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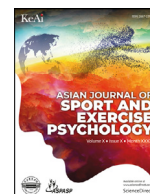
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Developing a skill acquisition framework for youth sport in Singapore

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ABSTRACT

Skill acquisition research has great potential to inform coaching practices and can impact skill development, especially at the youth developmental stage. However, it is not always easy for coaches to envision how research findings can be applied on the ground. The Skill Acquisition Framework for youth sport in Singapore is aimed at providing an easy to understand evidence-based resource for coaches on the topic of skill acquisition. The framework consists of 3 dimensions (i.e., *Desirable characteristics of youth athletes*, *Key Concepts* and *Key Design Principles*). Each of these dimensions will enable coaches to reflect on their current practices and facilitate discussions in a systematic manner. The first dimension provides coaches with the opportunity to think about the most important characteristics that they want to develop in youth athletes (motivated, adaptable, robust under pressure). The second dimension of the framework introduces *Key Concepts* related to skill acquisition that are crucial for coaches to consider when working with athletes. Finally, the third dimension presents the *Key Design Principles* that can underpin the design of training sessions.

1. Introduction

Are elite athletes born talented or does practice lead to perfection? Is it nature or nurture that plays the predominant role in determining elite status in sport? Sport scientists, coaches and policy makers alike seek the answer to this question in order to improve sporting performance. While there is no definitive answer at this point in time, there has been accruing evidence that supports both the nature and the nurture argument. For instance, studies have shown that genetics can provide us insights into certain physiological characteristics that are associated with different sports (e.g., I allele linked with endurance performance, and the D allele with power/strength/sprint phenotypes; MacArthur & North, 2005). Nevertheless, Rees and colleagues (2016) have cautioned against the use of genetic profiling for talent selection, instead, advising coaches and athletes in their developmental years to use this knowledge to make informed choices about sport type and specific events to pursue.

While we recognize the importance of genetics in shaping the individual, this paper focuses on skill acquisition, which falls on the nurture side of the argument (i.e., specifically how can practice lead to excellence). There is a large body of evidence to suggest that across a variety of different sports, practice is arguably the most important variable to consider when developing expertise in sport (Abernethy, 2001; Chow, 2013; Guadagnoli & Lee, 2004). The field of skill acquisition combines a rich body of knowledge from a variety of fields, includ-

ing motor learning and control, sport psychology, pedagogy and biomechanics, with the overarching aim of translating research into practice. Research has provided insight into the key motor, cognitive, perceptual and psychological factors that explain expertise in sport and subsequently this information has been used to design and examine training approaches that can expedite a learner's transition from novice performer to expert performer (Farrow, Baker & MacMahon, 2013; Hodges & Williams, 2020).

From a sport science perspective, knowledge of skill acquisition serves to advance our theoretical understanding of how individuals learn and what training paradigms are considered most effective for learning in terms of resilience over time and under pressure. From a practical standpoint, it is equally important to translate research into practice. Given that coaches are at the centre of any training session and act as the facilitators of learning, it is vital for them to have access to the latest evidence that is being generated. Interviews with coaches have revealed that limited access to sport science related information, the overuse of academic jargon and lack of perceived relevance to practice limit the utilisation of sport science information by coaches (Martindale & Nash, 2013; Reade, Rodgers & Hall, 2008; Waters, Phillips, Panchuk & Dawson, 2019).

Even though coaches see value in gaining novel ideas from sport science research, it can be challenging for them to condense information from complex theories and apply it appropriately to their daily coach-

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ing practices. The Skill Acquisition (SA) framework for youth sport in Singapore has been developed with an aim to present contemporary skill acquisition evidence in a manner that can facilitate its application in practice. The SA framework will provide a simple visual representation of principles and concepts that will help guide coaches in planning, monitoring and evaluating their current coaching practices. It is our aspiration that this framework can be used to spark discussions amongst coaches across sports - courtside or poolside.

1.1. Relevance of the skill acquisition (SA) framework for youth sport in Singapore

Skill acquisition exists as a unique specialisation in countries such as the U.K, Australia and New Zealand. In Australia, for instance, skill acquisition informs coaching practices and programmes across a variety of sports, including football and tennis (Football Federation Australia, 2013; Reid, Crespo, Lay & Berry, 2007; Farrow & Robertson, 2016). In Singapore, recent efforts have been made to introduce evidence-based practices to the coaching community via conferences, workshops and seminars. Through these various touchpoints it is becoming evident that there is a demand from coaches for more information pertaining to skill acquisition. The SA framework was developed to be a constant reference point for coaches of youth athletes, when it comes to skill acquisition knowledge and application. Skill acquisition frameworks have been developed in the realm of high performance sport in countries such as the U.K., Australia and New Zealand but still remain to be explored in an Asian context.

The main objective of developing the SA Framework for youth sport was to provide an evidence-based resource for coaches on the topic of skill acquisition. The framework introduces key concepts from the field and provides examples of how these concepts can be applied in everyday practice. It is also important to note that the framework was created to aid the continued professional development of coaches as well as the long-term development of youth athletes.

2. Methods

The authors of this paper formed a working group to combine their diverse expertise in skill acquisition (i.e., motor learning and control, sport psychology and pedagogy) to develop a framework that introduces coaches to the latest evidence from the domain in an easy to understand format. Thereafter, a scoping report was used to identify the current level of knowledge and the extent of practical application of the fundamental principles of skill acquisition by coaches who primarily work with youth athletes from a variety of different sports, including territorial-invasion sports (i.e., water polo, netball), net-barrier sports (i.e., badminton, table tennis), target sports (i.e., fencing, shooting) and general sports (i.e., swimming, sailing, climbing, athletics). The scoping report revealed the current gaps in knowledge in skill acquisition that exist in the Singapore coaching eco-system. The scoping report was followed by two rounds of focus group discussions (FGD), which were conducted with coaches working with youth athletes in Singapore. The main purpose of the FGDs was to receive input from the coaches on the content and language to be used, primarily because these have been considered by coaches to be the most problematic aspects (Martindale & Nash, 2013). For instance, with regards to the content, coaches were asked whether the three dimensions of the framework contained all the pertinent elements or whether there were any suggested additions. Coaches were also asked for feedback about the relevance of the different skill acquisition principles in their sport to ensure that the framework was applicable across a variety of different sports. The working group used the feedback from the two FGDs to adapt the framework content and language so it would be more easily understood by coaches. Note that no data from the scoping report or FGDs are shared in this paper.

