A theoretical basis for a constraints-led approach

Background

Coaches, teachers and other practitioners such as applied sport scientists seeking to use the methodologies of a constraints-led approach (CLA) to enhance skill acquisition and learner experiences are faced with a large body of information. The aim of this book series is to provide a nuanced understanding of the ideas and concepts in this body of work. Our aim is to ensure that the main theoretical ideas are accessible to coaches. Some sport practitioners have been using variants of a constraints-led approach in their work, for example to change conditions of practice, without being aware of the theoretical context behind it. While the language used in this theoretical framework can be somewhat technical, there is a lot to be gained by mastering the key ideas because there is a need for theoretical rigour to underpin the development of coaching as a profession. Familiarity and ease with the key theoretical ideas behind the CLA is needed by practitioners since its main methodologies should not be viewed as a *magic bullet* for all learners. Having a solid grasp of the theoretical ideas underpinning constraints-led coaching will help practitioners use pedagogical methodologies appropriately, effectively and efficiently.

So what, 1: we must view practitioners as environment architects

We argue that the role of the practitioner as the environment architect must be given greater emphasis. This perspective is in contrast and proposed as a challenge to the current popular mantra of considering the ‘game as the teacher’. While we would agree with the philosophical notions of that mantra, it could lead to practitioners developing an overly passive pedagogical approach. This misinterpretation has led to practitioners being too ‘hands-off’ at times. An under-appreciation of how nuanced the successful application of a CLA needs to be has led to the provision of rather vague practice environments that lack purpose and any form of targeted development. As we note in this first section, sport practitioners need to provide carefully designed environments which make available desired affordances that are functional for athlete performance, adhering to underpinning theories of ecological dynamics.

The CLA is founded on the theory of *ecological dynamics*, which considers athletes and sports teams as complex adaptive systems – a network of highly integrated, interacting sub-components (e.g. parts of the body in an athlete or members of a sports team). In complex adaptive systems, the multitude of parts continually form coordinated patterns (synergies), which are shaped by surrounding informational constraints. Through their interactions, one can identify the coordination states that emerge in a complex system in nature (see Figure 2.1).

A solid understanding of key concepts in ecological dynamics captures the nature of the learner and the learning process for sports practitioners. Viewing learning from this perspective will ensure that coaching practice is informed by theoretical principles rather than by guesswork, the latest fads or fashions, or traditional ways of doing things.

Figure 2.1 The human body is composed of a multitude of interacting components (molecules or neurons, muscles, joints, limbs, bones), which form patterns or synergies to achieve task goals, here identified as a rower training on a Concept 2 rowing machine.

A pause to gather your thoughts: James Gibson (1967) drew attention to a key idea: ‘There is nothing so practical as a good theory’ (p. 135). To which we would add: without a powerful theoretical framework, sport practitioners might be left at the mercy of outdated practical manuals, Internet forums for untested opinions or simply their own subjective experiences.

The importance of experiential knowledge

The statement from Gibson’s (1967) chapter was ahead of its time and it should not be taken to imply that experienced coaches and practitioners need to discard all their own valuable knowledge and insights gained from many days, weeks, months and years of working with athletes of different skill levels. Ideas expressed on Internet forums and blogs can sometimes be helpful and useful for inexperienced practitioners seeking to help athlete development. The *experiential knowledge* of elite practitioners can be useful, as long as it’s tested, supported and integrated with *empirical knowledge* of scientists and theoreticians interested in skill acquisition, learning and talent development (Greenwood et al., 2012). Many sport practitioners can be described as *expert without knowing*, whose practice design embraces a CLA without being able to articulate

