Learning and performing: What can theory offer high performance sports practitioners?

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Learning and performing: What can theory offer high performance sports practitioners?

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ABBREVIATIONS
RT Retention test

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ABSTRACT
Currently, the most prominent motor control theories that underpin the pedagogy of coaches in high performance sport are derived from the discipline of psychology with a dominant focus on internalised control processes for learning and performance. In contrast, ecological dynamics is a contemporary meta-theory focused on the person-environment scale of analysis for understanding human behavior, exemplified by strengthening the *relations between each learner and their environment*. In this tutorial, we outline key concepts in ecological dynamics that considers learning and performance as being distinct, yet inextricably linked. In our considerations, we raise questions on long-held assumptions about control process theories on learning and performance for practice designs in high performance sports. For example, how useful is inferring learning by describing improved *performance* as showing more relative permanence, greater stability and consistency, with commensurate lower levels of attention and movement variability? How relevant are traditional ways of measuring learning using retention and transfer tests in high performance sports? What is actually attained in an ecological view of learning, focussed on education of attention and calibration of actions to specifying information present in performance environments? An implication of these issues for high performance sport is that learning needs to be assessed by how well a learner adapts to the specific constraints and demands of a performance context. This key idea has important implications for performance analysis and evaluation in sport.

KEYWORDS: Learning | Performance | Ecological dynamics | Motor learning theory | Skill adaptability

INTRODUCTION

Currently, the most prominent motor control theories underpinning coaching pedagogies in high performance sport focus on internalised control processes for learning and performance [1,2]. These models of control invite coaches to organise their session intentions around developing 'robust' internalised motor programmes and schema, purported to result in alignment with an optimal movement model. Practising a technique is, therefore, of paramount importance and generally undertaken via isolated drills with feedback directed at reducing the gap between what the movement looks like and the putative 'ideal' technical model [3]. However, a somewhat puzzling observation when watching high performance athletes is that successful performers do not always (in fact rarely) have what may be considered to be the most biomechanically 'optimal' techniques. In contrast, success in high performance sport appears to be predicated on the ability of highly skilled performers to excel at learning in performance to quickly exploit opportunities to coordinate their actions to adapt to what the competitive context offers them, to function more effectively and efficiently. For example, the fastest sailors in a regatta continually (re)organise their actions, highly attuned to immediate changes in prevailing currents or winds at any moment; the skillful footballer adapts the weight of their pass to match it to the demands of a wet surface where the ball 'skids' or a dry surface which has greater friction; the expert cricket spin bowler quickly 'finds' the most optimal pace when bowling on a new pitch, and the skilled ice climber explores and perceives properties of a frozen waterfall when traversing a route on a rocky surface. It is clear from these examples that a key part of performing functionally (effectively and efficiently) is *learning (quickly) in competitive performance*. Put another way: performing competitively provides an invaluable context for motor learning through *skill adaptation in athletes* [4].

A key question for those involved in coach education and, in particular, increasing practitioners' awareness of contemporary models of skill learning, is why coaches continue to stick with outdated models? Indeed, whilst theories of skill acquisition have been contemporized in the last 40 years, approaches to practice design across educational and sporting settings have largely remained unchanged. For example, informal yearly surveys of our students since our first formal survey in 2014 [3] continue to reveal that 95% of practice in schools is still being delivered using either an atheoretical approach or teaching methods aligned (if aligned at all) with motor control theories based on cognitive models published between 1960-2000 (see [5, 6]).

In short, the teaching of skill acquisition on coaching courses appears to be failing to influence pedagogical practice. It has been suggested that a path dependence, an ideological inertia, has prolonged the shelf life of some inherited beliefs [7,8] associated with 'traditional' approaches to skill acquisition. This inertia to contemporization implies that they are somewhat *sticky* with practitioners, who as 'successful' products of these approaches [3] have a strong attachment to pedagogical methods promoted by them. An important question is how can we help practitioners to develop the skills and knowledge to change outdated practice ideologies? Alexander[9] suggests that practitioners need to identify 'what one needs to know, and the skills one needs to command' to make and justify the many different kinds of decisions of which teaching is constituted' (p.47). The role of skill acquisition specialists in coach education courses could, therefore, be viewed as providing practitioners with a 'familiarity and ease' with the key ideas underpinning contemporary theories to use the associated pedagogical methodologies appropriately, effectively and efficiently' [10]. This tutorial seeks to contribute to that goal. We propose that in line with ideas of Smith discussed in Ovens et al.[11], an ecological dynamics approach offers a 'plausible' theoretical lens for supporting context-specific skill-learning practices.

In this tutorial, we explain how some of the 'givens' in 'traditional' approaches to skill acquisition are so *sticky* with practitioners and discuss alternatives moving forward. Our main vehicle to explore the key issues will be to consider what we understand as constituting *learning* in the contrasting approaches and its relationship to performance. We consider the importance of re-framing the concepts of learning and performing to encourage sport practitioners to move away from long-held beliefs that underpin current coaching philosophies, predicated on the dominant view that skill learning is fundamentally founded on internalised control processes. This ideology is not aligned with contemporary theoretical models of movement coordination and the acquisition of coordination [12,13,14] or, even, more contemporary embodied cognitive approaches [15]. We begin by explaining how traditional beliefs shape practice designs, highlighting the limitations of such approaches given current understanding of skill learning. We next propose an alternate approach adopting an individual-environment scale of analysis to reframe explanations of skilled behaviour away from internalised processes [16].

