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# A constraints-led perspective to understanding skill acquisition and game play: A basis for integration of motor learning theory and physical education praxis?

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**Abstract**

Background: In order to design appropriate environments for performance and learning of movement skills, physical educators need a sound theoretical model of the learner and of processes of learning. In physical education, this type of modelling informs the organization of learning environments and effective and efficient use of practice time. An emerging theoretical framework in motor learning, relevant to physical education, advocates a constraints-led perspective for acquisition of movement skills and game play knowledge. This framework shows how physical educators could use task, performer and environmental constraints to channel acquisition of movement skills and decision making behaviours in learners. From this viewpoint, learners generate specific movement solutions to satisfy the unique combination of constraints imposed on them, a process which can be harnessed during physical education lessons.

Purpose: In this paper the aim is to provide an overview of the motor learning approach emanating from *the constraints-led perspective,* and examine how it can substantiate a platform for a new pedagogical framework in physical education: nonlinear pedagogy. We aim to demonstrate that it is only through theoretically valid and objective empirical work of an applied nature that a conceptually sound nonlinear pedagogy model can continue to evolve and support research in physical education. We present some important implications for designing practices in games lessons, showing how a constraints-led perspective on motor learning could assist physical educators in understanding how to structure learning experiences for learners at different stages, with specific focus on understanding the design of games teaching programmes in physical education, using exemplars from Rugby Union and Cricket.

Findings: Research evidence from recent studies examining movement models demonstrates that physical education teachers need a strong understanding of sport performance so that task constraints can be manipulated so that information-movement couplings are maintained in a learning environment that is representative of real performance situations. Physical educators should also understand that movement variability may not necessarily be detrimental to learning and could be an important phenomenon prior to the acquisition of a stable and functional movement pattern. We highlight how the nonlinear pedagogical approach is student-centred and empowers individuals to become active learners via a more hands-off approach to learning.

Summary: A constraints-based perspective has the potential to provide physical educators with a framework for understanding how performer, task and environmental constraints shape each individual's physical education. Understanding the underlying neurobiological processes present in a constraints-led perspective to skill acquisition and game play can raise awareness of physical educators that teaching is a dynamic 'art' interwoven with the 'science' of motor learning theories.

Professional Abstract for PE Matters

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## Introduction

Physical education literature has provided a significant amount of knowledge about structuring practices and the provision of learning opportunities (e.g., Siedentop & Tannehill, 1999; Metzler, 2000). Physical educators have benefited from the content knowledge of this applied research, which has informed practitioners on the ‘art’ of helping learners acquire game skills. Research in motor learning has also advanced our knowledge about processes involved in the acquisition of movement skills (e.g.; Handford, Davids, Bennett & Button, 1997; Magill, 2006; Schmidt & Lee, 2006). Ideally, the relationship between scientists and pedagogists should be symbiotic in that experiential knowledge from skilled pedagogists could inform researchers in their study of motor learning processes as well as aiding interpretation of key findings (Davids, Renshaw & Glazier, 2005; Davids, Button & Bennett, 2007). The continuous interaction between movement scientists and pedagogists is important for the development of adequate models of skill acquisition in physical education and the design of learning experiences in games teaching programmes.

In order to design appropriate environments for performance and learning of movement skills, physical educators need a sound theoretical model of the learner and of processes of learning. In physical education, this type of modelling informs the organization of learning environments and effective and efficient use of practice time. Modelling how learners acquire functional movement patterns is essential for considering practical issues such as: (i) selecting ergonomically designed equipment for each learner; (ii) organising and structuring learning environments and teaching tasks; (iii) planning and management of exercise and practice programmes; (iv) prevention of injury and associated health and safety considerations; and (v), understanding the nature of individual differences at various levels of performance.

Despite these arguments, the relationship between motor learning and physical education over the years has not been as effective as it could have been. In fact, the failure of physical education specialists to identify relevance of motor learning research was highlighted by a special issue of *Quest*. One thesis advanced was that motor learning, as typically represented and researched for the past 20 years, has led to few practical, empirically verified recommendations for physical education teachers, coaches, and teachers of sports skills (see Hoffman, 1990; Locke, 1990). Since that special issue there seems to have been little research effort to dissipate those original concerns.

Why was motor learning research deemed so irrelevant in that special issue? One possibility is that, since its inception, motor learning and control specialists had focussed too much attention on establishing a ‘grand’ theory of movement skill acquisition, and not enough effort was devoted to scientific research on pedagogical applications of data and theory (Hoffman, 1990). The result of this perceived imbalance was the design of non-representative laboratory experiments at the expense of applied work. Movement scientists defended this position by suggesting that applied research was only useful in answering specific questions, which should not detract attention from the scientific study of underlying motor learning processes.

Elsewhere in that special issue it was proposed that the theory and practice of motor skill acquisition required an inter-disciplinary perspective and the emergence of a new theory, the ecological approach to perception and action, was seen as the catalyst for future applied research using natural multiple degrees of freedom tasks (Newell & Rovegno, 1990). Despite the hopes of Newell and Rovegno’s (1990), and the noteworthy attempts of Rovegno and colleagues to advance understanding of motor learning amongst pedagogues via a ‘situated’ or; constraint-led’ approach (e.g., Rovigno & Kirk, 1995; Rovegno, Nevett & Babiarz, 2001; Rovegno, Nevett, Brock & Babiarz, 2001; Rovegno, 2006), since their paper very few applied studies on pedagogical practice have been undertaken by motor learning investigators. Research in physical education during this period has been dominated by theoretical discourse from a socially-constructed critical pedagogical stance (such as: Tinning, 1991; Macdonald & Kirk, 1996; Tinning, Macdonald, Wright & Hickey, 2001; Evans, Davies & Wright, 2004), rather than a performance-orientated approach. This state of affairs in physical education (with the exception of the work of Rovegno and co-workers) has been maintained because few movement scientists have actually collaborated with physical educators to develop the principles of a pedagogical framework based on motor learning theory which can substantially underpin practice in the field.

