An ecological dynamics approach to motor learning in practice: reframing the learning and performing relationship in high performance sport

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An ecological dynamics approach to motor learning in practice: Reframing the learning and performing relationship in high performance sport

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ABSTRACT

For practitioners working in high performance sport, the primary goal is to ensure that precious preparation time is utilised efficiently, effectively and resourcefully to provide maximal impact on the performance potential of the individual or team. To achieve this goal, there is a need to treat athlete learning and development as an integral part of performing with a key focus on increasingly aligning the *relation between the perfomer(s) and their environment*, which may differ according to practice and performance (Button et al., 2020b). This article critiqued the weaknesses and limitations of traditional learning approaches in sport, seeking to highlight instead the value of adopting a contemporary ecological dynamics perspective, informing how practitioners should design practice to support a greater connectivity between the contexts of performance and learning.

Introduction

Whilst theories of skill acquisition have contemporized in the last 40 years, pedagogical approaches to skill learning have largely remained unchanged. Essentially, the key findings from contemporary research programmes on motor learning, skill adaptation and talent development, exemplified by an ecological dynamics rationale, are failing to deeply influence pedagogical practice in some high performance sports organisations. There is a path dependence, an ideological inertia, shielding the inherited beliefs about how skill is understood and 'acquired' (Kiely, 2018; McWorther, 2011). Path dependency implies that 'traditional' approaches remain challenging to change and can be very 'sticky'. Contributing to this lack of knowledge, transfer and mobilization (the act of moving contemporary research into the hands of research users; see Gainforth, Latimer-Cheung, Athanasopoulos, Moore, and Ginis (2014) is sometimes limited by failure to implement adequate educational and training programmes to provide practitioners with the knowledge, expertise and skills to successfully implement contemporary ideas in skill learning (Chow et al., 2021).

A key to helping change coaching behaviour is education. Specifically, in our opinion, there is a need to reframe learning through an ecological dynamics lens to consider motor learning as an improved *fitness* of the individual's functionality in the performance environment (Gibson, 1979), rather than something that internalises within an individual (Schmidt, 1982). In this paper our goal is to describe how current *sticky*, traditional pedagogical approaches, originating in the models of Fitts & Posner (1967) and Schmidt (1975), and based on laboratory experiments of Martenuik (1976) and Stelmach (2014), Whiting (1975), may be limiting learning experiences in sport. This may be due to a continued reliance of sports pedagogy on such outdated models of learning and the learning process that see learning and performing as separate *sequential* events and fail to acknowledge that learning is an essential part of performing. We discuss how adopting an ecological dynamics approach to practice design reframes learning and performing as symbiotic processes. This perspective, framed by interconnectivity of complexity of systems, changes how we think about the processes of learning and performance, and ultimately how we design practices at all levels of skill and expertise. We conclude by illustrating how practitioners can work together with academic researchers by providing three exemplars from skill acquisition specialists embedded in high performance sports organisations, who have implemented an ecological dynamics framework for practice designs in beach volleyball, cricket and long jumping.

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Traditional views of skill learning: some deep-seated problems

Despite over 40 years of research by motor control scientists and attempts to update cognitive approaches through embodiment and embeddedness (Cappuccio, 2019), when it comes to enhancing skill in learners, coaches over the past decades continue to focus on stabilising internalised models of 'sport techniques' so that they are: (a) repeatable and 'automatic', and (b), hold up 'under the stress and pressure' of competition (Moy, Renshaw, & Davids, 2014; Whiting, 1975; Kiely, 2017; McWorter; 2017; Toner & Moran, 2021). To achieve this goal, coaches devise drills that are often isolated and reductionist (far removed from the performance environment) with the belief that the rate of 'skill learning' is suppressed under competitive pressures which may distract attention and narrow memorising (Rose & Christina, 2006; Schmidt, 1982; Whiting, 1975). Hence, traditional methods of skill learning have overemphasised repetitive rehearsal and 'rote learning' of movement techniques, based on the key belief that, only once a movement skill is relatively stable and programmed in the mind, will it become resilient to the stress of dynamic performance environments. Whilst this approach has been an established view in traditional motor learning theory and has become an essential feature of traditional coaching practice, its efficacy is questionable in terms of supporting the overarching goal of improving performance in dynamic environments where functional solutions are predicated on adapting to interacting individual, environmental and task constraints (Headrick et al., 2012; Maloney, Renshaw, Greenwood, & Farrow, 2022; Orth, Davids, Araújo, Renshaw, & Passos, 2014; Oudejans & Pijpers, 2009). However, because skill learning was viewed purely as an internal 'process', the term 'skill acquisition' denoted some property of that an individual gains (i.e., the body is said to "possess" a set of skills, perhaps constituted as a network entity (Baggs, Raja, & Anderson, 2020, p95). Essentially, motor control and learning specialists tended to view learning as a separate process that precedes performing. Therefore, they tended to spend more energy on identifying the key learning variables that result in changes in the neural mechanisms that they believed underpinned more skilled motor behaviour at the expense of improving the designs of practice tasks. A consequence of this is a tendency for practitioners to bandy around the term 'muscle memory' to refer to deeply internalised rehearsal effects of practice, despite there being no such muscular property in existence.