Teaching skill acquisition in coach education programmes

Despite the central place of skill acquisition in high performance sports coaching, it receives limited attention in many coach education programmes, typically being delivered in one two-hour 'module' by an academic skill acquisition lecturer from 'local' higher education institutions. Consequently, the key concepts covered tend to revolve around fundamental "givens" in sports coaching, such as the idea that movement techniques need to be taught first [5]. This accepted wisdom is predicated on cognitive, enrichment-based models of skill acquisition with an information-processing lens[17] with the optimization of motor programs and the development of schema as the major goals. An important concern for sport practitioners in high performance organisations, therefore, is how these ideas frame our understanding of learning and the implications for coaching practice design (i.e., what coaches' say and do). Most fundamental of all is to consider whether these ideas are still valid today.

Learning from a Cognitive Viewpoint

Uncontroversially, Schmidt & Lee (1999, p.264)[18] defined learning as "a process of acquiring the capability for producing and controlling skilled actions". Perhaps, more controversially, they also define this process as a purely internal one[17]. Motor control is considered to emerge from the skillful implementation of internalised control processes[19]. The most prominent and popular internal motor control theory is Schema Theory[1], countering initial ideas of Jack Adams[20] on closed loop control. Schmidt[1] further explored the emphasis in Adams' theory on learners re-producing movements in line with an established *reference of correctness* [19]. Each movement made in pursuit of this goal during learning, results in a gradual adaptation of a perceptual trace of that movement in the brain [21]. Learning is, therefore, proposed as a feedback-driven process of *internalised trace strengthening*, with skilled performers accumulating a greater number of 'correct' traces for controlling movements. The strengthening of a memory trace is directly proportionate to the number of practice trials undertaken and the quality of feedback available to learners. This key idea served to shape Schmidt's thinking about the memorization processes (recall and recognition) of a generalised motor program [21]. These dominant conceptualisations of motor control and learning underpinned ideas around deliberate practice[22]. Variable practice was proposed as a way to strengthen the schema built on the assumption that the generalized motor program, which controlled the sequencing and timing of muscle activity, was already acquired a priori.

The characteristics of learning from a cognitive perspective

In the dominant cognitive paradigm described above, learning is predicated on the elaboration of 'internal' control processes and, therefore, not directly observable, except through analysing performance repeated over time. Learning has to be indirectly inferred from characteristics of improved performance, such as showing more relative permanence, greater stability and consistency, with commensurate lower levels of movement variability and attention [23]. Relative permanence through greater stability and consistency is assumed to come from lower levels of variability as the motor program and parameterisation of the schema becomes more aligned to the target movement template. As movements become more 'automatic', less attention needs to be paid to cognitively controlling them[24]. Why reduced cognitive attention here results in better performance is not quite clear, but ideas put forward include: (i) no attention needs to be paid to the 'verbal-cognitive' aspects of the skill as now "we know" which pattern to use rather than still having to decide (i.e., in the cognitive stage of learning). In line with this idea is that control is hierarchical and learning leads to control moving 'from 'higher' decision-making levels to 'lower' motor program control level. (ii); the sub-routines (smaller composite programs developed in early learning) are combined as a single more extensive motor program (see Schmidt[25] citing Keele's 'gearshift analogy').

One other characteristic that learning is thought to be judged upon is the learners' ability to adapt 'to a variety of performance context characteristics'[23]. The process or mechanisms for this increased adaptability is not explained, but interestingly, is said to be needed because "we never really perform a skill when everything in the performance context is exactly the same each time" and, therefore, "successful performance requires adaptability to changes in personal, task and/or environmental characteristics"[23](p.258). Note the all-inclusive use of the term 'we'. This use of language is useful in highlighting how traditional theories on motor control processes and mechanisms adopt a task-based approach in which representation formation and feedback implementation seems to be universal, stage-based processes for all individuals. An individualised approach to performance and learning is eschewed. What does this signify? This idea does not appear to fit well with a mode of motor control residing in the construction of common representational programs. There is little attention paid to consider the influence of specific situations or contexts, ignoring the mutuality of the individual and the environment [26]. As such, a cognitive perspective on motor learning and control that adopts an asymmetric focus on the internal representations of an individual fails to consider how the relationship between that athlete and a performance environment is strengthened during their individualised learning and development experiences. Indeed, the suggestion is that key individual experiences and 'specific performance characteristics' such as emotions, changes in task constraints and the environment, should be removed when learning and when attempting to assess and analyse learning.

The distinction between learning and performance

A key feature proposed in cognitive models is that, while learning and performing are distinct processes, they are inter-dependent. Learning cannot emerge without performance and the latter needs to be assessed over time to evaluate the former. This results in a failure to consider how the relationship between that athlete and a performance environment is strengthened during their individualised learning and development experiences. Learning can lead to behavioural changes, but refers to the set of processes that support such changes[25]. Research in the field, therefore, became focused on identifying the variables that best supported learning, especially in the context that learning could only have said to have taken place if it led to a permanent, rather than a temporary change in behaviour. Accordingly, any variable that was seen to interfere with learning, or mediate the effect of practice was to be removed. Unfortunately, this meant that variables such as emotions, fatigue, or competition and *the uniqueness of the setting* are said to have the potential to affect a person's performance, but not the degree of learning the person has achieved [23]. Some variables (although Schmidt [25] highlights that sometimes it is hard to distinguish between a learning variable and a performance variable) are, therefore, irrelevant or detrimental to learning and need to be removed from practice contexts. In Schmidt's[25] own words; "If I know a certain variable only affects performance, and it is not important for learning, then I will not have to worry about adjusting the level of that variable in the learning situation (p.456-7). For us, this idea is problematic as it fails to take into account the necessity for learning experiences that emerge when performing in competitive performance environments where it is likely that individuals will experience intense emotions or have to 'deliver' a performance when fatigued, distracted or emotionally perturbed. In this definition, performance *in competition* is not seen as being a part of the 'appropriate conditions' to assess how much learning has taken place[23]. We argue that learning and performing are symbiotic, with both processes emerging simultaneously when individuals engage in motor behaviours in specific contexts e.g., a competition environment[17]. Consequently, when attempting to work with sports practitioners to prepare athletes to perform in competitive environments, performance variables cannot be ignored and removed because of the important relationship between performance and learning. In fact, we suggest that these variables should be sampled from competitive performance environments and embraced in practice designs as their presence can result in deeply significant changes in intentions, perceptions and actions to which an athlete needs to adapt [10]. We will delve further into this later after briefly considering how we have traditionally attempted to measure motor learning.

