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SEIFERT, Ludovic, PAPET, Valentin, STRAFFORD, Ben William <http://orcid.org/0000-0003-4506-9370>, COUGHLAN, Edward K. and DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123>

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Article

Skill transfer, expertise and talent development: An ecological dynamics perspective

Ludovic Seifert[1,*], Valentin Papet[1], Ben William Strafford[2], Edward K. Coughlan[3], and Keith Davids[2]

[1] Centre d'Étude des Transformations des Activités Physiques et Sportives (CETAPS) – EA 3832, University of Rouen Normandie, Faculty of Sport Sciences, Mont Saint Aignan, France
[2] Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, UK
[3] Department of Sport, Leisure & Childhood Studies, Cork Institute of Technology, Cork, Ireland

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Abstract – In this paper, we propose an ecological dynamics perspective on expertise and talent development, with a focus on the role of skill transfer. The ecological dynamics theoretical framework provides an integrated explanation for human behaviour in sport, predicated on a conceptualisation including constraints on dynamical systems, ecological psychology and a complex systems approach in neurobiology. Three main pillars are presented (*i.e.*, individual-environment coupling as the smallest unit of analysis; adaptation of a complex dynamical system to interacting constraints; and the regulation of action with perception) in order to discuss the functional role of behavioural variability, the usefulness of perceptual-motor exploration and the importance of general and specific skill transfer in the development of talent and expertise in athletes. In addition, practical implications for coaches and instructors are discussed, notably regarding early diversification and unstructured play and activities in talent development programs, but also through variable practice and constraints manipulation.

Key words: adaptability, neurobiological degeneracy, representative design, behavioural variability

Résumé – Transfert d'habileté, expertise et développement des talents : une perspective selon la dynamique écologique. Nous présentons une perspective selon la dynamique écologique sur l'expertise et le développement des talents avec un accent particulier sur le rôle du transfert d'habiletés. Le cadre théorique de la dynamique écologique fournit une explication intégrée du comportement humain dans le sport, fondé sur une conceptualisation incluant la théorie des systèmes dynamiques, la psychologie écologique et une approche « système complexe » en neurobiologie. Trois principaux piliers sont présentés (le couplage individu-environnement en tant que plus petite unité d'analyse, l'adaptation d'un système dynamique complexe à des contraintes en interaction et le couplage perception-action) afin de discuter du rôle fonctionnel de la variabilité comportementale, de l'utilité de l'exploration perceptivo-motrice et de l'importance du transfert d'habiletés générales et spécifiques dans le développement des talents et de l'expertise des athlètes. En outre, les implications pratiques pour les entraîneurs et les éducateurs sont discutées, notamment en ce qui concerne la diversification précoce et les jeux et activités non structurés dans les programmes de développement des talents, mais également à travers la pratique variable et la manipulation des contraintes.

Mots clés : adaptabilité, dégénérescence neurobiologique, design représentatif, variabilité comportementale

1 Introduction

Talent, sometimes misconceived as a gift that some people possess, consists of a rich combination of individual dispositions and tendencies that can be developed and harnessed through an individual's continuous interactions with specific performance environments in play, practice and competition (Araújo & Davids, 2011). Despite these theoretical insights, many elite sports organisations seek to identify and group talented individuals together to provide early specialised training from a very young age. These programs tend to group young athletes in an early specialisation pathway, where they can only participate and practice in a single target sport from a very young age (Mostafavifar, Best, & Myer, 2013). For example, the Chinese president Xi Jinping promoted a talent detection