In this paper we overview the motor learning approach emanating from *the constraints-led perspective,* and examine how it can substantiate a platform for a new pedagogical framework in physical education: nonlinear pedagogy (Davids, Chow & Shuttleworth, 2005; Davids, Button & Bennett, 2007; Chow, Davids, Button & Koh, in press). What then is Non-Linear Pedagogy and why should we consider the development of motor skills as being non-linear? Nonlinear pedagogy is predicated on the concepts and ideas of ecological psychology and dynamical systems theory and can be defined as the 'application of the concepts and tools of nonlinear dynamics' to teaching and coaching practice, (Chow et al., 2006, p.72). A such, proponents of a non-linear pedagogical approach, will underpin the design of practice by applying  key concepts such as the mutuality of the performer and environment, the tight coupling of perception and action, and the non-linear nature of systems that are made up of many interacting component parts that move between phases of stability and instability via processes of self organisation under constraints, (see Renshaw, Davids, Chow & Shuttleworth (in press) for a detailed discussion of these ideas).

A systems approach has been applied in human movement science to describe how each individual learner could be viewed as a complex neurobiological system composed of many degrees of freedom (roughly speaking component parts that are free to vary). Williams, Davids & Williams (1999) proposed that the key properties of nonlinear dynamical neurobiological systems include: (i) a high level of integration within the system; (ii) many interconnected and interacting parts or degrees of freedom (e.g., skeletal, muscular, and cardio-vascular systems) which can produce rich patterns of behaviour; (iii) a surprising tendency for order to emerge between interacting degrees of freedom; (iv) inherent tendencies for self-organisation (e.g., processes by which degrees of freedom of the body spontaneously adapt to changes in other parts); (v) the ability of subsystem components to constrain (influence) the behaviour of other subsystems, producing variable outputs; and (vi), similar system outputs being achieved by configuring system components in different ways.

In fact, the salience of non-linear models to explain the development of motor skills is now taken for granted. Indeed, as Adolph & Berger (2006) highlight the complimentary and compatible ideas and methods of dynamical systems theory and ecological psychology are the two dominant theoretical perspectives in this field. The concept that skill development is non-linear is captured in the words of Miller who indicate that “development can be a process of moving one step backwards for every two step forwards” (Adolph & Berger, p. 173). In learning sporting skills, the analogy could be drawn with attempts by athletes to relinquish an ‘old’ and stable technique in favour of a precocious movement accompanied by variability and poor performance. Indeed, the challenging nature of this transition may lead to initial regression back to the old technique. However, the motivation for enhanced performance appears to drive ambitious learners to relinquish the old in favour of the new (cf. Adolph & Berger, 2006).

In essence, non-linear development is predicated on the constant interactions of individuals and the environment where the learner is placed at the centre of the process as movements and decisions are made based on unique interacting individual, task and environmental constraints. As such, small changes to individual structural or functional constraints (such as increased strength), task rules or equipment, or environmental constraints in learning contexts can cause dramatic changes in movement patterns.

*A Constraints-Led Perspective on motor learning*

It has become apparent in the dynamic interactive settings of physical education that movement skill acquisition occurs as a consequence of the interplay of numerous interacting constraints, which need to be considered in pedagogical practice (e.g., see Davids, Chow & Shuttleworth, 2005). These constraints on learners include the morphology, emotions, cognitions, intentions and developmental status as well as social and cultural factors, which share strong interconnected relations with the environment and learning tasks (Araújo et al., 2004). Such an embodied model of motor learning (Van Gelder & Port, 1995) views mind, body and the environment as continuously influencing each other to shape behaviour. From this perspective, motor learning is a process of acquiring movement patterns which satisfy the key constraints on each individual (Davids et al., 2005). As movement skills emerge from the interactions of key constraints in learning situations, physical educators could adopt a pedagogical approach that considers the dynamic interactions that occur in teaching and learning interventions. Essentially, the role of the teacher is identification and manipulation of the key constraints to facilitate the emergence of functional movement patterns and decision-making behaviours in different sports and physical activities (Chow et al., 2006). Next we define the key constraints on neurobiological systems before we discuss the role of constraints in shaping system outputs in the form of movement patterns in team ball games.

*Performer, Environmental and Task Constraints*

Constraints have been defined as boundaries which shape the emergence of behaviour from a movement system (e.g., learner) seeking a stable state of organization (Newell, 1986). The interaction of different constraints forces the learner to seek stable and effective movement patterns during goal-directed activity. Through self-organisation processes, inherent to many different biological systems including human movement systems, constraints can shape the emergence of movement patterns, cognitions and decision making processes in learners (Passos et al., 2006). Because of the interconnectedness of such systems, a small change in one part of the system can reverberate through it leading to large scale global changes emerging. Although the efficacy of the constraint-led approach has not been formally tested via empirical work in school settings, there are numerous examples showing how constraints shape sport performance.  For example, changing the mode of ball delivery in cricket batting, from a bowler to a bowling machine, leads to a significant re-organisation of the timing and co-ordination of the forward defensive shot (Renshaw, 2007). This change is caused by de-coupling perception and action thus preventing batters from utilising pre-delivery information that is available with the bowler’s action (e.g., Müller, Abernethy & Farrow, 2006). (For more detailed reviews of key theoretical concepts in the constraints-led approach see Araújo et al., (2004) and Davids, Button & Bennett (2008).

Newell (1986) classified constraints into three distinct categories to provide a coherent framework for understanding how movement patterns emerge during task performance. The three categories of constraints are: performer, environment and task (see Figure 1).

*Performer constraints* refer to the unique structural and functional characteristics of learners and include factors related to their physical, physiological, cognitive and emotional make up. A learners' morphology, fitness level, technical abilities and psychological factors like anxiety and motivation may shape the way individuals approach a movement task. These person-related factors provide affordances (possibilities) for action and play a significant role in determining the performance style adopted by individuals. For example, taller basketball players are more likely to seek points from rebounds and dunks, than smaller players who may opt for set shots from different distances. These different constraints on individual learners illustrate the distinct strategies that games players may use to solve movement problems in team sports. The solutions which emerge from the activities of different learners has important implications for how pedagogists structure learning tasks for acquiring movement skills as well as game play. These unique performer characteristics can be viewed as resources for each individual that channel the way in which each learner solves particular task problems or characteristics that can lead to individual-specific adaptations. Personal constraints should, therefore, not necessarily be construed in a negative light by pedagogists, an important point in adaptive physical education. It is clear that movement solutions will vary as each individual strives to satisfy the unique constraints on him/her. Variability in movement patterning can play a functional role as each individual seeks to achieve a task goal in his/her own way (Davids, Bennett & Newell, 2006).