Measuring learning: retention and transfer tests

Excluding performance variables may seriously misrepresent the amount of learning that has taken place for each individual, given the over-reliance on experimental investigations of learning in motor learning. Also, in experimental investigations there is an over-reliance on specific methods and data to verify learning such as the need for a delayed test, to accurately assess learning[25]. A Retention Test (RT) generally requires learners to repeat the same activities acquired in learning to observe whether changes inferred from performance, undertaken during practice, have become relatively permanent. In experiments, cognitive motor control theorists emphasise the need to 'sanitise' the learning environment significantly by controlling potentially intervening variables in the RT environment to remove perceived contamination that could influence performance temporarily and reduce effectiveness of the pedagogical setting or the researcher's confidence to evaluate the impact of learning [25]. An additional way to test learning is to use a transfer test to examine the ability of the learner to adapt the skill they have learned to novel situations, or environments and may include requiring the production of novel variations of the learned skill. Tests of skill transfer also examine how participants cope with changes in performance characteristics such as dealing with stressful competition [23].

Linking back to earlier comments, there is significant research evidence to suggest that removing performance variables from practice until a skill has been well established [27] would be detrimental to learning. For example, suppressing or removing emotions from learning designs may actually be impossible, since all practice tasks, irrespective of being drill based or games based, still create emotions, feelings and thoughts and impact on participant motivation[28]. Indeed, research has shown that cognitions and emotions are intertwined with actions and consequently act to shape co-ordination[29]. For example, many studies (e.g.,[30,31,32]) have revealed how differing anxiety levels change intentions of performers, what they perceive and, consequently, how they move. Importantly, improvements in movement analysis technology, combined with more advanced methods of interpreting data, have enabled researchers to capture how so-called performance variables result in changes in movement co-ordination. For example, as aligned with Bernstein's[33] early evidence and insights on challenges of repeating simple aiming movements in a stereotyped way, Bauer and Schöllhorn (1997)[34] showed how movement patterns of high performance athletes changed from session to session across competitions and practice sessions. Further evidence has been found in studies of gait, which may be considered as an ideal task vehicle to demonstrate stable repeatable motor programs, given the significant number of trials undertaken over an individual's life span. However, the evidence suggests the opposite. While gait patterns are found to be unique, yet persistent in each individual, remarkably, gait has been found to change by 85-95% within and between days[35,36]. Further, performance variables such as fatigue and emotions showed that individual's gait patterns alter in fatigued conditions[37] Emotional states such as being happy, sad or angry[38] could also be differentiated through gait analysis. Notably, a key finding in these studies highlights that optimal movement co-ordination was highly individual and emphasized that group-based studies have limited value for assessing learning in high performance sport. In summary, these studies highlight the triadic relationship between intentions, emotions and actions and suggest there is a need for practitioners to embrace performance variables rather than attempting to cleanse the practice environments by removing them. We begin to address how these ideas can inform the work of practitioners next.

What does all of this mean for the practitioner?

For the sports practitioner who interrogates the motor learning literature, the separation of learning and performing may, at first, appear somewhat confusing, if not faintly ridiculous. For coaches and those invested in an individual or team's performance, the most important measure of learning concerns how a participant performs in competition. Performance is a reflection of the coaches' ability to 'prepare' performers for competition by 'teaching' or 'coaching' them, so they are capable of demonstrating the necessary skills in a performance setting. This requirement suggests that non-motor control specialists may require practice effectiveness to be judged by performance under the constraints of a competitive environment. Under these specific competitive constraints, the ability to perform when nervous, fatigued or required to adapt to unique contexts, such as when facing novel opponents or dynamic defensive formations, or when performing in a variety of weather conditions is paramount for understanding effects of learning.

To summarise so far, we have highlighted that any model of skill learning to be utilised to underpin practice design for high performance athletes needs to embrace the dynamic nature of competitive environments. Successful performance in competition requires athletes to adapt to dynamic task constraints, often when performing under intense emotional states induced by contextual events and surroundings, continually influencing their cognitions, perceptions and actions[39,40]. In the next section we provide an alternate viewpoint where learning and performing are seen as being tightly interconnected and in fact, performing requires direct learning and learning take place through performing in representative environments[41]. In this approach, motor learning is predicated on a transdisciplinary focus on movements in action rather than an isolated disciplinary view [42].

An ecological dynamics approach to learning and performing

> ‘The approach [the ecological approach], while yet in its infancy, may provide the next big shift in emphasis in attempting to understand motor behavior (p.18).’

This epigram, taken from the excellent chapter that plots the history of motor behaviour as an independent discipline was written by R.A Schmidt in 1982[25]. Setting up this comment, Schmidt cited the early work of important influencers in ecological dynamics, including Bernstein[33], Turvey[43] and Gibson[26]. In this tutorial we recognise Schmidt’s significant insights on ‘the ecological approach’[26]. Schmidt emphasized the basic premise that “our motor system was created through evolution and interaction with the physical characteristics of our environment and that we should, therefore, attempt to understand the structure and function of the motor system by using more natural research settings” p.18). Although we support this viewpoint, it is somewhat limited in recognising the potential value of an ecological approach as being restricted to a greater emphasis on use of ‘natural research settings’. In this tutorial we seek to support these early ideas by setting learning and performing as symbiotic processes within an ecological dynamics framework. Over decades, an ecological dynamics rationale has advocated the deep integration of learning and performing in a model of skill acquisition based on the key principle of the *mutuality of the learner and the environments in which they are required to perform* [44,45]. An ecological model of learning and performance also takes into account system complexity and variability[47], amidst the non-linear, dynamical interactions of individuals with environmental and task constraints. Specifically, we highlight the importance of adopting ideas of representative learning design[47] to maximize the potential for learning in practice tasks.