*Corresponding author: ludovic.seifert@univ-rouen.fr

and early specialisation program in football, *involving the nation's babies,* through the development of the world's largest football school (https://www.bbc.co.uk/sport/football/31658273). The "Evergrande Football School" is a full-time boarding primary and secondary football school involving 2800 students who practice football nearly every day. This program cost two billion yen to develop extensive facilities, including accommodation, an education building, a training centre, a performance testing laboratory, a conference auditorium and 48 football fields. Furthermore, in the English Premier League, Manchester City has created an "elite" team for under-5 year olds for the purposes of developing talented professional footballers (http://trainingground.guru/articles/manchester-city-under-5s-elite-squad-described-as-absolute-madness). The UK Coaching Head of Talent and Performance, Nick Levett, has described as "madness" the academy process of specialized training in such young children. What does the research evidence suggest on the identification and selection of children aged under 5 years as "elite athletes"? Data suggest that this path is not effective because there are challenges in identifying "talented" individuals at a very young age. Specifically, early specialisation and dedication to intense training in one sport could lead to problems of physical and psychological health and well being (Caruso, 2016; Côté, Horton, MacDonald, & Wilkes, 2009; Moesch, Elbe, Hauge, & Wikman, 2011; Wojtys, 2013). A key issue is that early specialisation is often associated with success at junior levels only (Güllich, Kovar, Zart, & Reimann, 2017), with limited evidence that such success translates to senior, adult level (Güllich & Emrich, 2013), mainly because of physical problems, boredom, dropout, or worse, burnout before progression to the older grades (Baker, Cobley, & Fraser-Thomas, 2009; Caruso, 2016; Fraser-Thomas, Côté, & Deakin, 2008). Many athletes who displayed potential in their youth may drop out, especially in sports training programs that are too structured, affecting the intrinsic motivation of individuals (Myer *et al.*, 2015).

Another potential reason proposed for lack of success in adulthood when early specialization is used in young athletes could be a lack of perceptual-motor adaptability (Seifert, Button, & Davids, 2013; Seifert, Komar, Araújo, & Davids, 2016). This adaptability relates to an appropriate balance between *stability* (*i.e.*, consistent behaviours) and *flexibility* (*i.e.*, functional variability) in actions (Seifert *et al.*, 2013, 2016; Warren, 2006) and is essential for skilled performance in many different sports. In fact, in early specialization the focus is geared towards one specific sport and not general athletic development. Worse still, training in a single sport can be targeted at high levels of automation of movement skills that might result from practising standardised, prescriptive drills and predictable routines. This type of practice can induce a limited ability to adapt behaviour when facing dynamic and interacting constraints in competitive performance environments (Davids, Glazier, Araújo, & Bartlett, 2003; Glazier & Davids, 2009). For instance, practising rock and ice climbing might help to develop higher behavioural adaptability to climb on various surfaces and textures. Performers who practiced rock climbing early in their development showed more fluent behaviours (smoother movements and fewer exploratory actions) during ice climbing task than performers who did not (Seifert *et al.*, 2013, 2016). Evidence shows that most successful elite athletes competed in, and trained for, multiple sports in their youth and only specialized during adolescence (Davids, Güllich, Araújo, & Shuttleworth, 2017; Güllich, 2018). Since there are many pathways to attaining expertise (Güllich, 2014; Phillips, Davids, Renshaw, & Portus, 2010) and since some skills acquired in one performance context may transfer (benefit performance) to another (Schmidt & Young, 1987), it has been argued that elite sports organisations should promote early diversification in sport (Hendry, Crocker, & Hodges, 2014). This approach may increase the engagement and intrinsic motivation of an athlete (Lidor, Côté, & Hackfort, 2009), reduce injury risk (Myer *et al.*, 2016), and enhance adaptive capacities of individuals (Araújo & Davids, 2011). Moreover, early diversification of sport environments (*e.g.* through variable practice and a constraint-led approach; Ranganathan & Newell, 2013) might promote skills transfer between those environments and consequently would develop adaptive perceptual-motor behaviours. As an example, Travassos, Araújo, & Davids (2017) suggested that playing futsal at an early stage would enrich the development of perceptual-motor repertoire in future football players, because it provides the opportunity to explore different offensive and defensive tactical behaviours. Indeed, as futsal is practiced with fewer players and on a smaller area in comparison with football, the players acquire a wide range of technical, perceptual and tactical abilities. Oppici, Panchuk, Serpiello and Farrow (2018) found that futsal players engaged in more visual exploratory actions (scanning behaviours) (54%) than football players in the same situations (16%). It also needs to be noted that such an early diversification approach is aligned with practitioner-led models of training and talent development in elite sports organisations, exemplified by the Athletic Skills Model (ASM) (Wormhoudt, Savelsbergh, Teunissen, & Davids, 2017).