*Environmental constraints* refer to physical factors such as the surroundings of learners including gravity, altitude and the information available in learning contexts, such as amount of light or level of noise in a gymnasium or sports field. Other important physical environmental constraints include the parks, backyards, empty spaces and alleyways that provide the backdrop for early sport experiences of many active children. The importance of these environments should not be under-estimated in the development of expertise in sport as they provide a non-threatening environment where children can learn to play sports without the pressure of adult interference. A second important category of environmental constraints includes social factors like peer groups, social and cultural expectations. Such factors are of particular relevance for young learners whereby motor learning is often strongly influenced by group expectations, trends and fashions, and the presence of critical group members such as the teacher or class-mates. Availability of parental support, access to high quality teaching and adequate facilities are powerful environmental constraints on movement skill acquisition recognized by physical educators.

Finally, *task constraints* are perhaps the most important constraints for physical educators because of their significance in learning. They include the goal of the specific task, rules of the activity and the implements or equipment used during the learning experience. The proficiency with which physical educators can manipulate task constraints like modifying equipment available to learners, or the size of playing areas, setting relevant task goals in games or enforcing specific rules for performance can shape the emergence of learner's behaviours in physical education. Task constraints play a powerful role in influencing learners' intentions and are open to manipulation within an instructional setting (see Williams, Davids & Williams, 1999). To exemplify, when using the popular Teaching Games for Understanding (TGfU) approach to teach net or invasion games, teachers often change the dimensions of courts or pitches as practice environments to encourage emergence of particular movement solutions desirable for learners to acquire. In badminton, for example, if children have no understanding of the important game principle of hitting to space, teachers often create a long and narrow adapted court compared to a wide and shallow court. The perceived information from the task constraints (long narrow courts), together with the intention of the performer, will accentuate the overall variations in length of shots (i.e., long and short). This manipulation of task constraints could lead to the performer hitting overhead clear and drop shots or underarm lifts in an attempt to win a rally by exploiting the space in front of or behind the opponent.

However, effective manipulation of task constraints requires physical educators to possess a mastery of knowledge and experience in specific sports, games, and physical activities to lead learners towards discovering functional coordination patterns and decision-making behaviours. Physical educators are well placed to make such small but important changes to learning environments, leading to large scale changes in movement patterns during motor learning. To summarise, Newell's (1986) constraints model provides an excellent conceptualisation to guide physical education practice because it adequately captures the rich range of diverse constraints acting on learners during skills learning and games participation. It provides a framework which emphasizes the important interactions of individual, environmental and task constraints in a balanced perspective. Since the first two categories are unique to individual learners, it follows that variability in movement solutions should be expected by physical educators (Davids, Button & Bennett, 2007). Understanding the unique task constraints on each learner will help physical educators to design effective learning environments in team games.

*Representative practice task design*

A key underpinning concept in ecological psychology is the mutuality of the individual and the environment (Gibson, 1986). The implication for physical educators is the need to identify the key information sources that learners can use to co-ordinate actions and make sure that this information is made available in specific performance contexts. Learners can then attune their movements to these essential information sources through practice, thus establishing strong 'information-movement couplings' to guide their behaviour. One of the most important task constraints to consider is the information available in specific performance contexts that learners can use to co-ordinate actions. Many neurobiological systems, including humans, are surrounded by huge arrays of energy that can act as information sources (e.g., sight, sound, tactile) to support movement behaviours, including decision making. Humans must not only perceive information in order to move, but must also move in order to perceive more information for action (Gibson, 1979). Learners can attune their movements to essential information sources through practice, thus establishing strong ‘information-movement couplings’ to guide their behaviour. The implication for physical educators is that they need to manipulate informational task constraints to direct learners towards functional information-movement couplings that will allow them to achieve task goals (Davids, Williams, Button & Court, 2001).

Representative task design is essential if the learning opportunities for children are not simply going to be based on a recipe book approach which have worked with other groups but have not been designed specifically based on the needs of the individuals in any specific situation. As such, skill interjections (see Kidman, 2005) and progressions in adapted games used in approaches such as TGfU should be based on an understanding of the key constraints acting on children at any one moment in time. We will return to this point later.

*Affordances*

Tightly enmeshed in the ideas of individual; environment mutuality and the circular relationship of perception and action is the concept of affordances. Gibson (1986) describes affordances as opportunities for action provided for the animal by the environment. Affordances are opportunities for action and are defined relative to the action capabilities relative to the individual (Fajen, Reilly & Turvey, in press). In games the outcome of a match can often depend on the player’s ability to determine whether or not a behaviour is possible. For example, the decision to kick for goal or kick for touch when awarded a 50m penalty in rugby union may determine the outcome of a tightly contested game. Crucial to the decision is that the kicker needs to know his action capabilities to decide if the distance is *kickable*.

Similarly, the centre in netball must be able to determine if a pass between two defenders to an open goal shooter will be *interceptable* or not. It is worth noting that an affordance may be transitory in nature. The kick maybe kickable on a firm pitch with no wind, but is unkickable on a soft surface with a strong wind in the kickers face. Similarly, if the defender delays the pass it may allow the defenders to move to close off the passing opportunity. What should be clear from this discussion is that athletes need to be placed in realistic learning environments where they can attune to information enabling them to make intelligent and informed decisions based on understanding of their own, team mates and opponents action capabilities (see Fajan et al., (in press) for an excellent, detailed discussion of the place of affordances in sport).

*Constraint-led teaching in practice*

Clearly, then research has shown that individuals can assemble relatively unique movement solutions in order to satisfy the interacting constraints of performance or learning environments. In this section we will consider some of the key implications of these ideas for games teachers in adopting a constraint-led approach.

Practice Design

In many team games, teaching movement skills by decomposing the task into manageable components is a traditional method commonly used to manage the information load on learners. Complex coordination patterns such as serving in volleyball, for example, are often taught by separating the toss from the hitting action. However, this traditional approach of *task decomposition* may decouple the relevant information-movement coupling so that it becomes quite challenging for learners to perform the action (Handford, 2006). Instead, *task simplification* is a method which allows different components of complex coordination patterns to be learned in tandem, allowing information and movements to remain coupled throughout. Task simplification in serving can occur as learners begin by hitting the ball out of the hand, before gradually releasing the ball into the air during the hitting action. Eventually, the toss and serve components can be practised as the simplified action is gradually made more challenging to learners. Additional manipulations to task constraints could facilitate effects of task simplification in learning to serve in racquet sports. The provision of bigger and softer balls or shorter handles on racquets could allow learners to successfully complete an overhead serving action without compromising the important time-position relationship in the movement. A similar decomposition approach is also common in invasion games to teach skills such as dribbling in soccer. Because the demand of perceiving the position of team mates and opponents is deemed too demanding for our limited attention system, young players are first taught to dribble in static drills often by dribbling past cones (Williams, Davids & Williams, 1999). However, given the superior perceptual skills of experts in invasion games to underpin their decision-making (Williams, Davids & Burwitz, 1994), there is a need for practices to facilitate the development of perception-action in unison. We provide an example of how teachers can adopt these principles when teaching the invasion game of rugby union and the striking and fielding game of cricket.