ECOLOGICAL DYNAMICS AND SKILL ADAPTATION

An ecological dynamics approach to skill acquisition adopts a systems orientation, focusing on coordination of actions with a dynamic performance environment. This systemic approach moves practitioners away from the asymmetric focus on internal control processes within an individual, and more specifically brain activity, to one that focuses on skill adaptation or skilled attunement to a performance environment[4]. Learning is, therefore, reframed as a *process* of continually improving the fit (functional relationship) between an individual and the environment by using surrounding perceptual information to continuously regulate actions. The aim of learning designs are, therefore, to render perception-and action more and more tightly coupled[13,26]. However, given the dynamic nature of the relations between an individual and a performance environment, the functionality of this fit is ‘a work in progress’ involving continuous adaptations and learning. It is a nonlinear, dynamic relationship which can regress, stabilize, or progress, depending on an individual’s experiences (practice, age, injury etc) over the life course. Davids and Araújo [48] highlighted how functional behaviours emerge in performance environments and that an individual's performance solutions may vary over different timescales. These variations are exemplified within individuals (e.g., changes in capacities and skills, changes through growth and maturation) over macro timescales of years as the sport evolves (e.g., performance surfaces, changes in rules and regulations, new technologies and equipment, tactical trends).

When learning is conceptualised as an ongoing process throughout the lifespan, it is seen as part of experience and a function of development[49]. It is important to note that learning does not only occur in formalized, structured teaching and coaching sessions. Learning opportunities also emerge in sport performance, providing contextualized experiences of engaging with constraints of competition environments. Over short, medium and long time frames, the skills and abilities that each individual develops are shaped by all the environments or landscapes of affordances, providing opportunities for actions, to which athletes are exposed[26,50]. For example, a tennis player who is brought up in a talent development program on clay courts is more likely to become a strong baseline player, whereas one brought up on grass courts, would more likely develop a strong serve and volley game as the affordances of these surfaces invite the player to develop these skills[51]. A cricket spin bowler who is brought up in Australia on hard pitches where the ball has lots of bounce, will typically bowl faster and with less variability in delivery speed than those spin bowlers brought up on pitches in the Indian sub-continent[52]. These experiences result in bowlers performing better in the environments to which they are most adapted or attuned to, based on their development [52].

Of course, development continues throughout the life span. The previous examples highlight the key idea that in an ecological dynamics approach, learning can be re-framed as "an ongoing dynamic process involving a search for and stabilization of specific, functional movement patterns" across the performance landscape as each individual adapts to a variety of changing constraints[13]. Learning is concerned with developing an increasingly functional **fit** between each individual and a performance environment and highlights that humans perceive information in the environment in relation to its value and meaningfulness detected in affordances. This theoretical framing provides insights into what people learn and know and how they decide to act [53,54].

An important point for learning designers is that the perception and learning of affordances is not an automatic internalized process, but requires periods of individualized exploration over time[55]. Exploratory activity enables individuals to 'fine-tune' their attention as they detect meaningful properties of the environment to support and exploit their action capabilities[55]. Consequently, practice tasks need to provide learners with the opportunity to educate: their 'intentions', 'attention' and then 'calibrating' actions to achieve performance solutions[13]. The implication for practitioners is that they should design learning for each stage by providing an initial period of *search and exploration, followed by a discovery and stabilization phase*. For more advanced performers learning activities should enhance their ability to *exploit* the available affordances[13].

Fine tuning attention emphasizes that learning involves specifying the information for skillful performance, implying the significance of learning which variables to ignore and which to attend to[56,57]. If a coach or teacher (wittingly or unwittingly) reduces or removes specifying variables present in an environment, thereby reducing task specificity, the opportunity to learn to exploit relevant information to regulate actions may be limited, as the opportunity to learn to differentiate between (un)helpful information is denied.

In contrast to the separation of learning and performing in traditional internal models, from an ecological dynamics perspective, the previous discussion highlights that practice should be designed by careful consideration of 'performance variables' present in performance environments; essentially this means carefully considering which ones to include, rather than exclude. A useful concept here is that of Representative Learning Design, proposing that practitioners should 'sample' the situation-specific information from the competitive performance environment. This sampling can lead to a contextualised simulation of the key demands on an athlete and team[41]. The degree of action fidelity (coherence between what is observed in practice and in the performance setting) is determined by the degree to which specifying affordances and the actions they support are made available in training tasks[58].

When designing practice tasks in which learning may transfer positively to performance, practitioners are provided with the key insight from Bernstein[33] that movement organisation is 'function specific', not 'muscle specific', the latter of which is a dominant idea in neuro-anatomically-dominated motor control theory[59]. A key implication of Bernstein's theorising is that, for sports pedagogues, it is the task that builds the action and not the other way around. The take home message from interpreting Bernstein's insights on practice is that: *context is everything* in designing useful tasks that challenge the perception, cognition and actions of a learner.

What are the characteristics of learning in an ecological dynamics approach?