Behavioural adaptability in expert athletes is characterised by the acquisition of stable coordination patterns (*i.e.* consistent over time) which are resistant to perturbations during performance and reproducible under different task and environmental constraints. These patterns are also flexible, not stereotyped or rigid, but can be functionally adapted to environmental changes, since neurobiological complex systems can exploit inherent degeneracy (Davids & Glazier, 2010; Seifert *et al.*, 2016). This suggests that variable practice from a younger age could develop functional behavioural variability at an older age (Ranganathan & Newell, 2013). This adaptability in performance means that expert athletes can change their coordinative structures without compromising their function and the performance outcomes achieved (Seifert *et al.*, 2016). In other words, enriching the perceptual-motor repertoire of a child through a constraints-led practice approach would continuously develop functional and adaptive behaviours across the lifespan for learners (Newell, 1986; Newell & McDonald, 1992). In this opinion paper, we present the innovative perspective of the ecological dynamics framework to expertise and talent development. Ecological dynamics integrates theoretical assumptions from dynamical systems theory and ecological psychology by considering motor learning at the ecological scale of analysis, *i.e.* by understanding how constraints continuously shape perception-action coupling during learning and transfer over extended periods of time. Processes such as education of intention, education of attention (perceptual attunement) and calibration (Fajen, Riley, & Turvey, 2009; Jacobs & Michaels, 2007) lead to a functional reorganization of the motor system degrees of freedom and could be integrated to Newell's model of motor learning and transfer. In such a way, the ecological dynamics framework proposes a modified three-stages learning model (*i.e.*, *search and exploration*; *discovery and stabilization*; *exploitation*; for more details, see Davids, Araújo, Hristovski, Passos, & Chow, 2012; Renshaw *et al.*, 2015). The ecological dynamics perspective considers talent development as a dynamic process where the individual and the environment are inextricably linked across continuous interactions as an athlete's perceptual-motor system adapts to a dynamic set of constraints to functionally achieve task goals (Davids, Güllich, Araújo, & Shuttleworth, 2017).

On this basis, we present first, the key concepts of the ecological dynamics perspective on expertise and talent development. Second, we will show how this theoretical perspective reconsiders skill transfer and learning as a significant adaptive process to support talent development. Third, we will present implications for practice, talent development and representative learning design in athlete development.

2 Key concepts of ecological dynamics perspective to expertise and talent development

The ecological dynamics theoretical framework provides an innovative perspective on talent development, motor control and learning in sport by emphasising a nuanced transitioning between specificity and generality of practice and transfer, as needed by each individual athlete (Araújo, Davids, & Serpa, 2005; Araújo, Davids, & Hristovski, 2006; Araújo, Davids, Chow, Passos, & Raab, 2009; Davids *et al.*, 2012, 2017; Handford, Davids, Bennett, & Button, 1997; Seifert, Araújo, Komar, & Davids, 2017). The ecological dynamics rationale is predicated on a theory of constraints on dynamical systems (Kelso, 1995; Newell, 1986), ecological psychology (Gibson, 1979) and a complex systems approach to neurobiology and neuroanatomy (Edelman & Gally, 2001; Price & Friston, 2002), and is supported by three main pillars (Seifert *et al.*, 2017). The first pillar considers that movement coordination patterns are a dynamically functional relationship emerging from a set of interacting constraints, including the environment, the task and the resources of a performer (Araújo & Davids, 2011). Therefore, athletic performance should be analysed on the ecological scale, which implies that the *performer-environment coupling* is the *smallest unit of analysis* worth examining to understand sports performance and expertise (Araújo & Davids, 2018), otherwise defined as a *complex adaptive system* (*i.e.*, a self-organising system, continuously regulating its behaviours without being regulated by an external regulator) (Davids, Araújo, Seifert, & Orth, 2015; Hendry *et al.*, 2014; Seifert *et al.*, 2017). For example, in rock climbing, we should be encouraged to view movement up the wall as the rolling motion of the body in reference to a surface of a climbing wall, rather than according to a longitudinal axis passing from the head to the feet of the climber (for more details, see Seifert *et al.*, 2015).

Second, considering performer-environment coupling as a complex adaptive system means that the perceptual-motor behavioural organization exhibits properties of *non-linear* and *non-proportional* dynamics (Chow, Davids, Hristovski, Araújo, & Passos, 2011). This idea questions whether performance, skill acquisition and talent development is enhanced in a linear fashion in line with a proportional increase in the amount of practice and increased engagement in the constraints of the environment, the task and the performer (Newell, 1986). Rejection of a strictly linear relationship between amount of practice time and the development of skill, expertise and talent in sport, questions the emphasis on number of hours spent in deliberate practice (Davids, 2000; Ericsson, 2016).