3. The skill acquisition (SA) framework for youth sport in Singapore

The SA framework (Fig. 1) is divided into three dimensions, which broadly cover: 1) the *Desirable Characteristics* of youth athletes that coaches aim to develop with regards to skill acquisition, 2) the *Key Concepts* outlining empirical evidence on skill acquisition, and 3) The *Key Design Principles* that can underpin the design of training sessions. The user would be encouraged to interpret the various dimensions from outside in, while always being aware of the interrelatedness of the elements from the other dimensions to appreciate the holistic view of the framework.

3.1. Desirable characteristics of youth athletes

Similar to the blueprint that is essential when constructing a house, the first dimension of the framework draws up a plan about the *Desirable Characteristics* of athletes. These characteristics were identified in consultation with coaches from the FGDs. A range of characteristics were proposed by the coaches. Deliberations led to similar characteristics being grouped together under three main themes. Eventually, the three main characteristics identified as important from a skill acquisition perspective were motivation, adaptability and robustness under pressure.

3.1.1. Motivation

The term motivation has its roots in the latin word 'movere' (to move). It includes factors within and/or around an individual that energize, direct and sustain behaviour (Sage, 1977). Motivation is more than just an innate predisposition, it can be greatly influenced by how practice is conducted, which includes a coach's training approach.

Self Determination Theory (SDT, Deci & Ryan, 1985) has been used in psychology to understand how motivation can be influenced by external rewards and has more recently been applied in the context of skill acquisition (Renshaw, Oldham & Bawden, 2012). Since our framework deals with skill acquisition, we will discuss the concepts presented in SDT within the context of learning and performance. SDT envisages motivation on a continuum from intrinsic motivation (i.e., doing an activity for the satisfaction derived from the activity) to extrinsic motivation (i.e., doing an activity as a means to an end). Given that the SA framework is designed for coaches working with youth athletes, it is important to develop athletes who are not only extrinsically motivated (e.g., to win competitions) but also intrinsically motivated (e.g., to master their skills), as the latter form of motivation is associated with longevity in sport (Cresswell & Eklund, 2005; Holmberg & Sheridan, 2013).

SDT provides relevant concepts that can guide coaches who wish to encourage intrinsic motivation. SDT postulates that there are three basic psychological needs, which, if satisfied, can help move an individual along the continuum towards intrinsic motivation. The first psychological need is autonomy, which refers to the perceived level of control that the learner has during the process of skill acquisition. The second is relatedness, the extent to which a learner feels connected and supported by the various individuals in their training environment (e.g., open communication between coach and athlete). Finally, competence refers to a learner's belief in their ability to have control over the learning process so that they feel able to achieve their personally set goals. With regard to skill acquisition, adopting coaching approaches that provide greater autonomy for athletes (i.e., less prescriptive) and providing learning environments that encourage perceived competence (i.e., appropriately challenging tasks) are more likely to increase intrinsic motivation (Renshaw et al., 2012).

3.1.2. Adaptability

Sport naturally demands a certain level of adaptability from athletes. In dynamic sports, such as water polo, players are required to swim (i.e., switch between freestyle and backstroke), perform the eggbeater kick