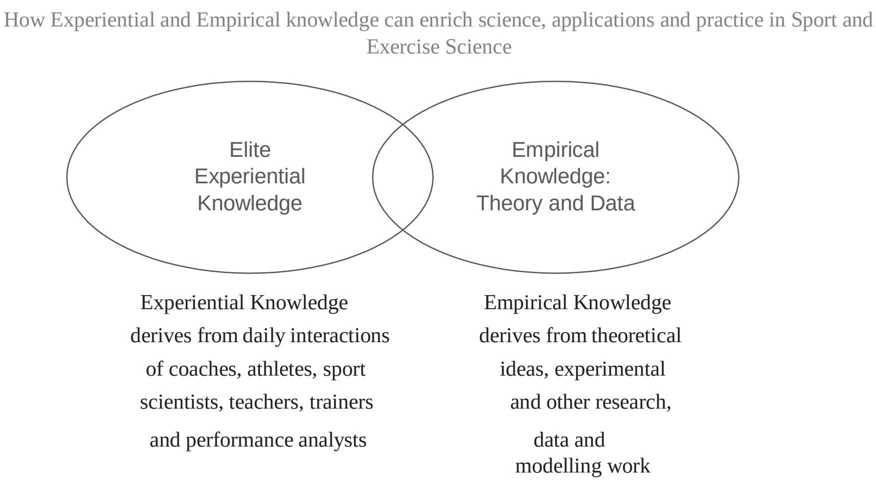

Figure 2.2 How experiential and empirical knowledge can be harnessed by experienced coaches to inform their work with athletes and teams. Inhabiting the space of overlap between knowledge derived by science and knowledge gained from experience can help experienced coaches understand how best to design practice tasks in sport.

the technical language behind the methodology that they use in their work.

Figure 2.2 captures how integration of experiential and empirical knowledge, which continually changes as a result of scientific progress and coaching advances, provides a powerful space for solving problems, making decisions, planning, organising and understanding how individual athletes and teams function. Ultimately, these different knowledge sources can sup- port *learning design* during practice in sport.

> A pause to gather your thoughts: Consider the question raised by Richard Allen of the ConnectedCoaches blog:
>
> www.connectedcoaches.org/spaces/10/welcome-and-general/blogs/press-release/177/do-we-really-know-how-to-utilise-the- constraints-led-approach
>
> Allen refers to the need for coaches to understand the rationale and time and place for manipulating constraints. He calls this the: *how*, *when*, *what* and *why* issues for using constraints manipulations, to which one could add *whom* for an individualised approach. His thoughtful piece implies that it's not simply a case of adding a touch of variability here, or more realism there, in a practice context for learning to magically emerge during a coach's manipulation of a randomly selected constraint or two. Resolving these five issues in practice will provide a substantial basis for using a constraints-led approach in sport.

In the three chapters of Part I, we reiterate the key theoretical ideas in ecological dynamics that underpin the methodologies of the constraints-led approach. We discuss where the ideas originated and their scientific influences so that practitioners may have a better grasp of the framework that underpins the methodologies implied. Having a deep understanding of the key theoretical concepts will help practitioners to use the CLA methodologies to design better learning and development experiences for athletes. To facilitate a deep understanding of the concepts in these initial chapters of the book, readers could continually cross-refer the theoretical concepts to their practical experiences of working with individual athletes and sports teams.

Historical development of a constraints-led approach in sport and physical activity

Where did the concept of *constraints* come from? The word has a special technical meaning in science and has a rich pedigree, having been studied for over a hundred years, particularly in the disciplines of chemistry, physics and evolutionary biology. A fundamental question in science is: how does order emerge in complex physical, chemical and biological systems as they change over time? That is: how do they evolve, adapt, develop, mature, alter, modify, adjust and (re)organise? The answer lies in the surrounding energy patterns in an environment that act as *information* that pressures (i.e. constrains) complex systems to adapt over different timescales (milliseconds, minutes, weeks, months, years and millennia), resulting in different interactive patterns emerging between system components. Nature abounds with complex systems such as flocks of birds, insects, human societies, sports teams and organisations. Even the multitude of interacting components of the human body has complexity. In complex adaptive systems, spontaneous order can emerge between system components, such as individual fish schooling together in response to the presence of a predator (see Figure 2.3). Parts of a complex adaptive system can form rich patterns or synergies, which are coordinated states that emerge due to the inherent capacity for parts to self-organise. *Self-organisation* refers to the spontaneous tendencies for adjustment and adaptation of system components to changes in other parts of the system, without the need for executive micro-management of each component. Many biological systems, such as a flock of birds, a school of fish, a colony of ants or human movement systems are *open* to continuously exchanging energy and matter with the environment. Complex systems are extremely sensitive to existing environmental conditions and rich patterns can form between system components as energy is exchanged with the surrounding environment.