The *non-proportionality* that exists between behaviour and performance could be exemplified by sensitivity to initial conditions, such as hormonal, neuronal and anthropometrical changes associated with moving from childhood to adulthood, when during practice a small change in behaviour can lead to a transition in performance and, conversely, a switching between two behavioural patterns can lead to a marginal change in the performance outcome (Chow *et al.*, 2009). The *non-linear* relationship between behaviour and performance can be observed in sudden transitions between two behavioural states, such as the change from walking to running on a treadmill, the task constraint increases linearly (the speed imposed by the treadmill rising incrementally), however, the movement changes in a non-linear manner (Kelso, 1995). Non-linearity could also relate to the presence of "multi-stability" (Kelso, 1995, 2012) induced by the inherent degeneracy of perceptual-motor systems, suggesting that behavioural organization can vary structurally (*i.e.* perceptual-motor coordination), without compromising function in achieving the task-goal (Edelman & Gally, 2001; Price & Friston, 2002). For instance, during their childhood, children are able to switch between various locomotor patterns (*e.g.* crawling, ramping, walking and climbing) to negotiate various obstacles and reach a target or an object. This concept of multi-stability implies there is no one stable behavioural state to satisfy interacting constraints that corresponds to a putative "expert model" of performance toward which a learner must transition in their development (Davids *et al.*, 2015; Seifert *et al.*, 2013). Rather, there is potential for multiple stable performance solutions to emerge, depending on affordances, described as action possibilities offered by the environment relative to a performer's capabilities (Gibson, 1979). In sum, a performance behaviour and an outcome do not share the same dynamics, but are co-determined and exhibited during periods of stability, destabilization and reorganization toward new coordination states that completely reshape the perceptual-motor repertoire (Newell, 1996).

This second pillar invites us to reconsider the *role of behavioural variability* in skill acquisition and talent development. Research within the ecological dynamics framework has emphasized that coordination variability should not necessarily be considered as noise that is detrimental to performance, which should be minimized to enable the production of a consistent, automatic and economic movement pattern, but should be accepted as an interactive part of the dynamic environment (Shmuelof, Krakauer, & Mazzoni, 2012). Nor should it always be viewed as error, or a deviation from a putative expert model, which should be constantly corrected in learners (Hastings, Hom, Ellner, Turchin, & Godfray, 1993). Several studies and reviews have provided evidence for the *adaptive and functional role of movement and coordination variability in order to satisfy interacting constraints* (*e.g.*, Glazier & Davids, 2009; Komar, Chow, Chollet, & Seifert, 2015; Pinder, Davids, & Renshaw, 2012; Rein, Davids, & Button, 2010; Seifert, Komar, Crettenand, & Millet, 2014), providing relevant insights to develop talent in sport. Research has demonstrated how an individual could exploit the system property of degeneracy by switching between various coordinative structures present in their motor repertoire to functionally achieve a specific task goal (Seifert *et al.*, 2016). For example in a study of cricket batting, skilled batters were able to functionally decide between forward (48% of time) and backward (52% of time) strokes to achieve task goals under similar constraints, *i.e.* when a bowler delivered the ball to a critical spatial region 6.5–7.5 m distance away from the stumps (Pinder, Davids, & Renshaw, 2012). Coordination variability can be a sign of a performer adapting to the changing constraints of a task and a performance environment (Davids *et al.*, 2003). For instance, Seifert, *et al.* (2014) manipulated task constraints for individuals swimming with the front crawl for 200-m by constraining the glide duration; notably, they investigated behavioural adaptations during performance in a freely-chosen condition of the glide with arms, compared to conditions when maximal and minimal glide durations were specified for performers. Interestingly in a maximal glide duration condition, swimmers were able to increase their leg beat-kicking up to 10 beat kicks (whereas 2, 4 and 6 beat kicks are the most common observed patterns) to functionally compensate for the long glide phase with their arms (Seifert *et al.*, 2014).

Interestingly, variability in movement coordination seems correlated with variability in gaze behaviours (Dicks *et al.*, 2017). In interceptive sports, when facing a ball travelling at such high speeds that skilled performers were not able to track the ball with their eyes, they anticipated ball displacement and/or target point, leading to highly varied gaze behaviours and movement coordination patterns. For instance, in cricket batting, gaze strategies differed (pursuit tracking or saccade) between players in the initial location of gaze prior to ball delivery, immediately after ball release and in mid-late flight (Croft, Button, & Dicks, 2010). In particular, Croft, *et al.* (2010) showed that across the range of ball delivery speeds (17 to 25 m.s^{-1}), some players could pursuit-track the ball from release to bounce point, but other individuals chose to make saccades along the trajectory. In conclusion, Dicks, *et al.* (2017) suggested the existence of a bandwidth of gaze-coordination variability that allows a combination of joints to act in synergy to achieve successful performance outcomes during skilled interceptive action.