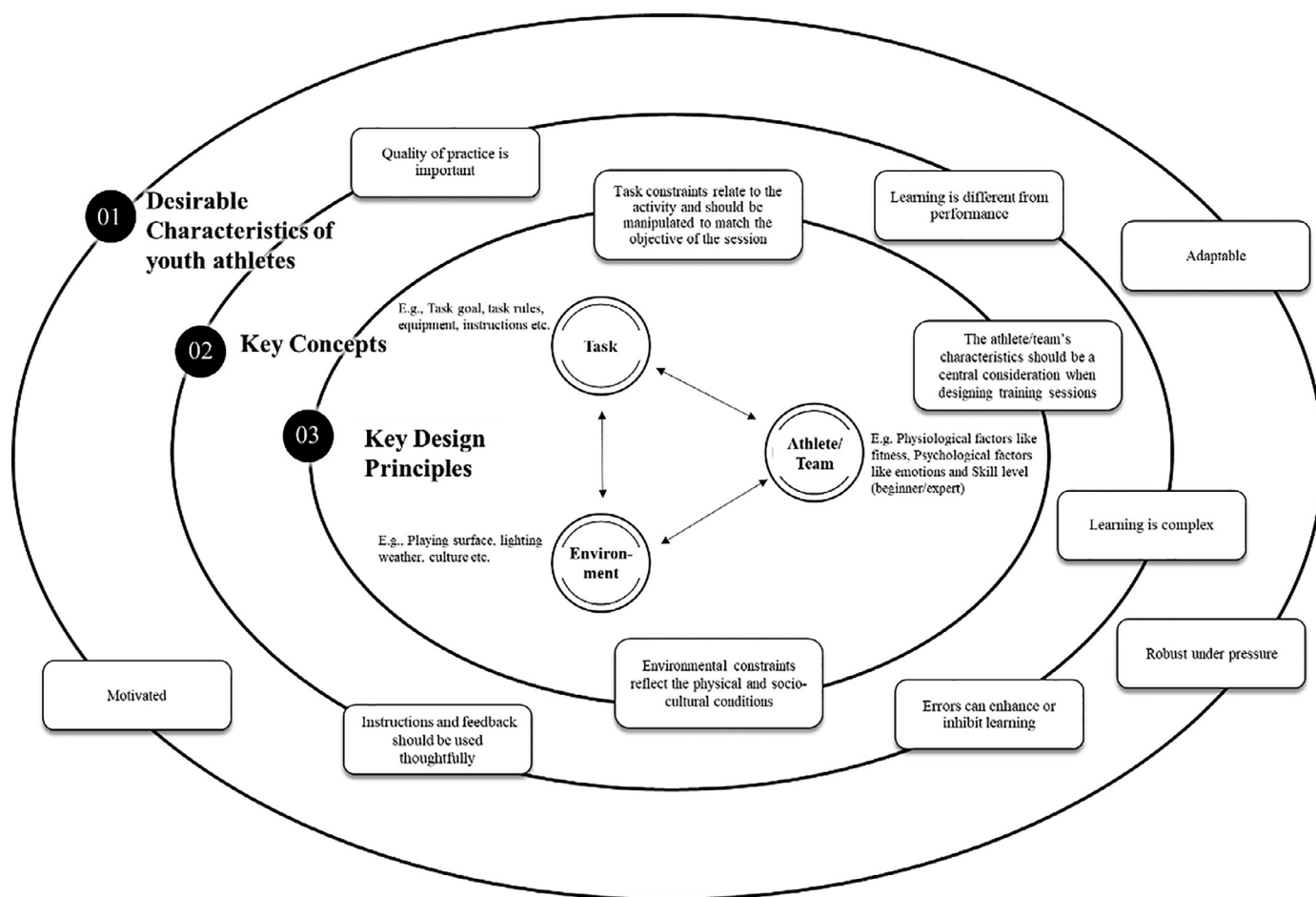


Fig. 1. A visual depiction of the Skill Acquisition (SA) framework for youth sport in Singapore.

to stay afloat, tackle opponents, quickly react to team mates' and opposition players' moves and pass or shoot when they identify a good opportunity to do so. These behaviours require the athlete to continuously pick up relevant information from the environment and refine and adapt their actions and decisions accordingly. Even for less dynamic sports, adaptability (i.e., incorporating both flexibility and stability) is essential. For instance, a closed motor skill like golf putting will require a player to adapt to the type of grass on the playing course. Some varieties of grass (e.g., poa annua) are more unpredictable and get less predictable depending on the time of day. Hence, reading the green and adapting shots accordingly are key factors that influence performance. For coaches, it is essential to develop athletes who are adaptable in these dynamic situations, as this will encourage movement flexibility (i.e., develop a wide array of movement solutions) and provide a competitive edge over opponents.

The theory of ecological dynamics provides a fresh perspective (see Button, Seifert, Chow, Davids & Araujo, 2020). It views skill acquisition as an ever evolving dynamic process in which the performer perceives and interacts with the environment and the task, which in turn provides more information that guides actions and decisions (Button et al., 2020; Davids, Handford & Williams, 1994). These complex interactions between the individual and the environment influence performance over the span of a few seconds during a game but also influence learning over time, throughout the developmental years (Chow, Davids, Renshaw & Rudd, 2020). The environment is viewed as a rich source of information that provides opportunities for actions (affordances) based on the individual's capabilities (Renshaw & Chow, 2019). Thus, coaches can design practices to make learners more *attuned* to relevant information sources through exploration and discovery. Nonlinear Pedagogy (NLP;

discussed further in Section 3.2.3.) is based on the ecological dynamics perspective, and is an approach that can be used by coaches to account for the complexities in the human system and the environment (Chow, Davids, Button & Renshaw, 2016). By accounting for these complexities, NLP can guide the learner to carry out goal directed behaviour while adapting to the ever changing elements of the environment around them (Chow et al., 2020).

3.1.3. Robust under pressure

During the early stages of learning, athletes focus on executing skills successfully in a training environment that allows opportunities for corrections or second attempts. Once youth athletes enter the competitive arena, including Interscholar competitions, National School Games or on a larger stage (e.g., Youth Olympic Games), they are exposed to additional pressures, such as evaluative audiences, financial incentives and fear of potential negative consequences. Thus, the real challenge is to be able to transfer skills such that they are robust under pressure. Researchers, particularly from the field of sport psychology, have dedicated a lot of time and effort to understanding the anxiety and performance relationship (Eysenck & Calvo, 1992; Eysenck & Wilson, 2016; Hanin, 2010; Masters & Malhotra, 2014; Masters & Maxwell, 2008; Woodman and Hardy, 2003). A large proportion of this research has examined sudden unexpected drops in performance that are colloquially described as 'choking under pressure'.

Some theories argue that skills break down under pressure, due to distraction of attentional focus to task-irrelevant stimuli, such as threats in the environment (Eysenck & Calvo, 1992; Eysenck & Wilson, 2016). Other theories propose that breakdowns occur due to increased internal focus and concomitant tendency to consciously monitor and control

movements and decisions (Kinrade, Jackson, Ashford & Bishop, 2010; Malhotra & Masters, 2019; Masters, 1992; Masters & Malhotra, 2014; Masters & Maxwell, 2008). Either way you look at it, training approaches that optimise attentional focus and reduce conscious control of movements can result in performance that is robust under pressure. In relation to the SA framework for youth sport, it is particularly important that coaches are made aware of how their coaching practices (e.g., instructions, feedback and tasks) can be designed to ensure maximum robustness under pressure.

3.2. Key concepts

Continuing with the house metaphor, once a blueprint of a house has been drawn up, the foundations can be laid. The second dimension of the SA framework introduces *Key Concepts*, which form the foundations that will guide coaches when designing training sessions. Put simply, it is important for coaches to understand “why” they do “what” they do.

3.2.1. Quality of practice is important

There is little debate that quantity of practice is essential for learning to occur but it is also important to think about ‘quality’ of practice. The first *Key Concept* highlights the difference between quality and quantity of practice. Skill acquisition practitioners emphasise that it is not only the amount of practice but also ‘how’ the time is spent learning skills that matters. Coaches cannot simply design sessions in which athletes complete a large number of repetitions of the same skill but they need ask to ask themselves “what is the role of repetitions?” in meeting session objectives.