An interesting question is: how does ecological dynamics view the identified characteristics associated with learning as described by Schmidt [25] and Magill & Anderson[23]? First, improvement with practice concerns the tighter coupling of the individual with the environment (i.e., the creation of more functional solutions through picking up specifying information) in a non-linear dynamical process. Consequently, relative permanence of an internalised representation of a movement technique is not a goal to be acquired, although clarifications of performance intentions is emphasised (e.g., I need to reach for a grip with my left hand, and not my right, on a vertical surface I am traversing during a climb). Stability and consistency in achieving intended action outcomes are key goals, but these are relative terms in individual-environment systems which dynamically adapt to decaying and emerging constraints in a changing affordance landscape[60]. Stability (of performance outcome) is, therefore, more likely to be achieved by movement adaptability through enhanced functional variability and the development of *softly assembled synergies* (temporary coordination patterns) that satisfy task demands at any moment. Skill adaptation is founded on the flexibility of systems offered by system *degeneracy* (i.e., the ability to organise system degrees of freedom (components) in multiple ways to achieve the same outcome goal)[61]. Movement and practice variability are viewed quite differently in contemporary theories, compared to how they are considered in traditional cognitive approaches.

Exposing learners to rich and varied practice environments can promote opportunities for individuals to develop *knowledge of*[26] the performance environment by learning to self-regulate and *adapt* (relatively) stable perception-action couplings to emergent problems[62]. This key challenge implies how coaches and sport scientists could design practice landscapes and use feedback and instructions to guide exploratory activities of learners[63]. Also, by infusing perturbations in learning, task constraints

variability can support exploration, affording novel opportunities for athletes to continuously self-regulate their coupling of perception and action as they seek a more *functional relationship* with varying performance contexts[45,64] over different time scales. For example, coaches can harness principles of unstructured play to enhance adaptive behaviours by inviting learners to interact with different constraints (e.g., in team games play against different age or mixed-sex groups, different numbers of players, and on varied surfaces or weather conditions).

From an ecological dynamics perspective, variability of practice is not simply the mechanical manipulation of task constraints such as varying putt length in golf or diving into a pool from different heights with the commensurate goal of developing schema built on motor programs. Instead, practitioners would vary individual, task and environmental constraints to promote exploration and search activities to guide learner's perceptual attunement and re-calibration of actions (i.e. through scaling the use of the perceptual variable) to enhance transfer of learning [65]. For example, cricket spin bowlers could be asked to practice on pitches with different soil properties to give them an opportunity to explore and exploit the affordances of the different surfaces[66]. Additionally, manipulating task constraints to add variability can help performers learn how to exploit system degeneracy at many different levels, e.g., achieving the same movement outcomes utilizing varying movement patterns[61]. It can help them learn to self-regulate performance to achieve consistent performance goals, a capacity termed 'dexterity' [33,67,68]. More directly, by infusing perturbations in the learning process, variability can support exploration and adaptation and not be viewed as a source of error in the system.

Learning in action is an integral part of performing

As highlighted, success in sport is predicated on a continuous process of learning and performing. The need to learn and perform at the same time provides significant demands on athletes as it requires a combination of exploratory and performatory actions[69]. Exploratory actions enable the perceptual systems to become progressively more 'attuned' to the invariants in the environment through direct experience in specific contexts[70]. Consequently, skilled athletes are able to use task specific experiences to perceive action possibilities and exploit opportunities offered by factors such as opponents' weaknesses or changes in environmental constraints such as winds, ambient temperature or surfaces. During performance, this improved fit emerges through a continuous cycle of perceiving and acting to readjust intentions with respect to the (updated) knowledge of the environment. For example, in games like golf or cricket, where competitions last for days, performance surfaces change throughout and between days and individuals need to continually readjust their actions to emergent conditions.

When preparing players or athletes to compete, **learning in action** needs to be 'as fast as possible' as task demands dynamically change as a result of interaction between task, environmental and individual constraints[13]. Often opportunities for action are brief and performers need to pick up relevant affordances fast. Under pressure of winning, undertaking exploratory actions is difficult and coaches who are wedded to traditional coaching approaches often discourage athlete exploration by rehearsing highly structured and pre-planned moves that can simply be run off 'automatically'. Clearly, some structure is important for athletes, for example clarifying strategic intentions, establishing ball-park start roles and positions in team games or using a set number of run-up steps in athletic jumps, for example. However, many athletes struggle with sudden changes in performance contexts, failing to practice taking clear and obvious opportunities to co-adapt to emergent constraints. Practice based on ecological dynamics principles, can offers 'safer' and less consequential opportunities to learn in action.

Redefining Transfer and Retention tests to connect practice and performance

As we highlighted earlier, traditional approaches to learning in sport have emphasised the removal of variables that are integral to performance contexts, sometimes resulting in 'feature-less and context-less' drills in practice. Consequently, there is a lack of motivation as to whether the drills are performed well or not. However, as highlighted by Schmidt[25], when learning studies utilise transfer tests (to test the adaptability of the skill to novel situations), the most consistent finding is that motor transfer is generally low unless the two tasks are so similar as to be practically identical [25].

For high performance sport (at least), this statement questions the value of practice tasks that are low in 'representativeness' in respect of the constraints encountered in a competitive environment. In this type of practice, task constraints may be considered as 'context-independent'[71] and may be of limited value for learning to prepare for competition in high performance sports organisations. When expert performance is predicated on the capacity to precisely calibrate actions to exploit the specific affordances available in competitive performance contexts[13], practice needs to occur much more often under 'context-dependent' constraints'[71] of competition to prepare athletes for performance[10]. Instead of *removing* variables that may ultimately influence each individual's emotions, cognitions, perception and action, an ecological dynamics rationale highlights the relevance of designing them **in**, to deeply contextualise practice task designs. Similarly, tests of transfer to assess learning need to take place in conditions that are as close as possible to those that learners will experience when they need to perform a skill in competition. This necessity begs two questions: (1) why not practice in conditions as similar as possible as the competitive performance environment, and (2), why not use competition performance as the (*ultimately relevant*) transfer test? If successful performance requires adaptability to changes in personal, task and/or environmental characteristics, why would we not practice in performance environments that challenge individuals to deal with dynamic individual, task and environmental constraints that emerge in competitive contexts?