*Practice as repetition without repetition: The functional role of movement variability*

What does a constraints-based framework imply for the process of practice? As a result of practice and experience, successful learners undergo a permanent behavioural change. In physical education settings this process involves learning to adapt movement patterns to achieve consistent movement outcomes in the face of unexpected changes as performance contexts vary e.g., due to the weather, surface or other environment factors (Liu, Newell & Mayer-Kress, 2004). The implication is that physical educators need to implement a variety of appropriate constraints to help learners effectively search for successful movement solutions in a practice environment. The search process should allow for flexibility and adaptability so that learners can generate a movement solution that is unique to his or her personal, task and environmental constraints. Functional variability in movement facilitates a 'discovery approach' in physical education lessons by allowing learners to establish effective coordination patterns which satisfy task constraints. This viewpoint not only provides a tangible link with existing pedagogical practice in approaches such as TGfU, but illustrates how some physical educators might require a different perspective on movement variability.

Movement variability has traditionally been viewed as dysfunctional and a reflection of 'noise' in the central nervous system (Slifkin & Newell, 1998). A constraints-led perspective, however, suggests that movement variability is an intrinsic feature of adaptive movement behaviour as it provides the flexibility required to consistently achieve a movement goal in dynamic sport environments (Williams et al., 1999). In fact, individuals find it challenging to repeat a movement pattern identically across trials (Davids, Button & Bennett, 2008). Variability in movement patterns permits flexible and adaptive motor system behaviour, encouraging free exploration necessary in dynamic learning and performance contexts like team games. During skilled performance it is important to consistently repeat a performance outcome, although the movement pattern used to achieve this outcome may not be repeated in an identical way every time. This feature of 'repetition without repetition' (Bernstein, 1967) in human movement systems provides learners with the capacity to invent novel adaptations to solve typical motor problems. This paradoxical relationship between stability and variability is necessary because skilled games players need to be capable of both persistence and change in movement during sport performance (Davids et al., 2003).

Another implication for physical educators is to accept that movement variability may be an integral process in learning and acquiring effective movement patterns specific to a task goal. However, this is not to say that physical educators should merely allow ‘free play’ and hope that learners complete a set task/ game situation in whatever way the learners deem appropriate! The essence of the constraints-led perspective is to facilitate new movement solutions by designing learning environments that provide controlled boundaries of exploration in dynamic settings through the provision of relevant task constraints. A coach who used these principles in his practice is Ian Connolly, Nick Faldo’s first golf coach. Connolly required Faldo to spend long periods of time hitting with only a six-iron. However, he would require him to hit all sorts of shots-high, low, draw, fade in order to create different flight trajectories. By doing this, the coach argued that Faldo was learning to ‘use his hands better’ and with that came a better feel for the shots (Concannon, 2001: and see Gallwey, 1979). In effect, Faldo was exploiting the motor system degrees of freedom available to him, allowing himself to develop adaptability and flexibility in his shot making repertoire.

*Harnessing the concept of self-organisation in physical education teaching*

As highlighted earlier, motor system degrees of freedom (or parts of the body) have the neurobiological capacity to self-organise, that is adjust to each other as task constraints change. Through these inherent processes of movement systems, the interacting constraints of the individual, environment and task can lead to the spontaneous formation of movement patterns. The term ‘spontaneous’, as used here, should not be taken to mean that the co-ordinated pattern is randomly constructed or that there are infinite ways that the body can organise itself.  Any coordination pattern that emerges during practice and learning (Williams et al., 1999) is a function of the mechanical principles of the structure of human movement systems as well as the interacting task and environmental constraints.

Many physical educators and practitioners have understood that athletes have this self organising capability, although they may not have studied the scientific concepts and tools to describe the neurobiological processes involved. For example, Gallwey (1979) based his Inner Game concept on the idea that, via exploration, the body will self-organise to produce goal directed co-ordinated movement patterns. In line with the ideas of Bernstein (1967), he suggested further that self organisation via experiential practice is a 'natural learning process' and that an over-reliance on prescriptive instructions by teachers has undermined the opportunity to learn in this (unconscious) intuitive way.

In physical education these ideas from neurobiology might be illustrated as a potential platform for explaining the successful implementation of TGfU. Existing research on TGfU has not adequately tapped into theoretical ideas on self-organisation from the constraints-led perspective as a mechanism to explain how movement skills and game sense might emerge. This omission might be a missed opportunity given that TGfU has been criticised for lacking a strong theoretical framework (e.g., McMorris, 1998). Chow et al. (2006, 2009) have argued that concepts such as self-organisation under constraints might illustrate how a constraints-led perspective could be valuable in explaining the merits of TGfU as a pedagogical approach in games teaching.

*How constraints decay and emerge during motor learning*

Setting appropriate challenges for learners is in itself a challenging task for physical educators. A key skill is identifying the most important performance aspect that an individual or a team needs to work on at any specific stage of their development. In essence, teachers need to be able to identify whether key constraints may act as 'rate limiters' to improved performance. Guerin and Kunkle (2004) highlighted how task constraints themselves are dynamic and can emerge and decay over time. For example, in a study of kicking in football, Chow et al. (2005) investigated how learners adapted to emerging and decaying task constraints within the same learning context. In a kicking task, novice participants practised kicking a ball over a height barrier onto specific targets for 12 practice sessions over a four-week period. Height and accuracy constraints were evident in the kicking task, as participants attempted to kick the ball over a bar (height constraint) so that it landed on specific target positions (accuracy constraint). Performance measures were determined over 480 practice trials. Results suggested the participants initially focused on kicking the ball over the bar with little concern for accuracy. Subsequently, as participants were able to clear the height barrier more consistently and successfully, they concentrated on ensuring that the ball landed accurately on the target. Specifically, the height constraint decayed in importance and the accuracy constraint emerged as increasingly more pertinent.