The role of repetitions cannot simply be to develop athletes who can execute a ‘perfect’ movement form in a predictable, stable environment (completing 100 passes to the same teammate from a set distance). Importantly, from an ecological dynamics perspective, it has been suggested that there are no perfect or universal forms for any particular movement (Glazier & Davids, 2009; Ng & Button, 2018; Seifert, Button & Davids, 2013). Specifically, movement forms are temporary solutions that are emergent to satisfy unique configurations of constraints further influenced by the perceived information for action.

Sport is rarely predictable and different athletes are likely to have their own motor solutions to the problem. Nikolai Bernstein (1967) first introduced the concept of ‘repetition without repetition’ to highlight the importance of engaging in practice that introduces variability in how we arrive at motor solutions. The key point is to repeat the movement problem but not to repeat the solutions to solving the movement problem. In other words, it is fine to clock up the hours doing repetitions but in order to ensure quality of these repetitions, coaches are encouraged to include variability in practice. Doing so will help to develop athletes who can demonstrate skills that are *adaptable* and *robust under pressure* (e.g., passing the ball from different distances while being defended) (see Section 3.1). Even for closed-motor skills, like a football penalty kick, the presence of spectators and the pressure to score a goal present a variable practice condition. Hence, the penalty taker will require a certain level of *adaptability* to maintain their composure for a successful outcome.

In the extended version of the framework, two types of variability are introduced: between-task variability and within-task variability. Between-task variability can be introduced by using approaches such as random practice in which a learner is required to perform a specified number of repetitions of multiple skills (e.g., shooting, passing, dribbling), but the order in which they perform these skills is randomised and unpredictable and no two repetitions of the same skill are carried out consecutively. This is contrary to a typical blocked practice approach in which a learner performs a specified number of repetitions of a skill (e.g., shooting) before proceeding to the next skill (e.g., passing) without re-visiting the previously learned skill in a single session. Within-task variability can be brought about by using variable practice during which frequent changes of the same skill occur. This can be introduced

using structured or unstructured noise-like variations (Ranganathan & Newell, 2013). A structured variation would involve systematically manipulating a specific movement parameter with the overall goal of transferring skills to novel task conditions (manipulating distance e.g., kicking from 11 m, 13 m and 15 m from the goal). An unstructured approach would introduce variations across multiple parameters simultaneously (e.g., manipulate distance, angles to goal, approach, follow-through). From a dynamic systems perspective these unstructured variations promote the emergence of the most optimal solution for a given task (see differential learning in Section 3.2.4.).

Research comparing blocked and random practice has generally found better skill execution during training for blocked practice but the long-term effects of learning and adaptability are better when using random practice. This has been demonstrated in tasks, such as a badminton serve and golf chipping shots (Aiken & Genter, 2018; Goode & Magill, 1986). Similarly, variable practice has shown more positive effects for learning of tennis groundstrokes than constant practice in which only one variation of the skill is taught (Sahan, Erman & Ertekin, 2018).

From a theoretical perspective, including variety in practice has been proposed to be effective because it causes more effortful cognitive processing via contextual interference (Lee & Simon, 2004). From an ecological dynamics perspective, it also provides affordances (opportunities for action) that can be explored by athletes during practice (Button et al., 2020). From a practical standpoint, variability introduces variety in training sessions that encourages greater *adaptability* and *robustness under pressure*, less tedium and perhaps enhances intrinsic *motivation* (Brady, 1998; Farrow & Robertson, 2016). Although it can’t be disputed that increasing quantity (increasing repetitions) alone might result in observable performance improvements during a training session, it is important for coaches to understand the long-term effects of using this approach on learning.

3.2.2. Learning is different from performance

Learning refers to the relatively enduring changes in thinking and skill execution that are usually brought about by practice (Magill & Anderson, 2010). Performance, on the other hand, refers to temporary fluctuations in thinking and skill execution that one can observe at a given point in time (i.e., during a particular training session or on competition day). Thus, observation of a solitary instance of ‘good’ performance should not be used as an indicator of learning (Soderstrom & Bjork, 2015). There are numerous processes that influence skill acquisition—some are persistent changes, including memory consolidation and/or forgetting, which work at a slower rate, whereas others are transient changes, including warm-up and fatigue decrements, which can have an immediate impact on performance (Verhoeven & Newell, 2018).

From a dynamical systems perspective, the emergence of a stable attractor state requires time. For example, training to adopt a new movement “form” presents a perturbation to the stable state. In the emergence of a new stable attractor state there will be periods of instability before stabilisation. During these transitions, the system can also revert back to the former attractor state if the perturbation is not significant enough. Thus, from an ecological dynamics view of learning, these transitional periods may suggest a lack of learning, although stabilisation of new learning may require more time.

This *Key Concept* in the SA framework highlights the importance for coaches to understand this seemingly subtle difference between learning and performance, as it has practical implications for how they should monitor and evaluate learning, which in turn influences practice design. For example, a coach who is trying to adapt the free-throw technique of an athlete (perhaps due to potential for injury from current technique), might observe their athlete achieving a very low level of accuracy during a single practice session and decide to give up on teaching this new technique. However, it is important that the transient changes in performance that the athlete is experiencing are not taken as ‘lack of learning’ as learning can continue to occur even though performance during train-

ing doesn't indicate this. Instead, it is important that coaches allow for gaps in training to allow memory consolidation and the emergence of new stable states.

Decades of research has revealed that not just lack of changes in performance, but in some instances also decrements in performance during training can be associated with stronger long-term effects of learning. As discussed in Section 3.2.1, random practice leads to worse performance during training but ultimately yields learning that is resilient over time and adaptable to novel contexts (Aiken & Genter, 2018; Goode & Magill, 1986; Shea & Morgan, 1979). Thus, coaches who view solitary instances of good performance as learning might be missing opportunities to reap the benefits of random practice.