The third pillar suggests that coordination variability emerges from a continuous co-regulation of perceptual and motor processes, referred to as *perception-action coupling*. The use of information is founded on picking-up information for *affordances* which can solicit and constrain behaviours in a specific performance environment (Gibson, 1979; Rietveld & Kiverstein, 2014; Withagen, de Poel, Araújo, & Pepping, 2012). Adopting an individual-environment scale of analysis, the complementary relations between an individual and an environment define affordances. Therefore, affordances are both objective and subjective to each performer since they are ecological properties of the environment picked up relative to an individual's own action capabilities, *i.e.*, they are body-scaled and action-scaled (Fajen, Riley, & Turvey, 2009; Turvey & Shaw, 1999). Body-scaled affordances describe the relations between the perceiver's body (including the scale of body dimensions such height and limb sizes that evolve throughout childhood) and a relevant property in the environment. In contrast, action-scaled affordances define how the perceiver behaves (*e.g.* jump reach height) relative to their environment (Fajen *et al.*, 2009). For instance, Warren (1984) emphasized that despite differences in body size, young adults accurately perceived stairs as no longer climbable in a bipedal fashion, when the step height exceeded 88% of their lower limb length. Regarding action-scaled affordances, rock climbing has been used to examine how individuals perceive maximal reach-and-grasp (Pijpers, Oudejans, Bakker, & Beek, 2006; Pijpers, Oudejans, & Bakker, 2007). These studies found that individuals with low levels of experience underestimated their maximal boundary of overhead grasp, *i.e.* they miscalibrated their reach and grasp actions according to how far away they perceived the target. In a similar task, Croft, *et al.* (2018) found that children of 6 to 11 years of age who estimated their maximal reach distance more accurately, completed the climb more often and more quickly. Thus, talent development corresponds to the enhanced capacity for children to exploit information about environmental and task-related constraints (*i.e.* improvement of perceptual accuracy toward better perceptual attunement and calibration) to functionally (re)organize and continuously regulate their motor behaviour to achieve successful performance outcomes.

Perceiving opportunities for specific actions requires *perceptual attunement and calibration to relevant informational variables*, meaning that children need to pick up a range of perceptual variables from various modalities (haptic, kinesthesis, auditory, visual) that specify a relevant property of a performance environment (Fajen *et al.*, 2009; Jacobs & Michaels, 2007). A relevant property means that this property enables the children to functionally achieve specific task goals. To perceive accurately, children must be able to attend to the relevant informational variable. Traditionally, a novice may attend to a variable that ambiguously relates to the perceived property (non-specifying information variable). The perceiver's perceptual accuracy can improve when he/she converges on the informational variable that relates one-to-one to a perceived property (specifying information variable) (Withagen & Michaels, 2005). For example, a springboard diver can use strength (internal force) to push the board down, and exploit relevant informational variables such as elastic properties of the board (external force) to jump effectively (Barris, Farrow, & Davids, 2014). With practice and skill, learners become more attuned to relevant informational variables, supporting higher levels of task achievement (Fajen *et al.*, 2009; Richardson, Shockley, Fajen, Riley, & Turvey, 2008). Moreover, perception of affordances also requires scaling to action capabilities to allow distinction between possible and impossible opportunities for action; this scaling process is called perceptual-motor calibration (Fajen *et al.*, 2009; van Andel, Cole, & Pepping, 2017). For instance, wrong calibration in springboard diving might lead to baulking, which can be considered as a maladaptive behavior because it leads to penalty points in the competitive environment, inhibits the diver from experiencing how to adapt ongoing movements to a varied, initial hurdle step, and can lead to a loss of hundreds of practice trials each week (Barris *et al.*, 2014).

3 Skill transfer and learning as adaptive processes to support talent development

Transfer refers to the influence of previous practice or performance of a skill on the acquisition of a new skill (Adams, 1987). An important question for talent development concerns the relationships between learning and pre-existing skills when task and/or environmental constraints are manipulated (Kelso & Zanone, 2002; Zanone & Kelso, 1997). Skill transfer occurs when prior experiences under a particular set of constraints influences performance behaviours in a different set of constraints compared to those where the skills were originally learned (Newell, 1996; Rosalie & Müller, 2012). Traditionally, near and far transfer were considered according to the degree of similarity between two tasks, assuming that far transfer tasks exist when the task constraints and performance information are quite different from the initial settings (Baldwin & Ford, 2006; Barnett & Ceci, 2002; Hung, 2013; Issurin, 2013).