Indeed, this traditional approach has led to a 'disconnect' between motor learning theory and sport pedagogy for some researchers (e.g., see Ulrich & Reeve, 2005). Practice task design was not seen as part of the explanatory responsibility of motor behaviour specialists, but sat with pedagogists and educators. In fact, the 'silo approach' to motor development, motor learning and control specialists has framed the way learning has been understood with little attention paid to the role of 'non-learning variables' such as growth, maturation and personal development (Fitts & Posner, 1967; Schmidt, 1982). This attempt to separate motor learning and motor development has led to needless effort on and confusing messages about defining which skills emerge 'naturally' through 'normal' motor development and which need to be practiced or 'acquired' (Newell & van Emmerik, 1990). An alternate and more contemporary viewpoint was expressed by the eminent motor development scientist, Karen Adolph (2019) who described the process as one of 'learning IN development'. Some pedagogues have adopted this idea to underpin their work and have demonstrated how this concept can be applied to inform talent development programmes in junior football (O'Sullivan et al., 2021b).

A further challenge for practitioners attempting to understand how learning and performing sit together is that 'performance' variables such as fatigue, motivation or competitive stress were also seen as completely unrelated to learning (Schmidt, 1982). We propose that these dichotomous approaches to motor performance and learning are long past their 'sell by' date. We posit that the time has come for an integrated approach which acknowledges that learning is an ongoing dynamic process. Here, the acquisition of coordination is perceived as a process of learning to satisfy the dynamically interacting constraints of a performance context at any moment in time, whether during practice or competition. During learning and performance development, given the continually evolving state of the individual throughout the life span and the resultant changes in developmental constraints, the motor system degrees of freedom (DoF) (i.e., the number of separate independent dimensions of movement in a system that must be controlled) are continuously reorganised to satisfy individual intentions, needs and different contexts encountered (Newell, 1986; Thelen, 1995). This perspective entails understanding coordination of parts of the body as a complex, integrated system, where the joints, muscles and limb segments of the body (i.e., the DoFs) concurrently and continuously (re)-organise as a function of learning based on interactions between specific task, environmental or personal constraints (Chow, Davids, Button, & Renshaw, 2021). There are numerous research studies (see Chow et al., 2021) in a wide range of sports that have shown how changes in constraints lead to re-organisation as individuals search for movement solutions that are functional (i.e., they work). Research examples in sports include, but are not limited to, kicking a soccer ball (Chow, Davids, Button, & Koh, 2008); basketball shooting (Rein et al., 2010), ice-climbing (Seifert et al., 2014), springboard diving (Barris, Davids, & Farrow, 2013), aquatic skills in children (Button, Button, Jackson, Cotter, & Maraj, 2020) and baseball hitting (Gray, 2020). Before we consider these new ideas, let us go back and look at why, what Kirk (2010) describes as the 'sport-technique drill' approach, remains ubiquitous in sports coaching and a persistent worldwide phenomena (Casey & Kirk, 2020), in physical education teaching.

Drills as a staple of form learning in high performance sports: the case against

When the goal of a practitioner is to build an internalised model of a movement in a motor program or schema to ensure automaticity, and repetitive consistency and persistence in skill performance (Magill & Anderson, 2017), learning is typically initially framed around technique drills that allow sub-components of the task to be decomposed for practice, acquired separately, before being put back together. Drills have come in for considerable criticism from those who advocate for more contextual practice (e.g., advocates for games based and constraints-led approaches). The problem is that drills decompose tasks and fail to provide the key information that is present in performance settings (Chow et al., 2021; Rudd et al., 2021). For example, the tendency to emphasis learning methods to 'automatise' movement in practice was criticised long ago by Nikolai Bernstein (1967). Back in the 1930s, he bitterly opposed traditional pedagogical practice, dominated by traditional, hierarchical models of the learner-practitioner relationship, typically captured by a neuro-mechanical perspective of learning with a focus on futile attempts to reproduce an idealised movement. Bernstein (1967, p. 234) acknowledged that 'mechanical repetition by rote' was a 'discredited' theory, almost 100 years ago. Instead, Bernstein favoured an approach where learners should be challenged to repeat the process of solving the same performance problem through varying practice conditions; a process he described as 'repetition without repetition' as opposed to repetition after repetition (Renshaw, Davids, Newcombe, & Roberts, 2019).

One reason for the 'stickiness' of such a discredited theory is that traditional and hierarchical models tend to place the sports pedagogue at the heart of an instructional process, as a kind of 'drill master'. This process subjects the learner to a continuous onslaught of verbal descriptive information for automatising a technique, abetted by prescriptive, sequential, corrective feedback for continued reproduction and compliance (Partington & Cushion 2013; Connor, Larkin & Williams, 2018). The perceived value of decomposed drills is further brought into question, when one considers another seminal insight of Bernstein (1967), that movement organisation is 'function specific', not 'muscle specific'. The latter was a dominant idea in neuroanatomically-dominated Russian physical education theory for many years. The 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 ecological message from interpreting Bernstein's insights on practice is that *context is everything* in designing relevant tasks that challenge the skills of a learner. This insight reveals some major issues with use of de-contextualised drills in sports coaching.

The potential problem of over-using drills was even highlighted by Schmidt (1982), whose significant theoretical contribution has been the proposition of generalised motor programs and schema theory. In fact, Schmidt spends a considerable amount of time in his work explaining how learning and performing are separate events and that factors that can disrupt learning (i.e., performance variables such as competition, fatigue) should be identified and removed from 'learning' activities. However, as we highlighted earlier, athletes have no option in learning to perform when such variables are inherent in competition settings (Araújo et al., 2022), In fact, Schmidt, (perhaps inadvertently) highlights the problem of this asymmetric approach in a different section of his 1982 book when discussing transfer:

In many learning situations, the task actually practiced in a session is not the activity of primary interest, the real concern being for some other task *related* to this activity (our italics) (Schmidt, 1982, p.513).