Hence, for coaches it would be helpful to consider multiple indicators of learning rather than take a unidimensional approach (e.g., if athlete is not improving they are not learning). For this reason, coaches can monitor and evaluate learning by measuring a variety of factors, including improvement, consistency, stability, persistence and adaptability (Magill & Anderson, 2010). Improvement refers to the advancement of skills, if a learner is still demonstrating improvement they are probably still learning the skill, with the exception of overlearning. Consistency refers to whether the task goals or movement outcomes are achieved regularly (shooting consistently at 80% accuracy) rather than whether the movement itself is carried out in a consistent manner. From an ecological dynamics view, consistency of movement form is regarded as less important. Instead, with variability being inherent in complex systems (Chow, Davids, Button, & Koh, 2007), variances that are functional and do not impact movement outcome are acceptable (Latash, 2012). Stability refers to whether performance remains stable despite perturbations to the system (e.g., robust under pressure). Persistence refers to the ability of the learner to retain skills over a longer term (e.g., after breaks from practice). Finally, adaptability refers to the potential to adapt skills to novel situations. Importantly, the evaluation of learning should be observed in movement scenarios that are representative of the performance environment instead of static environments where the information-action interaction is decoupled (Ng & Button, 2018). The number of factors that need to be assessed to know if a skill is learned underscores the complexity of learning, which brings us to the next Key Concept within the SA framework.

3.2.3. Learning is complex

Humans are complex systems, so the way in which we learn skills is complex. This Key Concept from the SA framework stems from the ecological dynamics perspective, which views learning as a complex, nonlinear process emerging from the dynamic interactions between various constraints (i.e., individual, task and environment). Nonlinear Pedagogy (NLP) is an applied approach that adopts learning principles that are specifically designed to account for this complexity. NLP is based on the tenet that learning is inherently nonlinear, which should be a central consideration when designing training sessions (Chow, 2013). Key design principles underpin NLP, including the need to: 1) incorporate representative learning contexts in practice (i.e., simulating actual performance contexts), 2) manipulate and scale constraints to shape the emergence of behaviours, 3) focus on task simplification to ensure perception-action coupling yet allow for success, 4) sensitivity to the impact of informational constraints where instructions pertaining to movement outcome can elicit more sub-conscious control of movement and 6) use practice variability to encourage exploratory behaviours. By considering the use of NLP and the associated design principles, nonlinearity in learning can be accounted for.

For coaches, this is an important Key Concept to understand for two reasons. First, it is vital to understand that skill learning does not occur in a linear and predictable manner, but rather it is nonlinear, entailing sudden improvements in performance or stagnation and even regression in performance, depending on the individual learners and the context in which learning is situated (Chow et al., 2020). The implications are that coaches must expect that changes in the environment or the

tasks designed may not be directly proportional to changes in performance. Being mindful of this enables coaches to monitor and evaluate learning using a slightly different lens (e.g., not interpreting regression as a need to immediately modify the training approach). Second, individual differences influence how skills are learned and executed. Each individual is unique (physiological and psychological characteristics), thus, individual variability is inherent and influences the way athletes approach a motor problem. Exploration encourages athletes to independently find solutions to overcome a movement goal. In other words, they learn to achieve the same goal with varied, functional movement solutions (Chow et al., 2007, Ng & Button, 2018). It is important to appreciate the influence of individual differences throughout the process of learning so coaches avoid prescribing 'a one-size fits all' motor solution (Button et al., 2020).

3.2.4. Errors can enhance or inhibit learning

There is a plethora of research on the role of errors in learning; with some researchers suggesting that errors should be encouraged during practice and others suggesting that there may be benefits from minimising errors during practice. The SA framework doesn't aim to come to a definitive conclusion; rather, it presents the evidence from both sides for coaches to reflect on in their own coaching practices.

As humans we are wired to problem-solve, and when acquiring or adapting skills in sport settings we continuously search for motor solutions. During this search for motor solutions, learners seek to correct movement errors using methods such as hypothesis testing or If-Then rules (Maxwell, Masters & Eves, 2003). For instance, a swimmer learning to dive from the side of the pool might initially dive too deep into the water causing them to think about how they can adjust their stance, 'Maybe If I reach my arms further up and aim long then I can land a bit flatter in the water'. Over time this hypothesis testing approach is likely to cause a build-up of verbalizable or declarative knowledge that gets stored in the long-term memory (Masters, 1992). Self-generated declarative knowledge might also be coupled with a coach's explicit corrections and technical instructions on how to dive. Although having declarative knowledge about how to execute skills is not in itself disruptive to performance, the use of this knowledge to guide actions and decisions can be. The Theory of Reinvestment proposes that there are individual differences in the tendency to use declarative knowledge to consciously control movements, referred to as 'reinvestment' or 'movement specific reinvestment' (Masters, 1992; Masters & Maxwell 2008; Masters, Polman, & Hammond, 1993). A higher tendency to use declarative knowledge to consciously monitor and control performance (measured by the Reinvestment Scale–Masters et al., 1993, or the Movement Specific Reinvestment Scale–Masters, Eves & Maxwell, 2005) can be disruptive, especially for experts who are accustomed to executing skills in an automated manner (e.g., Jackson, Ashford & Norsworthy, 2006; Jackson, Kinrade, Hicks, & Wills, 2013; Malhotra, Charlton, Starkey & Masters, 2018; Malhotra, Poolton, Wilson, Ngo, & Masters, 2012; Maxwell, Masters & Poolton, 2006).

