott, D., Schweickle, M., & Vella, S. A. (2018). A review of scientific progress in flow in sport and exercise: Normal science, crisis, and a progressive shift. *Journal of Applied Sport Psychology, 30*(3), 249–271 (doi:ggf57x).

Tavares, D., & Freire, T. (2016). Flow experience, attentional control, and emotion regulation: Contributions for a positive development in adolescents. *Psicologia, 30*, 77–94. https://doi.org/10.17575/rpsicol.v30i2.1119

Torrents, C., Ric, A., Hristovski, R., Torres-Ronda, L., Vicente, E., & Sampaio, J. (2016). Emergence of exploratory, technical and tactical behavior in small-sided soccer games when manipulating the number of teammates and opponents. *PLoS One, 11* (12), Article e0168866. https://doi.org/10.1371/journal.pone.0168866

Turvey, M. T. (2018). *Lectures on perception: An ecological perspective*. Routledge.

Umerez, J., & Mossio, M. (2013). Constraint. In W. Dubitzky, O. Wolkenhauer, K.-H. Cho, & H. Yokota (Eds.), *Encyclopedia of systems biology* (pp. 490–493). Springer. https://doi.org/10.1007/978-1-4419-9863-7.

Van Orden, G. C., & Holden, J. G. (2002). Intentional contents and self-control. *Ecological Psychology, 14*(1–2), 87–109. https://doi.org/10.1080/10407413.2003.9652753

Van Orden, G. C., Holden, J. G., & Turvey, M. T. (2005). Human cognition and 1/f scaling. *Journal of Experimental Psychology: General, 134*(1), 117–123. https://doi.org/10.1037/0096-3445.134.1.117

Van Orden, G. C., Kloos, H., & Wallot, S. (2011). Living in the pink: Intentionality, wellbeing, and complexity. In C. Hooker (Ed.), *Philosophy of complex systems* (pp. 629–672). North-Holland. https://doi.org/10.1016/B978-0-444-52076-0.50022-5.

Vuorre, M., & Metcalfe, J. (2016). The relation between the sense of agency and the experience of flow. *Consciousness and Cognition, 43*, 133–142. https://doi.org/10.1016/j.concog.2016.06.001

Wagman, J. B., & Blau, J. J. (2019). *Perception as information detection*. Routledge.

Wallot, S., & Kelty-Stephen, D. G. (2018). Interaction-dominant causation in mind and brain, and its implication for questions of generalization and replication. *Minds and Machines, 28*(2), 353–374 (doi:gdh85k).

Warren, W. H. (2021). Information is where you find it: Perception as an ecologically well-posed problem. *I-Perception, 12*(2). https://doi.org/10.1177/20416695211000366