Schmidt goes onto explain that the practitioner who sets the drill is typically not interested in how the learner performs in these drills, but is interested to ascertain that the activity of performing the drill will have a positive impact on automatising a targeted behaviour, which he suggests could be performance in a game. This makes perfect sense and would seem to be an efficacious strategy. However, as Schmidt then goes on to describe, designing successful drills is challenging and predicated on an unknown. That is, the "certainty that experience on the drill transfers to some criterion task (p.513)". He explains how challenging ensuring 'certainty' is for practitioners, when he made the critical observation:

One point that consistently emerges [in discussions about transfer] is that motor transfer is generally low unless two tasks are so similar as to be practically identical" (p513).

T*ransfer of training* (Issurin, 2013) is an old concept in motor learning and, as highlighted by Schmidt, is a key consideration when attempting to design functional practice tasks which faithfully simulate competitive performance environments in sport. The specific effects of a practice task on athletic performance are predicated on levels of task similarity (Barnett & Ceci, 2002). Their description of transfer considered the 'proximity' between tasks of the practice and performance environments, operationalised as 'near' (more similar) and 'far' (less similar). In ecological dynamics, near and far practice tasks can be considered in terms of how 'representative' the observed interactions of the individual and the environment are to those seen in the performance setting (Pinder, Davids, Renshaw, & Araújo, 2011a). This idea is captured by the congruence of 'action fidelity' observed in the two environments. Stoffregen, Bardy, Smart, and Pagulayan (2003, p. 120) described action fidelity as the "fidelity of performance" and proposed that fidelity exists when there is a transfer of performance from the 'simulator' (i.e. practice) to the 'simulated' system (i.e. performance). Fidelity can, therefore, be assessed by comparing how closely a performer's responses (e.g., actions or decisions) match those required in performance environment. Movement scientists could work with practitioners to assess action fidelity of simulated training, practice, and learning environments (Araújo, Davids, & Hristovski, 2006) by using objective measures such as time taken to complete a task and observed kinematic (coordination) data during performance. In the absence of scientific support, recently, Renshaw et al. (2019) suggested a simpler method for practitioners could be that they should ask themselves "does it (practice) look and feel like the real thing (the competition)?" With respect to near and far transfer, from an ecological dynamics perspective, it could be argued that, if a practice task is high in action fidelity, this would constitute near transfer (e.g., playing tennis against an opponent on a narrow court). On the other hand, if action fidelity is very low, it could be described as retaining far transfer (e.g., batting against a bowling machine (Pinder et al., 2011b).

To summarise so far, we suggest that the challenge of determining how effective practice tasks are likely to be in improving performance, is a problem for all pedagogues and not just those whose staple approach to practice is the focus on automatising a movement technique by building a motor program or schema through isolated drills. To explain, we next illustrate how poorly-considered practice tasks, irrespective of the pedagogical approach adopted, can result in limited transfer or even worse, negative transfer (a practice task has a detrimental impact on future performance). We will first discuss drills, before considering modified small-sided games as well as constraint-led approaches. First, we explore a typical drill ubiquitous to a traditional approach based on task decomposition; unopposed shooting in basketball. Next, we consider 'numerically uneven' small sided games, using soccer as our task vehicle (e.g., 6v4, 5v4, 4 v 3). Finally, we consider the efficacy of adding artificial task constraints such as non-representative rule changes (more points for scoring in specific playing areas) or removal of critical information that drives intentions and behaviours (e.g., keeping the score).

Limitations of unopposed practices in basketball shooting practice

The most important skill in basketball, shooting, has attracted significant interest from movement scientists in attempts to discover the optimal techniques and consequently the best ways to practice. However, evidence suggests that, in elite level basketball, this research has had little impact on practitioners as significant time is spent practising shooting using static blocked practice with an absence of defenders. The main goal is perfecting shooting technique through automaticity. Hand in hand with this type of practice are attempts to achieve putative 'correct movement form' with a focus on essential, 'non-negotiable' features of body orientation in shooting, such as the 'correct' stance, ball release height and hand positions on the ball. In contrast, research and performance analysis shows that shooting actions vary, dependant on individual constraints such as fatigue, body dimensions, strength, task constraints such as the preceding actions of the shooter (dribbling, faking, receiving a ball in a stationary position), the type of shot (jump or no jump, hook, standard, lay-up), body orientation in space and the distance of the shot from the basket, as well as the availability of visual information (i.e., the view of the basket) (França, Gomes, Gouveia, & Ihle, 2021). Additionally, so called 'non-negotiable' technique factors such as foot placement (if the feet are square to the basket or if one foot is advanced of the other) that are purported to underpin shooting performance have been shown to have no impact on shooting success (Williams, Webster, Spaniol, Bonnette, & Williams, 2016). A further limitation of unopposed shooting practice is that it might be expected that the presence of a defender would change the technical performance as the shooter also attempts to prevent interception of the ball. Evidence from empirical research supports such a prediction (Maloney & Gorman, 2016; Rojas, Cepero, Ona, & Gutierrez, 2000). A final consideration for practice is that task constraints enforce skill adaptations. In basketball, the 3-point rule has changed skill performance. Research shows that players who typically shoot from longer distances have adapted their techniques to account for such distances (Williams et al., 2016). A similar finding was found in field hockey, where hitting actions were shaped by the position played (Brétigny, Leroy, Button, Chollet, & Seifert, 2011), whilst actions used to dribble a soccer ball down field differs according to the absence, presence and proximity of a defender (Orth et al., 2014).