Late in practice, performance scores and percentage of successful kicks showed an increasing trend, suggesting that the accuracy constraint had emerged and participants were getting their kicks over the bar and accurately to target positions. From a nonlinear pedagogical perspective, the decay or emergence of task constraints demonstrates that constraints on behaviours dynamically evolve over time and should not be viewed as permanent (see Guerin & Kunkle, 2004). Rather, constraints on learning are temporary, and during person-environment interactions, they strengthen or decay on different timescales (Chow et al., 2006). Figure 1 summarises conceptually how task constraints, based on importance to the learner, decay and emerge as a consequence of learning in the soccer kicking study.

---------------------------------------------Insert figure two here-----------------------------

*How coaches and players have used the ideas of constraints-led coaching*

Although the constraint-led approach has only recently emerged as a theoretical explanation for motor learning, many thoughtful teachers have tended to use the ideas of constraints to facilitate performance improvement during physical education lessons. Below we provide some practical examples illustrating the use of constraints by teachers.

*Developing individual constraints*. A common weakness in young cricket batters is a failure to control the bat with the top-hand on the bat (the term 'top- hand' refers to the arm and hand unit). Usually, as most batters are right handed, the top-hand is the 'weaker' left. Coaches have adopted strategies to enhance the strength and endurance of this unit. For example, Indian batsman Virender Sehwag's first coach made him use just his top hand to swing a bat in a case filled with sand repeatedly in order to strengthen the arm. A consequence of a weak top hand in batting is often the inability to swing the bat in a straight line. So, in order to make him pick his bat up straight, Sehwag's coach stuck a piece of bamboo in the ground just outside off stump. If the bat was not picked up straight he would hit the bamboo (Wright, Ugra & Thomas, 2006). This practical example neatly demonstrates how a games teacher can use an understanding of the interaction of individual and task constraints in order to shape behaviour.

*Manipulating task constraints*. Manipulating task constraints is perhaps the most common way in which teachers and coaches have attempted to improve learners' performance from this theoretical viewpoint. Often, teachers introduce artificial rules in order to emphasise a specific aspect of performance (e.g., requiring teams to make 10 passes before scoring). However, from the point of view of no-linear pedagogy, changes to game rules must be based on the key pillar of task representativeness in order to provide learners to attune to key affordances in order to develop appropriate information-movement couplings. A good example of a coach who uses this approach in rugby is Wayne Smith, the All Blacks coach. He manipulates task constraints in training games that require players to work out task solutions for themselves; “You think of a way, e.g., if you want to work on your forwards picking the ball up and going through the middle of the defence, you create ways to spread the defence at training (Kidman, 2005, pp196).” In invasion games, task simplification by reducing the number of players in teams is a common strategy used by teachers in order to reduce the attentional demands on players. However, this approach has encountered some resistance from adults who want to see the children play the ‘adult version’ of games as soon as possible. The importance of playing small-sided games has recently been highlighted in the context of football by Fenoglio (2003). In a recent report on the use of 4 v 4 games at the Manchester United academy, Fenoglio (2003) showed that by playing 4 v 4 rather than 8 v 8 games, players made 135% more passes, had 260% more scoring attempts and scored 500% more goals. In addition, the number of 1 v 1 encounters between attackers and defenders increased by 225% while the number of dribbling tricks demonstrated by learners increased by 280%. The increased frequency of these important sub-phases of football during practice tasks clearly allows learners greater opportunities to practice basic skills and to gain more experience of tactical requirements in game contexts. The advantages of small-sided games for physical conditioning have also been demonstrated. A recent study by Impellizzeri et al. (2006) found that using small-sided games, compared to interval training for example, resulted in similar levels of improvement in aerobic fitness and match performance for junior soccer players.

In summary, there is some anecdotal evidence that teachers and coaches have intuitively tended to use the method of identifying and manipulating key constraints on learners. Regardless of this intuition it is essential that practitioners understand the theoretical concepts that underlie the constraint-led approach since this will enable them to develop a model of the learner and of the learning process that will further enhance their practice. For example, a good understanding of the concepts of decaying and emergent constraints can help them to construct practice sessions that are more attuned to an individual’s current developmental status.

In the following section, we use rugby union and cricket as examples to demonstrate how teachers can implement a constraints-led approach to develop all performance components in an inter-disciplinary manner. The activities in each of the sessions are based on creating learning opportunities that are based on the guiding principles of non-linear pedagogy in that they encourage self organisation under constraints by providing ‘repetition without repetition’, create high levels of variability in representative tasks that enable the participants to become attuned to key affordances. The design of the activities is not based on prescribing specific solutions, but encourages the development of adaptive performers who are able to find the best solution at any one moment in time (Button, Chow & Rein, 2008). An important pedagogical practice underpinning non-linear pedagogy is that verbal instructions and feedback should not prescribe movement solutions but encourage exploration and use of learning strategies to allow natural self organisation processes to take place. Forcing learners to attend to inappropriate information sources should be avoided and good practice would direct individuals to search for the most useful information to underpin their actions and decisions. As such, we provide examples of questions that may guide this search process as part of developing autonomous, intelligent performers who understand their own performance.

First, we will highlight rugby activities which have the aim of helping players to improve their ability to use and create space as individuals and as a team. We will show that by using this approach it is possible to teach the ‘unteachable’ attacking skills such as the body swerve or the support player changing his or her running line very late in order to receive a pass outside the immediate defender. Second, we will show how batting against spin (and bowling spin) can be developed within a cricket lesson. This approach will show how perceptual, decision-making and technical skills can be developed for batters and bowlers.

**Theory into Practice 1: Suggested activities for a rugby lesson in physical education**

A key feature of success in rugby is the ability to beat opponents in sub-phases of the game such as 1 v 1s and 2 v 1 and 3 v 2 scenarios. Some recent research has helped in developing our understanding of these staple scenarios in rugby union football. Passos et al. (2008) have shown that a key feature of the 1 v 1 is the median distance between the defender and attacker which can determine whether the status quo is maintained (defender between the try line and the attacker), the attacker is stopped via a tackle or if a change of pattern (the attacker goes past the defender). Gréhaigne, Richard & Griffin (2005) noted that the ability to identify a 2 v 1 situation in team games is highly dependent on expertise, since beginners cannot identify when an outside defender has not moved up in line with the inside defender. These empirical findings highlight the need to provide teaching activities that enable players to have as much experience as possible in situations that are representative of match demands.