To support this design goal, practice tasks could be based on the four environmental design principles identified by Renshaw et al.[10]. These key principles include: (1) Matching learner intentions in practice with those observed and verified by analytics in performance; 2) Ensuring that learning tasks are highly representative of performance environments and contain key specifying information and affordances promoting maximal positive transfer, with perception and action couplings demonstrating a high degree of fidelity to those seen in performance; (3) Practice by adopting the concept of 'repetition without repetition'[33], p.234) to promote exploratory and performatory actions to support the emergence of stable and adaptable movement solutions[72]; and (4), Design-in constraints that invite learners to pick-up and utilise affordances as and when they become available in a performance context.

CONCLUSION

This tutorial discussed the way that learning and performing have been traditionally conceptualised in motor control theories. We showed how pedagogical current approaches are very 'sticky' and persistent as many practice approaches are based on popular cognitive theoretical ideas from motor control theories from 1960-2000. This reliance has led to the majority of current pedagogical practices neglecting the environment in favour of developing internal control processes, with an asymmetric focus on automaticity and rehearsal to internalise idealised movement models. This bias has created an artificial disconnect between practice and performance, with an over-reliance on repetitive drills that fail to allow learners to develop functional perception-action couplings needed in dynamic performance environments.

An alternative approach is based on a trans-disciplinary model of skill adaptation that views learning as an increasingly refined fit between the learner and a performance environment. In this ecological dynamics approach, the learning designer is charged with creating practice environments that enable learners to self-regulate by eliciting desired intentions, dealing with emotions and coupling perception and action to succeed in performance. The ultimate goal is the creation of practice tasks that are maximally consistent with the principles underlying how people skilfully and effectively interact with the world [73]. Practitioners need an understanding of how a performance environment frames behaviour, which is more powerful and effective if built on a sound theoretical base [73]. Founding practice organisation on key ideas of *representative learning design* would better prepare performers to compete and allow practitioners to 'test' the effectiveness of their coaching practice. These evaluations would promote functional learning by treating competitive performance as akin to a transfer test.

Finally, a deepened understanding of learning and performance would benefit from the symbiotic contributions of academic empirical knowledge and sport practitioners' experiential knowledge 'of' learning and performance environments. The emergence of ecological dynamics, offers a 'plausible' theoretical lens for supporting context-specific skill-learning practices in high performance sport, highlighting the opportunity for motor learning specialists to co-create with practitioners (e.g., see[41,74]). This contemporary development in applied science suggests that there are exciting opportunities ahead for those interested in understanding and enhancing performance when interacting individual, environmental and task constraints shape performance.

REFERENCES

1. Schmidt RA. A schema theory of discrete motor skill learning. *Psychol Rev*. 1975;82(4):225. doi: 10.1037/h0076770
2. Martenuik RG. (1976). *Information processing in motor skills*. New York: Holt, Reinhart & Winston.
3. Moy B, Renshaw I, Davids K. Variations in acculturation and Australian physical education teacher education students' receptiveness to an alternative pedagogical approach to games teaching. *Phys Educ Sport Pedagogy*. 2014;19:349-369. doi: 10.1080/17408989.2013.780591.

4. Araújo D, Davids K. What exactly is acquired during skill acquisition? *J Conscious Stud*. 2011;18:7-23.
5. Partington M, Cushion C. An investigation of the practice activities and coaching behaviors of professional top-level youth soccer coaches. *Scand J Med Sci Sports*. 2013;23:374-382. doi: 10.1111/j.1600-0838.2011.01383.x.
6. Rudd JR, Foulkes JD, O'Sullivan M, Woods CTA. 'In: A Whitehead & J Coe, editors. Fundamental' Myth of Movement with a 'Functional' Solution In: *Coaching IMOS* (ed). 2021. p. Chapter4.
7. Kiely J. Periodization theory: confronting an inconvenient truth. *Sports Med*. 2018;48(4):53-764. doi: 10.1007/s40279-017-0823-y.
8. McWorther J. What scientific concept would improve everybody's cognitive toolkit? Path dependence. 2011. http://www.edge.org/response-detail/10852 accessed 16 November 2017.
9. Alexander R. *Essays on Pedagogy*. London: Routledge. 2008.
10. Renshaw I, Davids KD, Roberts W, Newcombe D. *Sport Coaching, Training and Performance: Principles of Constraints-Based Practice*. London: Routledge. 2019.
11. Ovens A, Hopper T, Butler J. Complexity thinking in physical education. Routledge Studies in Education and Youth Sport. London: Routledge: Taylor & Francis Group. 2013.
12. Newell K. Constraints on the development of coordination. , KM In: Wade MG, Whiting HT, editors. *Motor development in children: Aspects of coordination and control*. Dordrecht: M. Nijhoff. 1986.
13. Button C, Seifert L, Chow JY, Davids K, Araujo D. Dynamics of skill acquisition: *An ecological dynamics approach*. Champaign, Ill: Human Kinetics Publishers. 2021.
14. Wormhoudt R, Savelsbergh GJ, Teunissen JW, Davids K. *The athletic skills model: optimizing talent development through movement education*. London: Routledge. 2017.
15. Cappuccio ML. Introduction. In ML Cappuccio, editor. *Handbook of embodied cognition and sport psychology* - Cambridge, MA: MIT Press; 2019.
16. Wilson AD, Golonka S. Embodied cognition is not what you think it is. *Front Psycho*.2013;4:58. doi: 10.3389/fpsyg.2013.00058.
17. Schmidt RA, Wrisberg CA. *Motor learning and performance: A situation-based learning approach*. Champaign, Ill: Human Kinetics. 2008.
18. Schmidt RA, Lee TD (3rd edition). *Motor control and learning: A behavioral emphasis*. Human Kinetics;1999.
19. Baggs E, Raja V, Anderson ML. Extended skill learning. *Front Psychol*. 2020;11:1956. doi: 10.3389/fpsyg.2020.01956.
20. Sherwood DE, Lee TD. Schema theory: critical review and implications for the role of cognition in a new theory of motor learning. *Res Q Exerc Sport*. 2003;74(4):376-382. doi: 10.1080/02701367.2003.10609107.
21. Adams JA. A closed-loop theory of motor learning. *J Mot Behav*. 1971; 3(2):111-150. doi: 10.1080/00222895.1971.10734898.