Masters and colleagues argued that motor skills can be learned in an implicit manner (i.e., implicit motor learning), without concomitant accrual of declarative knowledge (e.g., Masters, 1992; Masters & Poolton, 2012; Masters et al., 2019). In brief, one can learn 'what to do' without being able to describe 'how to do it'. One such implicit motor learning approach is errorless (or error-reduced) learning, which increases the likelihood of successful performance by purposefully reducing errors, thereby alleviating the need for performers to test hypotheses about how to adapt movements. During errorless learning, the task typically is designed to be relatively easy early in learning so that errors are reduced. Gradually and progressively the task becomes more difficult as the performer improves. Errors can be minimised by putting constraints on certain aspects of the task (e.g., incrementally increasing the distance to the target or decreasing the target size). The errorless learning approach has been shown to promote skill acquisition that is less attentionally demanding, more stable over time, robust under

pressure and resilient to physiological fatigue in sports, such as golf and rugby (Capio et al., 2013a; Capio et al., 2013b; Lam, Maxwell, & Masters, 2010; Maxwell, Capio & Masters, 2017; Poolton, Masters & Maxwell, 2007; Maxwell, Masters, & Eves, 2000; Maxwell, Masters, Kerr, & Weedon, 2001). Since errorless learning has been shown to promote implicit learning it can be particularly beneficial for coaches to use with their athletes who have a higher tendency towards reinvestment (Masters, 1992; Masters & Maxwell 2008; Masters et al., 1993). Errorless learning could also be used with athletes who have low self-efficacy (e.g., novices or athletes returning from injury), as this form of learning increases the likelihood of task success.

An alternative approach that is gaining momentum is differential learning, which has its roots in the dynamical systems perspective (Schollhorn, Hegen & Davids, 2012). This approach advocates that training should occur without correction of errors and with increased fluctuations in movement patterns so as to facilitate the search for novel, functional motor solutions that can be adapted to different contexts. In soccer, differential learning approaches have been shown to be particularly effective in youth players in terms of creativity and performance (Coutinho et al., 2018; Memmert, 2015; Santos et al., 2018). This approach is especially useful for sports, such as soccer, where the dynamic nature of the game demands a certain level of creative and adaptable behaviour.

As mentioned earlier in this section, one learning approach will not be advocated over the other but rather we propose through the SA framework that tolerance for errors should be adjusted according to the session objective (e.g., the intended level of task difficulty). Further, we believe that coaches are best placed to decide when to allow room for errors. Our tolerance for errors can be calibrated based on the individual differences of athletes and/or teams, and the specific situations. For example, if a competition is just around the corner and a coach is working with an athlete who lacks confidence, their tolerance for errors in a training session may be low. Similarly, if safety is of a concern as would be the case in sports like diving or gymnastics, then tolerance for errors will also be low. On the other hand, if the athlete is confident and up for a challenge, a coach might have a higher tolerance for errors.

3.2.5. Instructions and feedback should be used thoughtfully

Coaches are often viewed as ‘directors’ of learning, so a key part of their role entails providing instructions to their athletes to carry out skills in a particular way. When athletes aren’t able to take these instructions on board coaches provide feedback on how to improve performance in upcoming attempts. Augmented feedback can be verbally relayed to athletes and supplemented with video footage, which is easily accessible via the use of mobile learning devices (e.g., tablets and phones). Given the increasing avenues for receiving feedback from the coach and perhaps independently (e.g., youth athletes growing up in a digital environment are likely to watch video footage of their performance on their mobile devices), this is an important *Key Concept* for the coaches of youth athletes. Nevertheless, this is potentially the most difficult *Key Concept* of the SA framework for coaches to accept—after all, what good is a coach who observes silently from the side-lines. It is important to clarify that this *Key Concept* does not advocate for a ‘silent coach’, but rather for a coach who thinks carefully about *what* instructions and feedback to provide and *when*.

Let us start with *what* instructions and feedback to provide. Verbal or explicit instructions are meant to guide an athlete and to facilitate learning, but we advise against the overuse of these for two main reasons. First, as highlighted in Section 3.2.4., providing instructions can increase the likelihood of reinvestment, which can hinder performance due to ‘overthinking’ movements and decisions (for a review see Masters & Maxwell, 2008). Second, the overuse of instructions and augmented feedback can compromise independent learning, potentially reducing the ability of an athlete to self-sufficiently arrive at their own motor solutions.

Evidence from the motor learning domain has revealed alternative approaches, which provide a middle ground between providing no instructions and providing a lot of instructions and feedback (Masters, 1992; Masters & Poolton, 2012). Implicit motor learning is one such approach, during which learning occurs without accumulation of verbal rules or consciously accessible knowledge about how to perform movements and make decisions. The early work in implicit motor learning made use of approaches, such as dual-task learning in which learners practiced a skill while simultaneously performing a highly demanding secondary cognitive task (i.e., calling out a random letter from the alphabet while putting a golf ball, Masters, 1992). Aside from demonstrating successful learning, the dual-task approach also resulted in skills that were robust under psychological pressure. Given that dual-tasking might not always be a feasible approach to incorporate into training sessions, other implicit motor learning approaches were developed, including errorless (or error-reduced) learning (for details see Section 3.2.4) and analogy learning. Analogies use well-known concepts from other domains of life to convey to the learner how the movements should be executed (e.g., Masters, 2000; Liao & Masters, 2001). This approach reduces the need to verbally present information or rules about how to move. For example, a young basketballer can be told to snap the wrist and point the fingers in order to create backspin in a basketball free-throw or alternatively can be told to “shoot as if you are trying to put cookies into a cookie jar on a high shelf”. Evidence suggests that analogy learning results in skill learning that is resistant to breakdown under multi-tasking and psychological pressure (e.g., Liao & Masters, 2002; Poolton, Masters & Maxwell, 2006). The use of attentional cues that direct attention externally to the movement outcomes (focus on ball’s trajectory) rather than internally to the movement itself (focus on wrist flexion) have also been shown to be effective in reducing conscious control of movements (Wulf, 2013). Coaches might find the use of external attentional cues particularly beneficial when using video feedback as they can direct their athlete’s attention towards certain aspects of the video (i.e., movement outcomes). Over time, this might also shape how athletes use video feedback independently (i.e., in the absence of the coach).

Now that we have discussed *what* instructional approaches can be used, we can move on to *when* coaches should provide feedback to their athletes. Similar to the use of instructions, the SA framework proposes that the less frequently feedback information is provided to the athlete the better. Approaches, such as bandwidth feedback, which is provided only when performance is outside a certain range (e.g., performance of >5% error) can be used in sport (Goodwin & Meeuwssen, 1995). In order to mitigate the risk of appearing to be a ‘silent coach’ who waits for an error before speaking up, bandwidth feedback can also be used along with questioning techniques. Questioning techniques ensure that the athlete is engaged in the task and also provide a certain sense of autonomy to the athlete. Bandwidth feedback and questioning have been shown to improve performance and technique of youth competitive swimmers and maintain effective coach-athlete relationships (Chambers & Vickers, 2006).