Returning to our basketball example, although basketball literature commonly promotes the use of similar shooting mechanics amongst all players, it would appear that, given the findings above, individuals' actions are shaped by the available affordances (invitations) of performance environments (Chow et al., 2021). This theoretical insight makes it essential to practice in dynamic contexts that are representative of performance settings for functional skill development.

Limitations of small-sided games as a practice method

Small-sided games (SSGS) have become a staple part of practice designs in many invasion team sports. They are sometimes used irrespective of the theoretical model underpinning session design, as they are considered to allow coaches to reproduce the physical, technical and tactical requirements of competitive match play (Aguiar, Botelho, Lago, Maças, & Sampaio, 2012). Typically, coaches manipulate variables such as the dimensions of practice areas (e.g., field width and length), practice game intentions and rules and, perhaps most frequently, player numbers (Sarmento et al., 2018). Whilst the majority of research has focussed on how SSGS can be used to develop players' conditioning (Alves et al., 2018), some studies have begun to focus on how manipulations in SSGS can be used by coaches to enhance tactical play (Aguiar et al., 2012; Coito, Davids, Folgado, Bento, & Travassos, 2020). An important requirement of SSGS designed to improve tactical ability, is that they need to invite players to perceive and act as individuals and to coordinate inter-personal interactions in similar ways that they would in matches (Vilar, Duarte, Silva, Chow, & Davids, 2014). An important consideration when designing SSGS is, therefore, understanding that attackers and defenders will co-adapt their continuous interactions in an attempt to achieve their intended goals (i.e., score or prevent scoring). Clearly, the benefits that arise from practice for players are highly dependant on the design of specific SSGS, with a need to carefully evaluate the impact of rule changes, such as creating uneven teams in attempts to work on factors such as passing.

One of the most common forms of SSGS, especially with younger players is the use of numerically unbalanced teams. The general idea is that giving a team numerical superiority will make it easier for attacking players to achieve the key principles of play, including: (i) keeping possession of the ball, and (ii), making penetrative passes that progress the ball towards the goal (Práxedes, Pizarro, Travassos, Domínguez, & Moreno, 2021; Wade, 1968). Logically, having an extra player or two ought to make it easier to make passes and penetrate defences; however, studies (e.g., Sarmento et al., 2018; Práxedes et al., 2021; Vilar et al., 2014) have revealed that the impact of uneven teams on performance was more nuanced with some unexpected consequences. These findings highlight that coaches need to tailor their use of the task constraint of numerical imbalances to the specific context in which they are working.

To explain, whilst the expectation of greater passing and shooting success was generally achieved in uneven SSGS, there were a number of significant caveats to urge caution about when to best use numerical imbalances. For example, when defences are deprived of a player, it led to the emergence of new defensive patterns to try and counteract the numerical advantage of the attackers. Essentially, defenders retreated deeper to defend their own goal (Sarmento et al., 2018; Vilar et al., 2014). This defensive format afforded 'safer' passing (in front of defenders by the attackers) as the inter-personal distances between defenders and attackers was reduced. But it made forward penetrative passing by the team with numerical deficits more difficult as the gaps between opposing players were much smaller.

An interesting question for coaches is how beneficial is it to play uneven SSGS prior to playing even number games. To find out, Práxedes et al. (2021) asked 4 teams of U-14 players to play two different sequences of SSGS (1): (NS (5 v 4) + NE (5 v 5) and (2); NE (5 v 5) + NE (5 v 5) using two different conditions to achieve game principles of keeping possession and progressing (the ball) to the goal. Performance was judged in terms of duration of ball possession and the number of ball touches made. Results highlighted that irrespective of order, when playing NS games significantly higher values were observed. However, playing a NE game after an NS game led to a tendency to decrease offensive play. Overall though, in the final two situations there were minimal differences found. The authors concluded that when players were at the formative stage, uneven number games should be utilised to enhance the learning of technical skills via greater number of ball contacts and longer ball possession sequences. However, as players improve continuing uneven games could delay tactical adaptation to real game scenarios and they should play equal numbered SSGS (Praxedes et al. 2021).

To that end, one final question is worth considering: Given that games are won by scoring goals, would coaches be better off designing games that helped players' develop the ability to split defences with penetrative passes? Indeed, this assumption was supported by a recent study of 103 German First division games by Rein, Raab, & Memmert (2017) who measured the effectiveness of a pass. They observed (perhaps unsurprisingly) that passes that penetrated defences or promoted space control in front of the opposition goal significantly related to the number of goals scored and the probability of winning a game.

In summary, overall, the empirical evidence suggests that playing SSGS is a much better way to practice than isolated drills to enhance player's technical skills in dynamic, variable game contexts. Further, with respect to SSGS with uneven numbers involved, they may be most useful with more novice players in order to improve their technical skills as it affords them the opportunity to make more ball touches and increase the time length of ball possessions (in teams with greater numbers). However, the majority of these passes are relatively 'harmless' to the defence and are perhaps only useful in the context of games where a team may be in the lead with a short time left and want to 'run the clock' down by keeping possession. In contrast, if the coach wants to work on helping players make more penetrative passes, then uneven teams is not the answer. In these contexts, more innovative strategies may be needed to provide affordances to invite forward pass that increases the chances of scoring a goal.