----------------------------------Insert Table 1 about here-------------------------------------

Below we discuss some learning activities (see Table 1) that show how these principles can be put into practice in a lesson designed to improve decision-making in rugby, often the key rate limiter in individual performance. The games and activities are set up so that players can develop perceptual, decision-making and technical skills at the same time. For example, with modifications to ‘standard’ ball handling warm-ups, players can work on developing game specific perceptual skills, leading to better decisions about timing and selection of pass, the support running line to take, and how to use and create space as an individual and as a team. In the warm-up activity in this lesson, players working in pairs (with one ball) are allowed to move freely around a grid. The grid sizes can be made smaller or larger depending on the skill level of the group and the ‘types’ of passing one wants to work on. For example, if one wants to work on close contact type passing such as pop passes, passes out of the tackle, ‘rolling maul/hit and rip’ type passes; the practice space may be reduced. On the other hand, if one wants to work on longer passes or lines of running typical of back play, the practice space may be enlarged. Teachers can provide players with options that allow them to make accurate decisions. For example, one could ask learners to decide to pass before they go past another player (an ‘opponent’) or to wait until they have advanced past him/her and then pass behind his/her back. Support players can be encouraged to adopt running lines that take them into or ‘through’ a space; Teachers could pose questions such as: Can you receive a pass as you accelerate between two players? Can you take the ball ‘short’ or long’? Can you change your running line at the last minute to go inside or outside an ‘opponent’? The value of this warm-up is that teachers can use creativity to replicate many re-occurring game situations. For example, the initial position of the support runner can be modified, or a few passive defenders could be introduced.

A common rugby drill where a group of four learners pass the ball down the line to the last player as they move across a grid before passing the ball on to the next four players who are waiting opposite (four groups would be used in each grid) has been adapted to develop the first ‘game’ in this lesson. In this game, each group of four has a ball and the first two groups, who are facing each other, work towards each other at the same time with the goal of scoring a ‘try’ over the opposite end of the grid (or pitch). Shortly after the first two groups have started, the teacher will start off the next two groups who will compete against each other. In order to successfully achieve the task, each of the players will have to make a decision to pass before or after he/she goes past the immediate ‘opponent’ (an individual in one of the two groups of four moving towards his/her group). The challenge to advance past an immediate opponent signifies time pressure for the learners, thus replicating the game demands. This game enables players to develop (a) an awareness of the timing of passes, (b) to be creative (and adaptable) in getting a pass away when a 'typical' pass is impossible, (c) to work on support running lines that use spaces between defenders (d) the technical skill of taking and giving a fast pass, and (e) fitness. As in the warm-up activity, teachers can increase the demands on the players by setting specific task goals that players must achieve before they can score. For example, teachers could add a rule that two players must change position before the team can score. Introducing new task constraints like these will lead to the players exploring new solutions and solving the problem in often innovative ways. For example, one may observe the players developing a normal 'loop', a 'miss move and a loop', a 'scissors' where the pass was made before the 'opposition' were passed, as well as a miss with a pass around the back of the 'opponent'. These task constraints encourage players to become inventive in their movement solutions.  These ideas illustrate how teachers can design lessons for developing individual and team flair when attacking in team games such as rugby. As we highlighted earlier in the paper, by adopting the constraint-led approach, teachers can manipulate constraints to expose players to 'repetitive' but constantly changing situations that require them to discover creative movement solutions by adapting to the movement patterns of opponents in evolving practice games.

The final game in this session has been designed to help children develop control over the ball when they are tackled. Analogy learning is emphasized focusing on movement effects on the environment since the aim of the drill is for the player to learn to 'set the ball in concrete' after being tackled. However, rather than practising the skill in a drill with static opposition kneeling on four corners of a grid (Biscombe et al., n.d), players learn via a game of 8 v 8, in which they are informed that if they can 'set the ball' correctly, their team would get a ‘free pass’, with the nearest supporting player acting as the scrum half (half back). Not only can this approach result in the tackled player setting the ball correctly, it can result in the other players lining up for ‘second phase’ play, a concept that young children can find difficult to grasp. The acquisition of the technical skill of placing the ball down within a game situation allows a change of focus for the lesson. Teachers can talk to the scrum half and ask questions about the most appropriate decision to be made to continue the attack *after* the tackle. These practice task constraints could encourage him/her to get the head up and make a decision about whether to attack alone (going to the blind or open side), or to make a pass to the open side or blind side. A knock on effect of these practice task constraints is that they can provide many opportunities for players to experience 4 v 3, 3 v 2 and 2 v 1 sub-phases of the game. Although this constrained game can be very effective for virtual beginners, similar task constraints have also been used with international players (e.g., Smith, O’Shea & Villepreux, 1991).

**Theory into Practice 2: Suggested activities for a cricket lesson to develop batting and bowling skills**

Recent research has highlighted the importance of cricket batters developing the ability to identify the type of spin put on a ball by observation of the bowler’s action (Renshaw & Fairweather, 2000). Additionally, developing this ability does not require verbal coaching instruction, but can be learned via exposure to bowling deliveries (Renshaw, Fairweather, Rotheram, & Oldham, 2003). The importance of identifying ball type has been demonstrated in a study that examined batting technique when facing a bowling machine and a bowler of comparable speed (Renshaw et al., 2007). This study showed that changing the perceptual constraints of practice (i.e., from ball delivery by bowler to bowling machine) led to significant differences in coordination and timing of a forward defensive shot. The lack of opportunity to extract information from the bowler's action led to batters waiting for early ball flight information before they could organize a response. These findings highlight the importance of players being exposed to spin bowling from an early age so that they can become attuned to perceptual information that is available from the bowler's action and from ball flight (Renshaw et al, 2003 and see Philpott, 1984).

Insert Table 2 here

In the suggested activities, a series of games are designed which provide practice task constraints to facilitate progression in the skill of bowling spin and perceiving spin for batting (a rate limiter for non expert batters). The first activity is a simple game which helps players to learn to spin the ball (with disguise), requiring them to identify the type of spin on the ball and couple their response to this action by catching it. The close proximity of the two players enables the receiver to have a close view of the ball as it is released from the hand, encouraging him or her to learn to associate specific hand and wrist movements with specific spin types imparted on the ball. Two-coloured tennis balls or cricket balls with the seam highlighted can be used to make it easier or harder to identify spin variety. Alternately, unmarked balls can be used (see Hyllegard, 2001) to show the importance of the seam in identifying spin type. To progress the task demands, players can move further apart and the ball should be bowled to each other's 'goal'. This task can now be made more realistic by bowling overarm as in a real cricket match. To encourage the 'batter' to attune to bowling action information (rather than waiting for ball flight information) one could ask him/her to move onto the line of the ball as early as possible (with points awarded for correct decisions). The final two games require batters to make decisions about shot selection to hit spun balls through scoring zones. To facilitate this decision-making, the ball is delivered by a team-mate. This mutuality emphasizes the reciprocal relationship between the actions of teammates and opponents in sport showing why isolated skill drills may not be the most appropriate way of developing performance.