3.3. Key design principles

Once the foundation is laid, it is time to start building the house. Similarly, the *Key Design Principles* of the SA framework shed light on how to start designing training sessions. In brief, it is “what to do” as a coach.

The third dimension of the framework is anchored by the constraints model (Newell, 1986). Constraints can be understood as boundaries within which individuals can explore and discover functional movement solutions. Constraints can be purposefully manipulated by coaches to facilitate goal-directed behaviour (Renshaw, Davids, Newcombe & Roberts, 2019). There are three main constraints that coaches should consider when designing training sessions (Renshaw, Chow, Davids & Hammond, 2010). First there are the athlete/team’s characteristics,

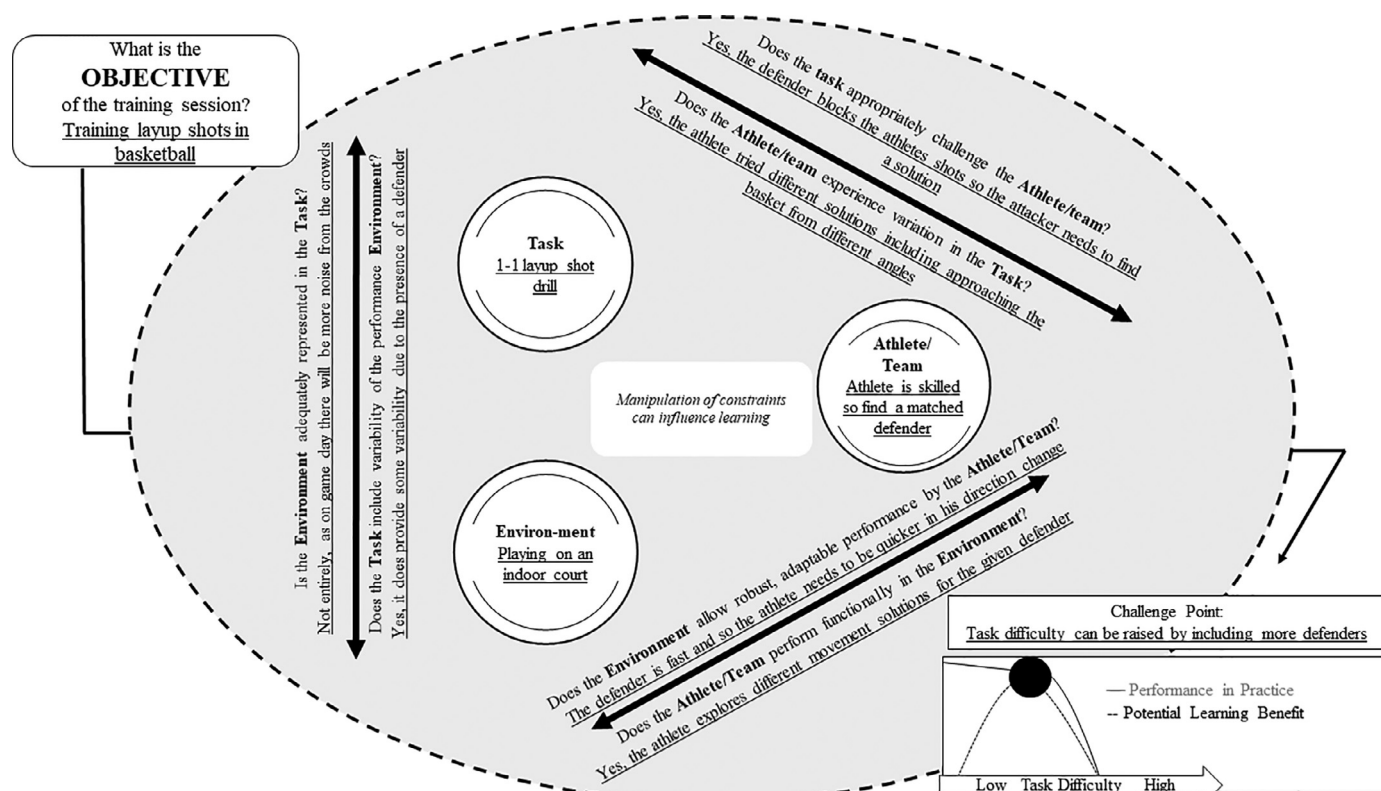


Fig. 2. Elaboration of the third dimension, Key Design Principles with a sport specific example (underlined).

which should be a central consideration. Athlete/team constraints can be physiological aspects, such as fitness, strength, height, weight; psychological aspects, such as emotions, motivation and cognitions as well as the current skill level of the athlete/team (i.e., beginners or experts). Next, there are the task constraints, which include but are not limited to the task goals, rules of the game, size and weight of the equipment, amount and type of instructions and feedback. Finally, environment constraints reflect the physical conditions, such as playing surfaces, weather conditions and socio-cultural conditions (e.g., team or organisational culture). Coaches are reminded that when manipulating constraints (e.g., adapting rules of the game, playing surfaces), it is important for them to ensure that the information being provided to athletes is similar, but not necessarily identical, to what the athlete would experience in a competitive performance environment i.e. *representative learning design* (Pinder, Davids, Renshaw & Araújo, 2011). This ensures that the information can be more closely coupled to the movements in order to modulate, refine and adapt movements.