Limitations of constraints-led approaches to practice design

In the previous examples, we discussed how drills and small-sided games are often used as *part* of the typical practice session design. However, some practitioners have begun to use a Constraints-Led Approach to underpin the design of the *total* session. However, this does not insulate them from adding in constraints that can either over-constrain actions or lead to the emergence of new behaviours or to promote team play that is not representative of performance needed in competitive games. Which constraints to design-in, is an extremely important part of sports pedagogy that needs very careful consideration by coaches and trainers. A good example in team games practice is when rugby coaches allocate more points for scoring points in wide areas in an attempt to promote greater passing and width in attack. The thinking behind this constraint manipulation is to encourage players to move the ball wide to exploit space 'around' the defence. A key problem with this approach is that because defenders know that there is more value in scoring out wide, they will co-adapt their movement behaviours to deal with this new rule, with the likelihood that they would change their positioning to defend the wide areas at the expense of central areas. Now the space becomes available between defenders, not 'outside' them. However, the attackers are now being strongly invited (by the adapted rules) to attack highly defended areas, with the high likelihood of failure because of the defenders' heightened awareness and attention to protect the wide areas. However, once again, in a similar way to the use of uneven teams, the value of this practice task is potentially being limited by 'over constraining' methods and it is likely to result in defenders acting in a different way than they need to, under the much more uncertain conditions in the competitive environment. Of course we should note that in this example the attacking team is not 'forced' to attack wide and may choose to keep the scoreboard ticking over by taking the 'easier' opportunities in the centre of the field. So, given the *stickiness* of the types of practice discussed here, we need to change coaches' thinking by introducing new ideas about skill. We start by considering what skill actually is.

Reframing skill

The first step in changing thinking about the relationship between learning (in practice) and performance environments is to reframe skill as a *process* (not an outcome) that is concerned with continually improving the fit between an individual and the environment in the pursuit of a goal-directed action (Gibson, 1979). In that respect, individuals with high rates of success in achieving their desired goals are characterized as being 'well-adapted' or 'fit' to their environmental niche (Shaw & Kinsella-Shaw, 1988). Hence, rather than the internal 'acquisition' of a movement technique or skill internalised in the brain of the individual, an ecological dynamics approach frames skill as 'skill adaptability' or 'skill attunement" to the environment (Araújo & Davids, 2011). When we consider skill from this perspective, learning is about perceiving the performance environment in relation to its **meaningfulness for the learner (**i.e., what it affords or offers the performer (Gibson, 1986) in respect of the guiding intentions of the learner). Skilled attunement is, therefore, predicated on each individual's ability to exploit the goal-specific information in the environment by assembling functional co-ordination patterns that are coupled to that information (Shaw & Kinsella-Shaw, 1988). This re-framing of the concept of skill provides practitioners with guidance in terms of what performers need to learn and know and how they can decide to act. This revision of the term skill consequently underpins how coaches need to shape learning environments (Araújo et al., 2006; O'Sullivan, Vaughan et al., 2021a).

What do we mean by learning from this contemporary perspective?

When learning is about adapting to the environment, it is much less concerned with the rote learning of a mechanical movement technique, as Bernstein (1967) highlighted long ago. Rather, learning can be re-defined 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 (Button et al., 2020b, p.141). Building on Newell (1986) three-stage model of learning (co-ordination, control, skill), Button et al. (2020b) provide a three-stage model for understanding learning from an ecolgical dynamics perspective. These authors suggest that practice tasks need to provide learners with the opportunity to educate: (i) their intentions, and (ii), 'attention' through an initial period of *search and exploration, discovery and stabilization*, followed by (iii)*, exploitation* of affordances *by calibrating* actions to *execute* solutions to the problem they have been set (Button et al., 2020b).

Stage one of educating intentions relates to creating a tighter alignment between the task demands and the learner's selection of particular perception-action couplings that are deemed 'fit-for-purpose'. Different intentions will shape how the individual organises their perceptual and action systems differently. For example, if the intention of a long jumper is to make a safe jump, they will run-up at a different speed than if they were seeking a maximal jump (McCosker, Renshaw, Polman, Greenwood, & Davids, 2020). If a tae-kwon do player is ahead on the scoreboard, they will fight differently than if they are behind (Maloney et al., 2022).

When a learner has found the 'best' available solution, the next stage is to discover and stabilize new and better solutions, which means educating attention. As certain perceptions and actions are more beneficial than others in some contexts (Jacobs & Michaels, 2007), the purpose of educating attention is for the learner to become perceptually attuned to the more useful (or specifying) information to be 'picked-up' as opposed to the non-specifying informaton that they may have initially utilised in stage one (Jacobs & Michaels; 2007; Gibson, 1979). Of course, the information that a performer learns to pick-up is task specific.One good example emanates from a basketball study that investigated the decision to drive to the left or right of a defender, when the defender was asked to stand 'square' to the attacker or with one foot leading. The data reveald that irrespective of skill level (novice or intermediate), attackers made affordance-based decsions to drive to the side of the defender's more advanced foot (Esteves, de Oliveira, & Araújo, 2011). The final stage of exploitation via calibration highlights that the performer develops the capability to immediately adapt in the moment by exploiting the perceptual and action degrees of freedom that enables a task goal to be solved in many different ways. For example, this type of skill adaptation exists in: (i) the basketball player who is able to adjust their shot as a defender bumps them when shooting; (ii) a long jumper who subconsciously adjusts the vertical impulse of their steps in the last few steps as they perceive they are going to overshoot the take-off board; and (iii), the highly experienced ice climber who is able to (re)shape their actions through being highly attuned to the information afforded from the properties of holes in the frozen surface (Seifert et al., 2014).