22. Ericsson K. Development of elite performance and deliberate practice. In A Starkes J, Ericsson K. editors. *Expert performance in sports: Advances in research on sport expertise*. Human Kinetics. 2003. p. 49-83.
23. Magill RA, Anderson DI. (11th Edition). *Motor learning and control: Concepts and applications*. New York: McGraw-Hill Publishing. 2017.
24. Fitts PM, Posner MI. Human performance. Belmont, CA: Brooks/Cole Publishing Company. 1967.
25. Schmidt RA. *Motor Control and Learning: A behavioural emphasis*. Champaign, Ill: Human Kinetics. 1982.
26. Gibson JJ. *The ecological approach to visual perception*. Boston: Houghton: Mifflin. 1979
27. Hutto DD, Kirchhoff MD, Renshaw I. Emotions on the playing field. *Handbook of embodied cognition and sport psychology*. 2019. p. 23-46.
28. Renshaw I, Oldham A, Bawden M. Nonlinear pedagogy underpins intrinsic motivation in sports coaching. *Open Sports Sci J*. 2012;5(s1):88-99. doi: 10.2174/1875399X01205010088
29. Araújo D, Hristovski R, Seifert L, Carvalho J, Davids K. Ecological cognition: expert decision-making behaviour in sport. *Int Rev Sport Exerc Psychol*. 2019;1;12(1):1-25. doi: 10.1080/1750984X.2017.1349826
30. Nibbeling N, Oudejans RR, Daanen HA. Effects of anxiety, a cognitive secondary task, and expertise on gaze behavior and performance in a far aiming task. *Psychol Sport Exerc*. 2012;13(4):427-35. doi: 10.1016/j.psychsport.2012.02.002
31. Pijpers JR, Oudejans RR, Bakker FC, Beek PJ. The role of anxiety in perceiving and realizing affordances. *Ecol Psychol*. 2006;18(3):131-61. doi: 10.1207/s15326969eco1803_1
32. Graydon MM, Linkenauger SA, Teachman BA, Proffitt DR. Scared stiff: The influence of anxiety on the perception of action capabilities. *Cogn Emot*. 2012;26(7):1301-15. doi: 10.1080/02699931.2012.667391
33. Bernstein N. *The coordination and regulation of movement*. Oxford: Pergamon Press. 1967.
34. Bauer HU, Schöllhorn W. Self-organizing maps for the analysis of complex movement patterns. *Neural Process Lett*. 1997;5(3):193-9. doi: 10.1023/A:1009646811510
35. Horst F, Kramer F, Schäfer B, Eekhoff A, Hegen P, Nigg BM, et al. Daily changes of individual gait patterns identified by means of support vector machines. *Gait Posture*. 2016;49:309–314. doi: 10.1016/j.gaitpost.2016.07.073
36. Horst F, Mildner M, Schöllhorn WI. One-year persistence of individual gait patterns identified in a follow-up study–A call for individualised diagnose and therapy. *Gait Posture*. 2017;58:476-80. doi: 10.1016/j.gaitpost.2017.09.003
37. Janssen D, Schöllhorn WI, Lubienetzki J, Fölling K, Kokenge H, Davids K. Recognition of emotions in gait patterns by means of artificial neural nets. *J Nonverbal Behav*. 2008;32(2):79-92. doi: 10.1007/s10919-007-0045-3

38. Janssen D, Schöllhorn WI, Newell KM, Jäger JM, Rost F, Vehof K. Diagnosing fatigue in gait patterns by support vector machines and self-organizing maps. *Hum Mov Sci*. 2011;30(5):966-75. doi: 10.1016/j.humov.2010.08.010
39. Jones MV. Controlling emotions in sport. *The sport psychologist*. 2003;17(4):471-86. doi: 10.1123/tsp.17.4.471
40. Lewis MD, Stieben J. Emotion regulation in the brain: Conceptual issues and directions for developmental research. *Child Dev*. 2004;75(2):371-6. doi: 10.1111/j.1467-8624.2004.00680.x
41. Pinder RA, Davids K, Renshaw I, Araújo D. Representative learning design and functionality of research and practice in sport. *Int J Sport Exerc Psychol*. 2011;33(1):146-155. doi: 10.1123/jsep.33.1.146
42. Woods CT, Rudd J, Gray R, Davids K. Enskilment: An Ecological-Anthropological Worldview of Skill, Learning and Education in Sport. *Sports Med Open*. 2021;7(1):1-9. doi: 10.1186/s40798-021-00326-6
43. Turvey MT. Coordination. *American Psychol*. 1990;45(8):938–953. doi: 10.1037/0003-066X.45.8.938
44. Handford C, Davids K, Bennett S, Button C. Skill acquisition in sport: Some applications of an evolving practice ecology. *J Sports Sci*. 1997;15:621-640. doi: 10.1080/026404197367056
45. Davids K, Kingsbury D, Bennett S, Handford C. Information-movement coupling: Implications for the organization of research and practice during acquisition of self-paced extrinsic timing skills. *J Sports Sci*. 2001;19(2):117-127. doi: 10.1080/026404101300036316
46. Davids K, Handford C, Williams M. The natural physical alternative to cognitive theories of motor behaviour: An invitation for interdisciplinary research in sports science? *J Sports Sci.* 1994;12(6):495-528. doi: 10.1080/02640419408732202
47. Pinder RA, Davids K, Renshaw I, Araújo D. Manipulating informational constraints shapes movement reorganization in interceptive actions. *Atten Percept Psychophys*. 2011;73(4):1242-54. doi: 10.3758/s13414-011-0102-1
48. Davids K, Araújo D. Innate Talent in Sport: Beware of an organismic asymmetry – comment on Baker & Wattie. *Curr Sports Med Rep*. 2019;4:102. doi: 10.15203/CISS_2019.102
49. Newell KM, Vaillancourt DE. Dimensional change in motor learning. *Hum Mov Sci*. 2001;20(4-5): 695-715. doi: 10.1016/S0167-9457(01)00073-2
50. Rietveld E, Kiverstein J. A rich landscape of affordances. *Ecol psychol*. 2014;26(4):325-352. doi: 10.1080/10407413.2014.958035
51. Girard O, Eicher F, Fourchet F, Micallef JP, Millet GP. Effects of the playing surface on plantar pressures and potential injuries in tennis. *Br J Sports Med*. 2007;41(11):733-738. doi: 10.1136/bjsm.2007.036707