However, the issue for practitioners is not to determine only the degree of similarity between one task and another, but to establish a stable coordination pattern for a new action in the presence of a pre-existing stable coordination pattern. According to the three pillars discussed in the ecological dynamics framework, capacity to transfer learning to different performance conditions could be related to opportunities to explore different coordination tendencies (Newell & McDonald, 1992) and the perception-action coupling that regulate them (Davids, Button, & Bennett, 2008). For this reason, practice task constraints should seek to sample aspects of ecological constraints of performance environments. Indeed, practitioners often expect learners to transfer their practice performance into competitive situations (Williams & Grant, 1999).

The essence of transfer is being able to adapt an existing movement pattern to a different set of ecological constraints (Issurin, 2013; Newell, 1996; Rosalie & Müller, 2012). In this view, research within an ecological dynamics framework has investigated the specificity-generality of skill transfer (Seifert *et al.*, 2013, 2016; Travassos *et al.*, 2017). *Specificity* of transfer can emerge under practice task constraints where existing intrinsic dynamics of an individual cooperate with the dynamics of a new task to be learned, facilitating the emergence of successful performance behaviours. On the other hand, *general* transfer can occur when intrinsic and task dynamics do not cooperate closely and the individual athlete only has the potential to further develop *general capacities* that exist as part of their current intrinsic dynamics, such as perceptual skills, like anticipation and visual search, cognitions, emotional self-regulation, strength, or postural stability (Ward & Williams, 2003). Thus, general transfer occurs when general processes that support performance behaviours are used under a new set of performance constraints, but it may also occur when non-specifying information for action is present in a learning design, which highlight the role of information designed into learning environments for young athletes (Davids *et al.*, 2017).

More specific information can lead to greater specificity of transfer. The less specific the information present in a practice environment is to the constraints of the task in competition, then transfer will be more general. For instance, Seifert, *et al.* (2013, 2016) examined whether the intrinsic dynamics of climbers who practice regularly on an indoor climbing wall cooperate or compete with the constraints of climbing on a frozen waterfall (an icefall). On an indoor climbing wall, routes consist of holds composed of similar texture, which afford gripping with the fingers in an almost constant internal environment (*e.g.* ambient temperature remains the same during ascent; there are no weather changes to consider and the consistency of the climbing surface remains consistent). In ice climbing, properties of an icefall require use of tools on the feet (crampons) and in the hands (ice axes), and performance conditions (*e.g.*, weather, temperature and surface properties) can change significantly within and between climbs. It could be expected that *generality* of transfer between previous experiences on an indoor climbing wall and performance on an icefall would be obvious, leading to some benefits on performance revealed by the emergence of perception-action coupling, management of body weight with respect to the environmental constraint of gravity and the discovery of surface properties with exploratory finger and feet actions. Specific transfer reflects the emergence of a highly coupled performer-environment system such as the complex system of "climber-ice, tool-icefall" in ice climbing. In indoor climbing such tools play no part in ascending a surface but are necessary for ice climbers to explore the physical properties specific to the icefall environment (density and thickness), in order to estimate ice fragility.

Another example relates to the task of swimming indoor compared to outdoor aquatic environments (*e.g.* river, ocean, harbour), which helps us to understand specificity-generality of skills transfer (Button, 2016). According to Button (2016) and Stallman, Moran, Quan, & Langendorfer (2017), general transfer of skill could be expected between swimming in a pool and in outdoor aquatic environments. Indeed, in the pool, water temperature does not fluctuate and water remains in a quasi-steady state, whereas in the sea, current, rips, waves, wind, ambient temperature could fluctuate at a point that swimmers must stop swimming and dive to avoid a wave, float to take benefit from the current or tread water to estimate time gap between two waves. Thus, outdoor aquatic environments require different skills than the classic four swimming techniques, including water safety skills like treading, floating, diving, etc. (Stallman *et al.*, 2017). In the same vein, Travassos, *et al.* (2017) investigated possible skills transfer between futsal and football and made a distinction between "donorsports", those with a similar environmental, and task constraints across the sports, and "multisports" where minimal similarities exist. General transfer could occur between futsal and football because in both sports, there are interactions between players, which are mediated by the ball and orientated toward a similar goal. However, specific transfer also occurred as futsal is played in a smaller field (80 m^2 per player *vs.* 490 m^2 per player), with different texture and with lower numbers of players (5 *vs.* 11-a-side game) than football. Thus, due to the number of players involved, and especially the space and time available for playing, futsal is an intense sport, which requires constant changes of direction, accelerations and decelerations, quick and precise tactical and technical actions with and without the ball to successfully perform (Travassos *et al.*, 2017). In contrast, football is characterized by intermittent actions, combining periods of maximal/near maximal efforts with explosive technical actions, which mean high intensity activities with and without the ball, but with more time and space to perform these actions in comparison with futsal (Travassos *et al.*, 2017). In sum, for skills transfer to occur, instructors and coaches must be encouraged to design representative learning and training situations in order to favour exploratory behaviours, adaptability to interacting constraints and information-movement coupling (Davids *et al.*, 2015).