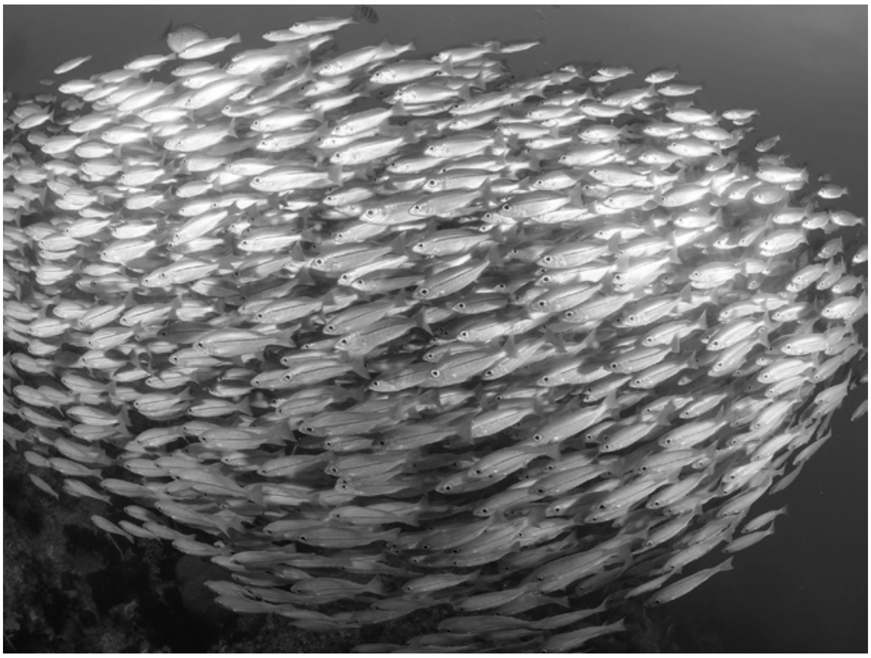

Figure 2.3 Nature abounds with complex systems and many biological models to study in understanding how synergies can be continually formed by system components (rich patterns of behaviour) under constraints.

Complex adaptive systems can influence, and in turn are easily influenced by, the (optical, acoustic and neural) energy flowing in and around them. For example, fish can use on-board sources of energy to swim in any direction in the vast ocean, but instead are constrained by optical information (sight of an approaching predator) to school in rich patterns, swirling to confuse and distract attention.

In sport, individuals are also engaged in the free exchange of matter and energy, moving to provide and perceive information from surrounding energy flows. An invasion game defender engaged in a 1v1 dyad will be attuning to various optical energy flows such as the visual information from the body angle and orientation of the attacker, ball position and the location on the pitch. The defender will also be providing optical energy via the positioning of the leading foot and the distance from the attacker.

Mathematical models have explained how such open, dynamical systems manage to move between different stable states of organisation, depending on the internal and external constraints pressurising (acting on) system stability at any instant. Coaches need to avoid getting bogged down in the common, everyday use of the term *constraints*, which may have negative connotations as a binding or limiting factor on someone. Because of the rich pedigree of the term ‘constraints’ in science, in this book the term is used in its scientific sense to focus on a feature of the environment which acts as *information to shape or guide the (re)organisation* of a complex adaptive system, rather than being viewed as negative or positive factors, constraints are best understood in neutral terms. They are best conceived as boundaries that shape the form/structure of a biological system searching for a functional state of organisation (i.e. a state of organisation that can help the system achieve task goals such as moving into space, avoiding other objects or intercepting an object or balancing on a surface). Any change in the internal or external interacting constraints has the potential to perturb the system and cause instability, thereby promoting a re-organisation of the movement system.

A key point to reflect on is how, at the level of perception and action, constraints shape the behaviours of people during their goal-directed activities.

A pause to gather your thoughts: Constraints are, broadly, information sources that can act over long timescales, such as in evolution, medium timescales such as in growth and development, or in short timescales such as the instantaneous perception of the rabbit or duck (Figure 2.4) in an illusion or spotting the movement differences in a table tennis player’s disguised topspin serve.