52. Crowther RH, Gorman AD, Spratford WA, Sayers MG, Kountouris A. Ecological dynamics of spin bowling in test match cricket: A longitudinal analysis of delivery speed between Australia and India. *Int J Sports Sci Coach*. 2018;3(6):1048-1056. doi: 10.1177%2F1747954118761202
53. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. *Psychol Sport Exerc*. 2006;7(6):653-676. doi: 10.1016/j.psychsport.2006.07.002
54. O'Sullivan MO, Vaughan J, Rumbold JL, Davids K. The Learning in Development Research Framework for sports organizations. *Sport Educ Soc*. 2021;1-15. doi: 10.1080/13573322.2021.1966618
55. Gibson EJ, Pick AD. *An ecological approach to perceptual learning and development*. Oxford University Press. 2000.
56. Gibson EJ, Spelke ES. The development of perception. *Handbook of child psychology*. 1983;3:1-76.
57. Jacobs DM, Michaels CF. On the apparent paradox of learning and realism. *Ecol Psychol*. 2002;14(3):127-139. doi: 10.1207/S15326969ECO1403_2
58. Davids K, Araújo D, Seifert L, Orth D. Expert performance in sport: An ecological dynamics perspective. In Baker J, Farrow D. editors. *Routledge handbook of sport expertise*. London: Routledge. 2015. p. 130-144.
59. Miller M, Kiverstein J, Rietveld E. The Predictive Dynamics of Happiness and Well-Being. *Emotion Revi*. 2022;14(1):15-30. doi: 10.1177/17540739211063851.
60. Guerin S, Kunkle D. Emergence of constraint in self-organizing systems. *Nonlinear Dynamics Psychol Life Sci*. 2004;8(2):131-146.
61. Edelman GM, Gally JA. Degeneracy and complexity in biological systems. *Proc Natl Acad Sci*. 2001;98(24):13763-13768. doi: 10.1073/pnas.231499798
62. Woods C, Davids K. Thinking through making and doing: Sport science as an art of inquiry. *Sport Educ Soc*. 2022. doi: 10.1080/13573322.2022.2054792
63. Otte FW, Davids K, Millar SK, Klatt S. Understanding how athletes learn: Integrating skill training concepts, theory and practice from an ecological perspective. *Applied Coach Res J*. 2021;7:22-32.
64. Rudd JR, Pesce C, Strafford BW, Davids K. Physical literacy-a journey of individual enrichment: an ecological dynamics rationale for enhancing performance and physical activity in all. *Front Psychol*. 2020;11:1904. doi: 10.3389/fpsyg.2020.01904
65. Hacques G, Komar J, Dicks M, Seifert L. Exploring to learn and learning to explore. *Psychol Res*. 2021;85:1367-1379. doi: 10.3390/ijerph19052753
66. Crowther RH, Gorman AD, Renshaw I, Spratford WA, Sayers MG. Exploration evoked by the environment is balanced by the need to perform in cricket spin bowling. *Psychol Sport Exerc*. 2021;57:102036. doi: 10.1016/j.psychsport.2021.102036
67. Bernstein NA. Dexterity and its development.ML Latash, MT Turvey (editors). *Motor development in children: Aspects of coordination and control*. New Jersey: Lawrence Erlbaum Associates, Inc. 1996. p. 341-360.

68. Davids K, Button C, Bennett S. *Dynamics of skill acquisition: A constraints-led approach*. Human Kinetics. 2008.
69. Seifert L, Wattebled L, L'Hermette M, Bideault G, Herault R, Davids K. Skill transfer, affordances and dexterity in different climbing environments. *Hum Mov Sci*. 2013;32:1339-1352. doi: 10.1016/j.humov.2013.06.006
70. Araújo D, Davids K, Renshaw I. Cognition, emotion and action in sport: An ecological dynamics perspective. *Handbook of Sport Psychology*. 2020. p. 535-555.
71. Juarrero A. Complex dynamical systems and the problems of identity. *Emerg: Complex Organ.* 2002;4(1):94-104. doi: 10.1080/15213250.2002.9687738
72. Pacheco MM, Newell KM. Transfer as a function of exploration and stabilization in original practice. *Hum Mov Sci*. 2015;44:258-269. https://doi.org/10.1016/j.humov.2015.09.009
73. Kirlik A. *Requirements for psychological models to support design: Toward ecological task analysis*. *CRC Press*, 2018. P. 68-120.
74. Morris EC, Otte FW, Rothwell M, Davids K. ‘Embracing turbulent waters’: Enhancing athlete self-regulation using the ‘PoST’framework for performance preparation at the 2020 Tokyo Olympic Games. *Asian J Sport Exer Psychol*. 2022;2(1):8-17. doi: 10.1016/j.ajsep.2022.03.001

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