4 Implications for practice, talent development and representative learning design

Designing learning and training situations where children navigate between specific and general skill transfer might educate them of intention and of attention (Jacobs & Michaels, 2007). In particular, early diversification and unstructured activities (*i.e.* activities that are not supervised by an adult or coach, but emerge amongst peers from a performer-environment coupling) might favour exploratory behaviours and educate children's intentions to specify what needs to be achieved in a performance context (Jacobs & Michaels, 2007). Indeed, in certain situations, particular perceptions and actions are more functional than others, and with experience, children improve at choosing perceptions and actions to achieve task goals. However, early diversification and unstructured activities might also educate children's attention as they would converge from sources of information that may be only partly relevant in one situation (*i.e.* non specifying) to sources of information that are more relevant (*i.e.* specifying) under a variety of circumstances (Jacobs & Michaels, 2007; Withagen & Michaels, 2005). For example, activities such as Parkour, which consists of acrobatically moving in an urban area in an unstructured context (*e.g.* need for fun), favour the exploration of environmental resources to coordinate actions (*e.g.* objects, surfaces, ledges, and inclines). In this activity, environmental resources are exploited in a way unexpected by the architects, underlying skills transfer between a set of different ecological constraints (*e.g.* jumping from bench to bench in a park). Therefore, it could be expected that with practice, early diversification would develop adaptability to interacting constraints as children would explore the limits of their motor solutions and learn how to consequently search for new information-movement couplings (Davids *et al.*, 2012). With practice, children become attuned to a wider range of informational variables that more precisely specify how to perceive and act more effectively (Jacobs & Michaels, 2007). Specificity of transfer emerges as children learn to precisely scale their perceptual-motor system to available information in the environment.

Thus, to develop talent in youth, practitioners should design dynamic interventions that consider interacting constraints on movement behaviours, an appropriate sample of informational variables from the specific performance environments, and an opportunity for the functional coupling between information and movement to occur. Behavioural adaptability would ensure that: (i) the degree of success of a performer's actions are controlled for, and compared between contexts (supporting skill transfer), and (ii), performers were able to achieve specific goals by basing actions in learning contexts (movement responses, decision making) on comparable information to that existing in the performance environment (Pinder, Davids, Renshaw, & Araújo, 2011). Following the ecological dynamics framework, which is promoted within the ASM (Wormhoudt, Savelsbergh, Teunissen, & Davids, 2017), behavioural adaptability could be trained through variable practice as it invites individuals to face different interacting constraints where skills transfer is expected (Ranganathan & Newell, 2013). As many pathways could lead to expertise in sport (Güllich, 2014; Phillips, Davids, Renshaw, & Portus, 2010), a late specialization programme does not necessarily mean that athletes waste time, especially when the capacity for skills transfer is ecologically designed to contribute to the development of sports expertise and talent development (Abernethy, Baker, & Côté, 2005). For example, Nicolas Thépaut, an acrobatic ski champion is a former gymnast (Léger, 2017) and Zlatan Ibrahimović, a famous footballer, is a taekwondo black belt (Macphail, 2012). However, we must not confuse sports specialization and specialization within the activity. For example, in artistic gymnastics, coaches tend to specialize children in the practice of artistic gymnastics, but try not to specialize them on a particular apparatus before they reach adulthood. In fact, we can hypothesise that general skill transfer can occur between two pieces of apparatus, such as a somersault in trampoline and on a sprung floor or the ability to be parallel to the ground on Olympic rings and on the pommel horse. However, specific skill transfer might persist according to the apparatus used to perform. While traditional coaches prescribe the skill-to-be-learned with a single solution, where minimal skill transfer might occur, an ecological dynamics framework would propose to navigate between situations that promote general and specific skill transfer in a nuanced way. As already mentioned, specific skill transfer would occur in situations specifying informational variables for relevant action and task goal achievement. However, situations favouring general transfer may also be useful to promote rich environments (*e.g.* teaching water competence in outdoor aquatic environments rather than swimming technique in the pool) that propose a large landscape of affordances by "connecting" the children to the environmental resources (Rietveld & Kiverstein, 2014).