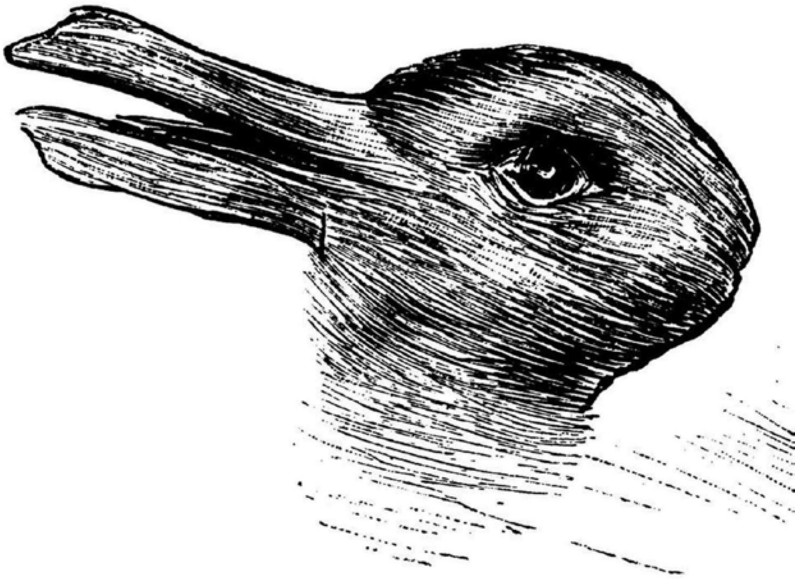

Figure 2.4 The rabbit and the duck illusion.

Interacting constraints in sport and physical activity

In sport, this idea can be applied to the study of athletic performance, as functional coordination patterns in an athlete or sports team emerge under specific constraints, and less useful states of organisation become less stable. In the 1990s, sport scientists became more interested in ideas like this as the powerful theoretical framework behind the constraints-led approach began to emerge. Some were attracted by the potential for an interdisciplinary framework so that sport scientists and practitioners did not have to work in their separate silos. This was a radical idea at that time (and is perhaps still a challenge for some sport scientists and their educators). The importance of interdisciplinarity (or what is now sometimes termed transdisciplinarity) did not have universal approval in the wider sports science community at that time, but it was influential in shaping thinking in some sub-disciplines such as movement behaviour and skill acquisition.

> A pause to gather your thoughts: Nowadays, calls for groups of sport scientists to work collaboratively, while adopting an interdisciplinary approach, are embedded in official organisations such as the European College of Sport Science (http://sport-science.org) who noted that: 'scientific excellence in sport science is based on disciplinary competence embedded in the understanding that its essence lies in its multi- and interdisciplinary character'.

A position paper published in the *Journal of Sports Sciences* by Davids et al. (1994) drew attention to key ideas on constraints shaping emergent behaviours in movement systems, calling for a radical overhaul in the way that sport scientists conceptualised coordination and control of actions in sport. This article marked the beginning of a prolonged period of theoretical work that re-conceptualised the nature of athletes' relationships with specific performance environments. The essential thesis of the paper was that athlete performance and behaviours during learning and development needed to be embedded in context to be better understood: That is, the role of the (performance, learning) environment needed to be more carefully considered, to complement the copious efforts devoted to studying individualised traits, and personal features and characteristics of athletes and teams.

So what, 2: the constraints-led approach is not a magic bullet

In its simplest sense, CLA encourages practitioners to understand and explore how various individual, group and environmental factors impact upon learning and shape the development of human behaviour. This approach requires a deep understanding of context (the sport or activity), human movement (the biomechanics, anatomy, physiology and skill learning of movement), the individual (the psychological and socio-cultural being) and the environment (the learning space we create, and the broader social and political landscape). The development of this holistic understanding allows coaches, teachers, and sports practitioners to appreciate and negotiate these interacting elements in their context, thus developing practitioners who can effectively shape the landscape they provide for their learners. A CLA design is present in all practice environments, from highly structured to unstructured, since interacting constraints (Task, Environment and Person), which the athlete or sports team need to satisfy by continually adapting and (re)organising their behaviours, are ever-present (Newell, 1986).

However, it is most important to emphasise that the CLA is a method that can be employed both successfully and unsuccessfully, and here lies the crucial issue. As highlighted by academics when referring to alternate pedagogies, just because we call it CLA does not necessarily mean it is being used effectively by a sport practitioner (Reid & Harvey, 2014). The CLA is no 'magic bullet'!