In summary, these stages of learning posit that, once a functional task goal for a performer has been specified in their intentions, then a process of continuous exploration eventually leads to the emergence of a useful solution to the task that satisfies the immediate constraints on the individual. Further practice results in this task solution becoming more refined and leads to a strengthening of the connections between different parts of the body as a functional coordinative pattern. Next, we focus on how the practitioner can facilitate this process.

A constraint-led approach to skill learning

To support this goal, it has been proposed that the design of learning environments can be based on the four environmental design principles identified by Renshaw et al. (2019). These key principles include:

(1) Ensuring learner intentions reflect those needed in performance. And this requires: 2) learning tasks that are highly representative of a performance environment in order to create high levels of transfer in terms of providing opportunities for performers to learn what to do and how to do it in specific contexts. As we highlighted in an earlier section, the degree of action fidelity that is possible in practice is determined by the degree to which specifying affordances and the actions they support are made available in training tasks (Araújo and Davids, 2015); (3) including 'repetitions without repetition' (Bernstein, 1967) that allow exploratory and performatory actions to support the emergence of stable and adaptable movement solutions (Pacheco and Newell, 2015); and (4), Designing-in constraints that invite learners to pick-up and utilise affordances as and when they become available in the performance context.

In the next section, we provide examples from high performance sport to demonstrate how practitioners have designed practice sessions based on the key ideas of ecological dynamics. By adopting the key ideas covered above, we show how learning and performing are two sides of the same coin and involve a combination of exploratory and performatory activities.

Case studies

Case study 1: international volleyball with mike maloney

Aim

The intention of the coaches was to improve the skill of hand setting of a female international beach volleyball player in competition.

Practice design

Our first step was to perform a task analysis to understand the constraints acting on the hand setting skill (Davis & Burton, 1991; Kirlik, 2018). Understanding the demands of the performance task is important to inform the design of representative learning tasks. An experienced coach, the athlete, and a skill acquisition expert sought to co-design the practice context (Woods, Rothwell, Rudd, Robertson, & Davids, 2020) and performed the initial task analysis together. The benefits of this collaboration were many; participants were able to oper-

Table 1
Key constraints and their progressions identified from an ecological task analysis (Davis & Burton, 1991).

Constraint	Progressions		
	Low representativeness	Moderate representativeness	High representativeness
Feed	Coach feed	Easy serve	Competitive serve
Decision making	Decisions on 1 of: 1st touch, 2nd touch, 3rd touch	Decisions on 2 of: 1st touch, 2nd touch, 3rd touch	Decisions on all of: 1st touch, 2nd touch, 3rd touch
Variability	Blocked, within skill or between skill variability	Within skill or Between skill variability	Within skill and between skill variability
Information	1 of: Team mate, opponent, context (time/score)	2 of: Team mate, opponent, context (time/score)	All of: Team mate, opponent, context (time/score)

ate in a space informed by experiential (of experienced coaches and athletes) and empirical (e.g. ecological dynamics) knowledge. A main goal of the task analysis is to identify key constraints that influence task performance. This task analysis identified 4 key constraints (Table 1) acting on the volleyball handset and formed the basis of the plan for our learning intervention. If learning is seen as an adaptation to key performance constraints, or improving the 'fit' between performers and their environment, then it is important that we design representative learning tasks that sample key variables to support athlete performance development.

We then built a skill periodisation plan that was informed by our task analysis and adapted according to the challenge point framework. We began by simplifying and/or decomposing the task so the difficulty level (i.e., the challenge point was appropriate for the athlete. As the skill became more stable, we increased task representativeness by gradually introducing and/or progressing the different constraints. Our final progression was a 'pressure test' where multiple volleyball matches were simulated over the course of a week. At the beginning of our intervention the practice tasks looked quite different to hand setting in competitive performance. However, informed by representative learning design, our intention was to move as quickly as possible away from this. By the mid-point, the tasks looked like sampled 'sub-phases' of the game. By the end, the learning tasks did not look and feel very different to the competitive performance task.

What did you find out about the relationship between learning and performing?

In skill learning interventions, performance and learning are intertwined. 'Learning' tasks provide performance opportunities and 'performance' tasks provide learning opportunities. Throughout, there is a level of performance required for these tasks as we explored what could, or what does work (i.e. the functionality of different solutions). However, the task is scaled so towards the end of the intervention the practice task is virtually the same as the 'performance' task with shared intentions and a learning opportunity to adapt skills to the performance task. Therefore, there is little point in attempting to define tasks as learning or performance as, within the ecological dynamics approach to skill acquisition, performers are considered to be constantly adapting to and improving their fit *with* their performance environment.

Implications for learning and performance

A major challenge for coaches and practitioners is understanding how to design and progress practice tasks that optimise transfer to performance environments. How do you strike a balance between meeting the learners' needs (i.e. setting task difficulty at an appropriate challenge point for the individual) and representative design? Ultimately both considerations need to be met, which is why skill learning interventions require an adaptive and periodised approach that reflect the dynamics of learning (i.e., their phases in terms of ebbs and flows). Understanding the relationship between learning and performance, and how one can support the other, can help practitioners and learners find their way through such interventions.