Indeed, to pick up opportunities for action, children must interact with the environment and develop exploratory behaviours. Following the example relating to the development of water competencies, interaction with the water properties (*e.g.* density, visibility, nature of the fluid flow) may help children to exploit the current of water, and at the same time, he/she might discover how to streamline his/her body and regulate his/her breathing to minimize active drag and optimize buoyancy. According to Gibson (1979), to perceive the environment is to co-perceive oneself. Following this idea, the coach is like a "designer" who should promote exploration in every landscape of affordances (Bruineberg & Rietveld, 2014). Therefore, there are still some specific and general skills transfer that can occur, sometimes with lag time and/or long term benefits. Early diversification (or late specialisation) would help to develop the richness of the landscape of affordances, and should not be considered as a lack of time in the main activity nor detrimental for performance. As an example, Benoît Caranobe, a famous French artistic gymnast who won a bronze medal in the Individual All-Round in gymnastics at the Beijing 2008 Olympic Games, specialized in artistic gymnastics at the age of 15 years. Coaches and instructors should consider early diversification (*e.g.* through variable practice and constraints manipulation) and unstructured activity to favour exploratory behaviours, and adaptability to constraints. This may lead to general and specific skill transfer and information-movement coupling in the development of talents and expertise in sport. Indeed, the level of activity dropout due to demotivation associated with early specialisation and excessive supervision, should invite us to rethink the role of the coach as *learning designer* and facilitator rather than an instructor and supervisor (Davids *et al.*, 2017).

5 Conclusions and implications for future research

Based on the severe problems in youth sport being highlighted in research, theoretical frameworks like ecological dynamics are calling for new models of talent development and pedagogical practice in sport. Knowledge is needed that compares the experiences of developing athletes with an ecological dynamics rationale compared to an early specialization approach. The ecological dynamics theoretical framework provides an integrated explanation for human behaviour in sport predicated on a theory of constraints on dynamical systems, ecological psychology and a complex systems approach in neurobiology. Three main pillars (*i.e.*, individual-environment coupling as the smallest unit of analysis; adaptive complex dynamical system to interacting constraints; information-movement coupling) support the functional role of behavioural variability, the usefulness of perceptual-motor exploration and the importance of general and specific skill transfer in the development of talent and expertise in sport. Some existing knowledge comes from sports systems that have implemented a new model of talent development, for example the ASM used by Ajax Football Club. Together with nonlinear pedagogy, the ASM, proposes a different approach to athlete development. Practical implications for coaches and instructors relate to early diversification and unstructured activity through variable practice and constraints manipulation, which would place children in a variety of situations, representative of the richness and the ecological context of the competitive performance environment.

There are clear testable questions to examine in future research, which compares the developmental experiences and performance levels of athletes developing under traditional and new pedagogical systems. These questions relate to, for example, athletic performance, skill levels, capacities for self-regulation, and overall achievement levels of different sports organisations that use different approaches to athlete development. Having stated all this, there may be a limited role for experimental studies in examining specific issues related to the comparison of traditional and ecological dynamics models of skill acquisition and talent development. For example, one testable prediction of ecological dynamics could be to investigate how the specificity/generality of information leads to specific/general transfer of skill. Pinder, *et al.* (2009) already provided insights in this direction when they compared the performance behaviours of a batsman in cricket when facing a bowling machine *vs.* a bowler bowling the ball. In particular, they emphasized that the use of ball projection machines in practice might remove key information sources from the performance environment and significantly affect the timing and control of interceptive actions in cricket batting (Pinder *et al.*, 2009). In particular, significant differences were observed between the practice task constraints, with earlier initiation of the backswing, front foot movement, downswing, and front foot placement when facing the bowler compared to the bowling machine (Pinder *et al.*, 2009). Therefore, greater specificity of skill transfer for a batsman (supported by functional coupling between perception and action processes) could be expected when a facing a bowler bowling the ball, while general skill transfer might occur when batting against a ball projection machine.

Author contributions statement

All authors contributed equally to the manuscript preparation.

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