**Summary of implications for physical educators**

We have argued that a constraints-based perspective has the potential to provide physical educators with a framework for understanding how performer, task and environmental constraints shape each individual's physical education. We presented some important implications for designing practices in games lessons, showing how a constraints-led perspective on motor learning (e.g., Davids, Button & Bennett, 2007), could assist physical educators in understanding how to structure learning experiences for learners at different stages. Valid categorisation of the constraints on each learner could help physical educators to understand how differences in intrinsic dynamics lead to different, yet appropriate performance outcomes for different learners and to effectively plan progressions in lessons and activities in physical education. We discussed how, in nonlinear pedagogy, the design of activities and modified games based on principles of ecological psychology and dynamical systems approach such as task representation, self organisation and the need to provide opportunities for attunement to affordances can provide a channel for manipulation of task, personal and environmental constraints on each individual. We noted how these applied scientific ideas were harmonious with some tenets of the popular games teaching approach of TGfU. In the exemplar lesson activities, we showed how a teacher could present more complex activities by progressively manipulating specific task, performer and environmental constraints to guide learners to explore relevant movement solutions. The challenge for teachers is not just to understand how to manipulate constraints, but to identify key individual constraints that can be presented to students to encourage learning. The nonlinear pedagogical approach is student-centred and empowers individuals to become active learners. The manipulation of constraints within physical education lessons encourages learners to engage in self-discovery that could lead to greater psychological engagement in sport and physical activity. The focus on the individual in the constraint-led approach enables the teacher to design a range of games and tasks based on their intrinsic dynamics and focus on overcoming rate limiters. This approach has important psychological benefits as it facilitates student achievement at a level appropriate to their unique intrinsic dynamics. This is important, because as Thorpe in Kidman (2005) points out, lesser-skilled players can still play games well (they make good decisions based on an understanding of their capabilities). However, despite the abundance of studies using movement models that demonstrate the efficacy of the constraint-led model to explain performance, more research on nonlinear pedagogy is needed to determine how changes in learning contexts can be organised through the application of key principles from the constraints-based framework on motor learning in the school setting. It is only through theoretically valid and objective empirical work of an applied nature that a conceptually sound nonlinear pedagogy model can continue to evolve and support research in physical education.

The exemplar lesson activities provided some implications for physical educators concerning the role of constraints in acquiring movement skill and game play knowledge. Physical education teachers are aware that learners do not present themselves as a blank slate and that every individual enters a new learning situation with pre-existing set of physical attributes as well as skill capabilities. Moreover, interactions with the environment and task constraints in a learning context will shape the emergence of movement behaviour that may or may not meet the task goal. The challenge for the teacher is to manipulate task constraints so that a functional movement solution may be acquired by each learner. Task constraints should be manipulated so that information-movement couplings are maintained in a learning environment that is approximate to a real performance situation. Physical educators should also understand that movement variability may not necessarily be detrimental to learning and could be an important phenomenon prior to the acquisition of a stable and functional movement pattern.

There really is no silver bullet for all teaching and learning situations. However, understanding the underlying neurobiological processes present in a constraints-led perspective to skill acquisition and game play can raise awareness of physical educators that teaching is a dynamic ‘art’ interwoven with the ‘science’ of motor learning theories.

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Figure 1: Graphical representation of the interacting individual, task and environmental constraints that act to shape behaviours. The role of the teacher is to manipulate constraints based on assessment of the needs of individuals and groups (adapted from Newell, 1986).

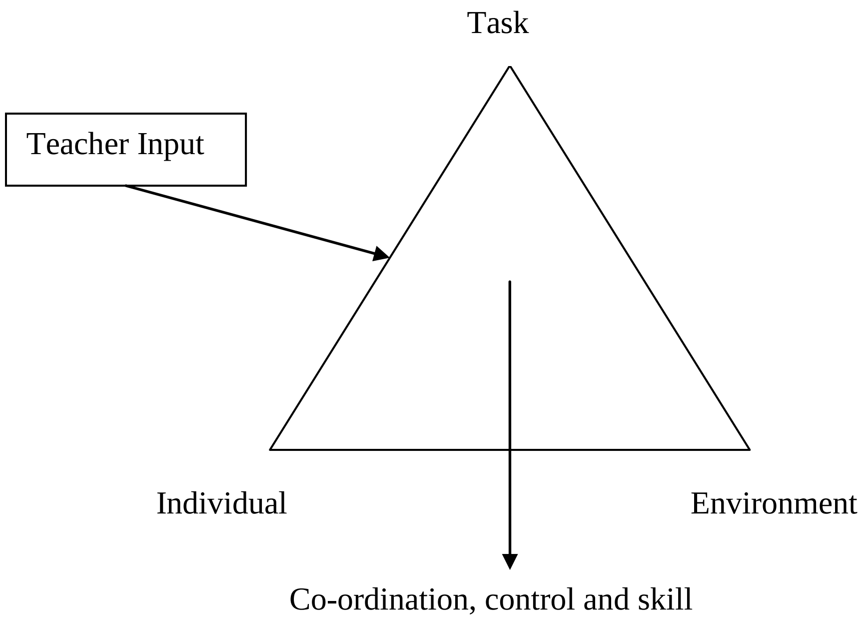

Figure 2: A conceptual summary of how task constraints, based on the importance perceived by the learner, decay and emerge as a consequence of learning in the soccer kicking study.