Ultimately, we practise to get better at performing in competition; and the more learning tasks overlap with performance tasks (i.e., are representative) the more that positive transfer is likely to occur (Snapp-Childs, Wilson, & Bingham, 2015). Due to sporting competitions' unique affective and cognitive constraints, the highest level of skill transfer cannot be guaranteed. However, coaches and practitioners can maximise their time, efforts, and resources and provide learners with the best possible chance at transferring their skills through the way they design and progress practice tasks. If transfer to performance environments is the intention, then ecological dynamics and specifically, representative learning designs can provide a key framework to guide learning task design and progression. In this sense, understanding the demands of the performance task is the first step to designing representative learning tasks that promote transfer to performance environments.

Case study 2: spinning around the world: preparing young spin bowlers for international cricket-Rian crowther

Introduction

In the last 10 years, the odds of the home team in international test match cricket has a win to loss ratio of 1.98, indicating the home team will win almost double the number of they will lose, some of which can be attributed to the pitch playing characteristics (CrickViz Intelligence at the next level). No countries home test match win to loss ratio is higher than that of India's (8.5) .[1] These data highlight the significant advantage of playing in conditions that are very familiar to you (Connor et al., 2021). Environmental constraints such as atmospheric conditions or pitch characteristics are unique to regions and countries and this historical landscape of affordances shape the skill sets young players develop. Current practice approaches are predominantly contextless and take place off the field in 'nets'(in Australia) and result in bowlers reaching international level having little experience of playing on pitch surfaces different to those typically found in their own country. However, they are then expected to be able to transfer acquired spin bowling skills to novel international environments *quickly* in situations where a high demand and expectation is placed on winning performances. Since context is everything in an ecological dynamics rationale for practice design, it can be seen that spin bowlers in Australia are being set up to fail when seeking to adapt current skills to performance in the unique performance conditions of the Indian sub-continent.

Aim

Our aim was to find out if highly skilled cricket spin bowlers were able to adapt their bowling style to a bespoke pitch surface designed to replicate international test match cricket played in India.

Designing the practice environment and task

To answer our question, we built a bespoke pitch that sought to simulate the pace, bounce, and atmospheric variations typical of Indian conditions (i.e., very different to the typical Australian pitch). We then asked the bowlers to play in three short games, first one on a typical

[1] Win odds only compared to test playing nations who have played more than five test matches in home condition in the past 10 years (2012 to 2021)

Australian pitch, followed by two more games under the environmental constraints of the "Indian" pitch.

Bowlers' performance was measured quantitatively to record delivery speed, spin rate and pitching location to understand how action variables were changed as they adapted the way they bowled. They were also interviewed during and post-performance to gain a qualitative understand of what influenced their intentions in each environment.

What did you find out about the relationship between learning and performing?

The bowlers demonstrated an improved fit to the environment through a continuous perception and action cycle where (their) perceptions sampled during their performance were linked with measured action variables (i.e. how they bowled). This analysis demonstrated that they calibrated their bowling actions as they got to 'know of' (Gibson, 1986) the pitch due to a better attunement to its properties. We directly observed adaptations in each player's ability to perform skills in a performance environment. How "relatively permanent" these changes were, is an ongoing issue for future study. In some sports (like rock climbing) *exploratory* and *performatory* movements can be separated (Seifert, Boulanger, Orth, & Davids, 2015), with exploratory movements (exploring by touching a potential hold) preceding performatory (grasping a hold) actions. However, in cricket spin bowling, exploratory and performatory movements occur simultaneously and learning the appropriate balance between the two types of behaviour is a challenge that often emerges in the performance arena.

Exploration is a vital part of the learning process in cricket spin bowling, when performing in both familiar (more task orientated) and unfamiliar environments (more environmental related). In the familiar 'home' conditions, players were able to rely on their previously-practised set of skills they have spent much of their years practising (Crowther, Gorman, Renshaw, Spratford, & Sayers, 2021, 2018). They could, therefore, devote their exploration to the tactics associated with the task. However, in the unfamiliar 'Indian' pitch conditions, players' attention and exploration was directed to the unfamiliar environmental constraint (pitch), as they explored different ball delivery characteristics that could be used to exploit affordances of the environment. Ultimately, spin bowlers had to balance the need to explore the affordances of the pitch to enable them to exploit them (later), while at the same time, 'competing' in the moment (Crowther et al., 2021).

What are the implications for learning and performance?

Players typically practice in a netted environment that is not representative of the performance environment and played one or two practice games prior to their first away test match series; recent history would suggest this method is flawed (Australia has not won a test series in India since 2004). In cricket, **these** typical non-representative learning environments allow vast amounts of exploration to take place; however, they generally lack consequences for the bowlers (Pinder et al., 2011a). As such, building purpose and consequence into learning tasks through adopting the principles of representative learning design can invite players to find the appropriate balance between performing and exploring. We posit that this can only be truly learnt in competition. Designing representative learning tasks in the practice environment should, of course, encourage additional *representative* transfer to the performance environment. However, nothing can replace a lifetime of attuning to different representative performance context in the competition arena where players' performance is truly tested, evaluated and assessed. However, if high performance coaches design representative practice environments such as the one described previously, young players will be given the best chance to develop the capability to manage the essential ability to learn to attune and exploit the affordance of the environment such as pitches while at the same time, staying in the contest.