In the SA framework, coaches are provided with a visual (Fig. 2) of how they can use the constraints model to design and evaluate training sessions. As shown in Fig. 2, the SA framework suggests that the first question coaches should ask themselves is “What is the objective of the training session?”. Once the objective is clear, coaches are directed to think about what are the most important constraints to consider when planning a session. Generally, we argue that the athlete/s should be a central consideration when designing sessions, as individual differences (e.g., cognitions, skill level, motivation) determine how the athlete will approach a task during a given session. It is also important to note that it is always good to consider all constraints but not necessary to manipulate all constraints during every session. This also depends on the sport in question. For instance, a sailing coach almost always needs to account for key environmental factors (e.g., wind direction), which form the basis of skills in sailing. In contrast, a table tennis coach might not be inclined to manipulate environment constraints as much as a sailing coach, since it is an indoor sport. However, we do

recommend that coaches should always consider whether manipulating environment constraints will enhance skill acquisition (e.g., the presence of a crowd when approaching competition season). This particular dimension also reminds coaches to consider the effects of the interaction between the manipulated constraints when designing training sessions. To help coaches reflect on whether they have accounted for the interaction between constraints, some guiding questions are presented in this dimension (the bi-directional arrows in Fig. 2). To illustrate, if coaches want to check if they are accounting for the interaction between the Athlete/Team and the Task constraints they can ask themselves “Does the Task appropriately challenge the Athlete/Team?”. Alternatively, they can ask themselves, “Does the Athlete/Team experience variation in the Task?”

Another concept that the framework introduces is the challenge point (Guadagnoli & Lee, 2004). The challenge point framework proposes that learning is dependant on the information that is available to and comprehensible by the individual. Thus, when information is available there is potential to learn. However, coaches should think about the amount of information that is being provided to their athletes. If the information is too much or too little there could be a setback in learning. The challenge point framework proposes that the most effective learning occurs when there is an optimal amount of information available to the individual (i.e., an ‘optimal challenge point’).

The greatest potential for learning is when the challenge point is set at an appropriate level of challenge for athletes. If the tasks are ‘too easy’ then there is little potential to learn and similarly if the tasks are ‘too difficult’ then learning is likely to be less as learners cannot process the information efficiently. Coaches can adjust task difficulty to achieve the optimal challenge point by using approaches such as ‘errorless learning’ to decrease task difficulty and ‘differential learning’ to increase task difficulty (See Section 3.2.4). It is important to acknowledge that identifying an athlete’s optimal challenge point might be tricky for coaches as it requires them to consider a variety of different factors (i.e., athlete capabilities, complexity of the skill, environment).

The other factor to consider is the skill level of the athlete, because the same task could be viewed as too difficult for a novice but too easy for an expert. For example, if a coach is training layup shots in basketball by getting their athletes to run up from a set distance undefended, the expert will likely make every shot and hence they will not gain any new information from watching the shot enter the basket. However, for a novice the same task might present a few challenges (e.g., taking more than two steps and risking travelling) and this will provide information on the run-up. The novice might also pick up information on shooting based on the visual feedback they attune to depending on how far off they were from the basket. In this instance, a coach can look back at the three constraints and consider adapting them in the next session. For the expert, the coach might add defenders or set task rules (e.g., you can only approach the basket from your non-dominant side), in order to increase the challenge slightly (see Fig. 2). For the novice, the task constraints might be adjusted to reduce task difficulty.

Relating the challenge point back to the first dimension of the framework, *Desirable Characteristics*, it is possible that if the challenge is set too low for highly skilled youth athletes they might experience lack of *motivation* and also be less *adaptable* when they are playing against defenders. For low skilled youth athletes, if the challenge is too high, perhaps due to a lack of coordination or poor shooting skills, they may experience lack of *motivation* due to their limited success in achieving the objectives of the set training task.

4. Future directions

The SA framework has been developed to enable coaches to apply skill acquisition principles to their everyday coaching practices in order to influence the long-term development of youth athletes in Singapore. In order to facilitate the application of the SA framework in everyday practices, the team will aim to provide coaches with more information about how they can apply some of these principles in their sports via an e-booklet and a series of workshops. The primary objective of the workshops will be to encourage coaches to put the framework into practice and discuss some of the challenges of doing so.

We view the framework as ever evolving and dynamic. We expect the *Key Concepts* and *Key Design Principles* to evolve in line with emerging evidence that is generated within the skill acquisition space. Future research should consider validating the SA framework with respect to its impact on coaching development and practice, its effectiveness in implementation and its influence on long term athlete development. Validation of the framework might uncover elements that need to be adapted for greater impact in the sporting ecosystem of Singapore. Despite being developed for youth athlete coaches specifically, there is a possibility for this framework to be adapted for application at the grass-root levels as well as in high performance sport. An adaptation for the grass-roots level might include more information on movement competency (Ng & Button, 2018), whereas for high performance sport it might include more information on the use of technology to augment learning and performance.

5. Conclusion

From the outset, the SA framework helps coaches to think about the kind of athlete they are trying to develop. Motivation is key, especially for youth athletes, as it can influence longevity in sport. We hypothesise that training programmes are a key factor in keeping athletes motivated, as the task design and even the autonomy given to the athlete all work together to influence athlete motivation. In order to prepare youth athletes of today for the high performance arena of tomorrow, it is essential to acknowledge the importance of adapting skills to contexts such as pressure. The *Key Concepts* allow coaches to reflect on some of the fundamentals of skill acquisition that must be understood before they can begin to apply these into training plans. The *Key Design Principles* provide a chance for coaches to plan, monitor and evaluate their training

sessions to stay in line with evidence-based practices of skill acquisition. Not dissimilar to the last *Key Concept* in this paper (see Section 3.2.5), the SA framework is not prescriptive in its approach but rather it is aimed at encouraging coaches to think more deeply about their current and future coaching practices. In the extended version of the SA framework, coaches are provided a worksheet for planning and evaluation, to bring together all of the information from the three dimensions. The worksheet comprises sections covering: 1) which constraints are being manipulated during a training session, 2) how to account for the interaction between constraints, 3) the level of task difficulty, 4) which *Desirable Characteristics* a training session is contributing towards, 5) whether an optimal challenge point has been reached within a training session, and 6) what constraints coaches can consider manipulating in their next session to help set an optimal challenge point.

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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