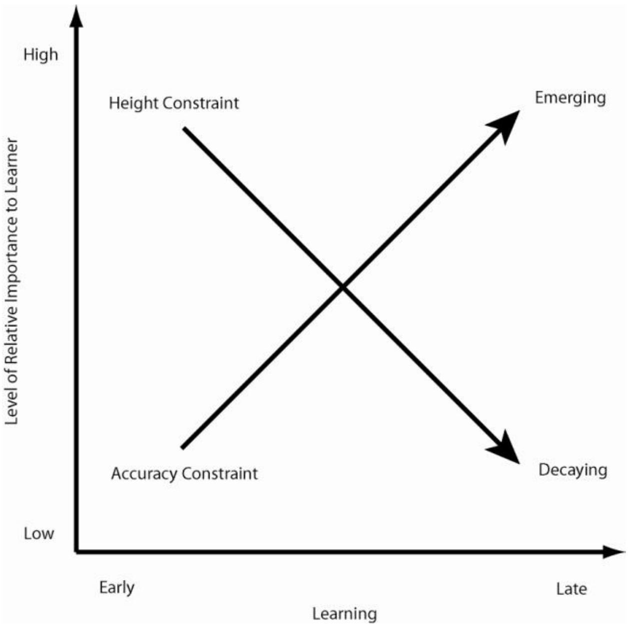

**Table 1:** Exemplar Rugby lesson activities:

**Individual Constraints:** Limited recognition of the affordances guiding action in attacking play; losing control of the ball in the tackle.
**Task Constraints:** Manipulating time and space, game rules, player numbers

**Aim of the session: To improve individual and team decision making.**

## *Background Information*

Equipment Needed: Playing area: 30x20 Number of Players: 12-18 Session Length: 60 mins Age: 13
Experience level: Intermediate/Advanced

| Time | Task | Organisation | Questions |
|---|---|---|---|
| 0-10 mins | Warm-up:<br>In pairs passing as you move around the grid.<br>• Pass before, after, over, change direction, off the ground,<br>• Start side by side, start truck and trailer<br>• Find different ways of passing… | 20x20 (30) | What sort of passes could you use when the space is tight?<br>How can you pass when a defender is in the way? |
| 10-25 | Game One: Attacking using pace and movement<br>• Work across the grid and back.<br>• Score a try with everyone touching the ball at each end.<br>• Score as quickly as possible (no need for everyone to touch the ball) but must go to end player and back to start player.<br>• Score with last man but middle two players must change position<br>• Take the pass short inside the defender or long outside him | 1 channel of 10 x 20 m<br>4 per group | Can you hear the players talking?<br>How do you get the ball through your hands faster?<br>How can we get the ball wide quicker?<br>Who calls and when? |
| 25-40 | Game Two: Going through or going round<br>• The try must be scored at the end where you started (there & back)<br>• On way back attack in zone A, B or C<br>• Require the players to bring variety into their solutions | 3 channels of 10m x 20 m (A, B & C) | Which channel should you attack in?<br>On what information should you base the decision?<br>Who calls it?<br>When is the call made?<br>What determines how quickly we can get the ball wide? |

| | | | |
|---|---|---|---|
| 40-60 | Game Three: 8 v 8 game (1 v 1 scratch scrummage)<br>• If tackled player places ball down (still) the attacking team get a free pass)<br>• Extension: Score tries by finish positions being different to the starting positions 2nd phase ball | 8 v 8 in 22 m (wide and short pitch) | Which side should the “half back” attack? Why?<br>How do you decide your starting position?<br>Can you integrate some of the decisions from the previous practices? |

**Table 2:** Exemplar cricket lesson activities:

**Individual Constraints:**

Perceptual skills: Inability to identify ball type from bowler's actions; Decision-making: Poor shot selection. Actions: Limited action capabilities (ability to spin the ball, limited range of sweep shots).

Task Constraints: size of playing area, scoring zones, ball type

**Aim of the session:**

1. To improve the ability of the players to bowl spin.
2. To provide opportunities to develop perceptual, decision-making and technical skills of batting against spin.

## *Background Information*

Number of Players: 12-18 Session Length: 60 mins Age: 12+ Experience level: Intermediate/Advanced

| Time | Task | Organisation | Questions |
|---|---|---|---|
| 0-10 mins | **Game One: Spin it to win it.**<br>**Aims:**<br>• To develop perceptual skills of 'picking' spin bowlers.<br>• To develop the skill of catching<br>• To develop disguise in bowling<br>•<br>**Rules:**<br>1. Standing on the edge of one side of the square, the ball must be delivered underarm to land on your opponent's side of the court.<br>2. Your opponent must catch the ball before it bounces twice or you score a point.<br>3. Alternate "serves".<br>4. Play a 5-point game (win 5-0, 4-1, 3-2).<br>5.<br>**Extensions:**<br>1. Catch with one hand.<br>2. Increase length of pitch (you can now stand where you want but you have to let the ball bounce). | 2m x 2m square with a line across halfway.<br><br>(1 ball & 4 cones) | • How can you make it more difficult for your opponent?<br>• How can you work out what spin is on the ball?<br>• Where is the best place to stand in the "long court" game? |
| 10-25 | **Game Two: Pick It!**<br><br>**Aims:**<br>1. To develop disguise and variety in spin bowlers.<br>2. To develop the skill of wicket keeping | | • How can you disguise the deliveries? |

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| | catching<br>3. To develop the ability to pick spinners<br><br>**Organisation:** 2 sets of stumps across the hall.<br>**Equipment:** 1 ball<br><br>**Rules:**<br>1. Bowl the ball to your opponent.<br>2. Your opponent must ‘move’ in the direction of the spin before the ball lands.<br>3. A correct call gets one point.<br>4. A successful two-handed catch after the ball has passed the stumps gets one point.<br>5. First to score 20 points.<br><br>**Extensions/Changes:**<br>1. Bowl underarm<br>2. Change the type of ball | | • How can you make it more difficult to catch the ball?<br>• How can you tell what type of spin is on the ball?<br>• What is the most effective way to catch the ball? |
| 3060 | **Game Three: Sweeps**<br><br>**Aims:**<br>1. To develop the skills of sweeping.<br>2. To develop the skills of decision-making when playing spin<br>3. To develop decision-making skills when setting fields to spin bowling<br>4. To practice fielding when the ball is spinning.<br><br>**Rules:**<br>1. Each batter will face 6 balls<br>2. The feeder/bowler will be from the batting team (underarm)<br>3. Score one every time you hit the ball through a zone.<br>4. Fielders can choose which zone(s) to defend.<br>5. Out caught loses 6 runs.<br>**Extensions/Changes:**<br>1. Bowl overarm<br>Change the scoring system | 2 v 2. 1 set of stumps and a cone.<br>4 hitting zones for lap slog, sweep, paddle, reverse sweep<br><br>1 ball. 2 bats.<br>8 cones | **Fielding side:**<br>• Where should you try to defend?<br>• Where should you leave gaps to encourage risk?<br><br>**Batting Side:**<br>• What are the safe options?<br>• What are the risky options? |

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