Case study 3: international long jumping - Chris McCosker

Introduction

Long jump performance has largely been understood from traditional motor control and biomechanical investigations (e.g., Bridgett & Linthorne, 2006; Glize & Laurent, 1997; Hay, 1993; Montagne, Glize, Cornus, Quaine, & Laurent, 2000) which largely fail to recognise the complex nature of the performance environment and its impact on performance. As such, there has been a tendency for coaches to direct their attention at training to making 'critical' parts of a performance repeatable, often with no recognition of the value of key constraints that may impact performance during competition (e.g., Brown, 2013; Fischer, 2015). This lack of understanding of the complexities of performance movements and how interacting task, individual and environmental constraints impact performance, potentially limits the effectiveness of learning in training environments as the coupling of information to movement is specific to the unique interaction of constraints that shape each performance (Savelsbergh & van der Kamp, 2000).

Aim

To identify the competitive behaviours and key constraints shaping long jump performance to allow for a more nuanced understanding of long jump and the more effective design of practice environments where learning and performance should not be viewed as separate entities.

Study design

Using qualitative and quantitative techniques, athlete behaviours in competition environments were investigated. Firstly, a statistical analysis of 108 elite level long jump competitions, including Olympic Games, World Championships and Diamond Leagues, revealed that performance in both male and female long jumping was influenced by the rules of the sport (foot behind take-off line to register a legal jump), an athletes' strategic intentions (i.e., jump for maximal distance) and the wind (McCosker, Renshaw, Greenwood, Davids, & Gosden, 2019). Further to this, the experiential knowledge of elite level long jump coaches revealed that athletes were required to navigate three performance contexts – *perform, respond and manage* – whilst attempting to achieve key performance goals (McCosker et al., 2019). Importantly, these performance goals were observed to vary between rounds depending on the needs of the competition and each performer's capabilities. Common to both of these initial investigations, was the difficultly associated with adequately meeting the critical accuracy demands of the sport (i.e., placing the take-off foot behind the take-off line in order for a jump to be measured) and how this key constraint further influenced intentions, emotions and cognitions of athletes. Analysis of footfall data on approach to the take-off board during national level long jump competitions revealed different movement behaviours emerging during legal and foul jumps in addition to each individual having their own movement solutions that varied between jumps (McCosker et al., 2020, 2021).

What did you find out about the relationship between learning and performing?

Investigations revealed the adaptive nature of movement patterns as constraints changed across each performance trial and each competition. With evidence suggesting that performance is less about repeating a 'text-book' technique and more about finding solutions that work to meet the demands of the competition, more traditional ideals on the separation of learning and performing must be questioned. Further, since different movement patterns emerged when comparing legal and foul jumps for each participant, it could be suggested that during these foul jumps, athletes were unable to calibrate their actions to the emerging constraints of the environment at that point in time. These findings provide evidence that performance in competition environments requires athletes to learn to adapt to the conditions of the competition whilst still meeting their own performance goals. This is important and provides support to the conceptualisation that athletes must learn to *perform, respond and manage* within performance environments (McCosker et al., 2019).

What are the implications for learning and performance?

Findings reveal important implications for practice design, where finding a better connection between learning and performance should be emphasised. Rather than searching for a repeatable technique in training often performed with no context and with limited information from the competition environment, practice tasks can be designed that provide opportunities for athletes to learn to adapt movement solutions to changing information from the competition environment whilst still requiring them to meet performance goals. This could be achieved by requiring athletes to *perform, respond or manage* to co-designed performance contexts in training allowing athletes to self-regulate and adapt to changing task constraints (McCosker et al., 2019b). For example, through creation of competition specific 'vignettes' (Headrick, Renshaw, Davids, Pinder, & Araújo, 2015) an athlete may be required to *perform* during Round 1 of a Three Round practice competition. In such a scenario, the athlete will be provided with the opportunity to learn to self-regulate actions, emotions and cognitions in response to fluctuations in wind conditions, the performances of other athletes (i.e., training partner or virtual scoreboard) and to meet the accuracy demands of the sport whilst attempting to jump a pre-determined jump distance. The implementation of such strategically designed training environments highlights the importance of recognising the connectedness between learning and performance and enhancing the fit between the individual and the environment and the development of movement solutions that are adaptable and meet the dynamic nature of competition environments.

Summary

To overcome the *stickiness* of traditional approaches to skill learning, we propose that, in order to reframe the relationship of learning and performing, we need to consider the concept of skill in a new way, one where skilled regulation of action is actually distributed over the person-environment system (Gibson, 1979). Here, we have argued that we need to move away from the separation of learning and performing in a cyclical fashion to a more integrative approach where learning environments are designed based on a much more careful and detailed sampling of the performance environment in order to contextualise learning. In this paper, we have shown why it is no longer acceptable to merely repeat and rehearse a movement technique in isolated drills that lack meaning, value and context. This approach to practice and performance preparation, which is central to an ecological dynamics approach to skill acquisition, enables the process of learning to lead to the emergence of highly functional perception-action couplings in athletes. Essentially, we have re-iterated how (far) transfer from practice to performance will be much stronger by adopting the ideas of representative learning design, where key information sources, essential to the way individuals play/perform in games and competitions, is 'designed-in' to practice tasks.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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