This was a radical idea for a theory of movement coordination and control, skill acquisition and port performance, seeking to establish its scientific credibility at the time. It was specifically argued that current theorising was too narrow and obsessed with a computer or mechanical metaphor for understanding brain and behaviour. This digital emphasis missed the benefits of a natural, biophysical approach in considering the contexts of athlete behaviours. The paper acted as a launch pad for a series of position papers, chapters and books over the next two and half decades, currently framed as the theory of ecological dynamics.

Key theoretical influences in ecological dynamics

Numerous powerful and influential ideas exist in the theoretical framework of ecological dynamics that underpins a constraints-led approach. Key ideas were contributed by: **James J. Gibson** and **Egon Brunswik** on ecological psychology (perception-action coupling, affordances and representative design); **Scott Kelso** on coordination dynamics of brain and behaviour; **Michael Turvey** and colleagues on the functioning of natural physical systems. But the most powerful impact derived from the thinking of **Karl Newell** on how coordination emerged under constraints, operating at different timescales. The original constraints model proposed by Newell (1986) sought to explain development processes in infants and children and did not mention applications to sport performance, skill acquisition, coaching and learning. But within a decade, it had given its name to the methodological model in sports pedagogy that is currently known as the constraints-led approach.

A pause to gather your thoughts: From launchpad to grand unifying framework – the relevance of theory underpinning the constraints framework in sports science is still the subject of intense discussion today. In 2016, Paul Glazier outlined a grand unifying theory (GUT), based on Newell's constraints framework, for understanding sport performance. The purpose of the GUT is to provide a rich, unifying framework to integrate the work of scientists in the many different sub-disciplines that inform sport science.

These influential scientists in the development of a constraints-led approach were somewhat subversive in their thinking, not afraid of going against current conceptual trends in areas like psychology, behavioural neurosciences and movement science. The vision of an interdisciplinary approach to understanding sport performance and athlete development needed a powerful interpretative framework. And it got one, as the relevance of their ideas for understanding coordination in sport performance (Davids et al., 1994), skill acquisition (Handford et al., 1997) and human behaviour more generally, was gradually explored over the next decades.

Key theoretical insights underpinning the constraints-led approach

The ecological psychologist James Gibson (1979) offered innovative insights into the relationship between perception and action, which underpin how constraints shape the behaviours of athletes and sports teams during practice and performance. James Gibson's theoretical work guides practitioners towards appreciating *the importance of context for understanding performance and learning.* This idea derives from the notion that the *person–environment relationship* is the appropriate scale of analysis for understanding human behaviour. In sport, this means that the *athlete–environment relationship* forms the basis of understanding performance and development, rather than the focus on personal qualities only. Scientists and practitioners need to recognise the biases involved in considering athlete performance (i.e. genetic composition, specific movement techniques or patterns of thinking) *separately* from a particular performance environment (e.g. a swimmer's thinking out of the water, a climber's emotions away from a surface such as an icefall or a vertical wall or team games player's performance in static drills away from a game context).

Similarly, there are limitations in considering environmental influences *only* (such as in practice approaches like deliberate practice), without regard for how an athlete's individual *effectivities* (skills, personal characteristics, experience levels and capacities) interact with key environmental properties. According to Gibson (1979) environmental properties provide *affordances* for each individual (opportunities for action). Indeed, certain information sources in a performance environment *invite* actions (Withagen et al., 2012, 2017). With learning, experience and knowledge, athletes can become skilfully attuned to the perceptual variables available in a performance environment to regulate actions. For example, a tennis player who is struggling to 'pick' the direction of his/her opponent's serves at the beginning of a match may begin to notice the patterning of the changes in the hitting action as the match progresses. This information may be found in obvious places such as observing a change in the server's body orientation in volleyball, tennis or badminton, or sometimes from more unexpected sources. A great example of this was recently revealed by the tennis player Andre Agassi who described how he struggled when first playing against Boris Becker, who beat him the first three times they played. Agassi highlighted that the main reason he could not beat Becker was that he found it hard to pick the direction of his serves. Agassi searched for any sources of information that might give him a clue. Becker kept everything the same whether he served wide or down the middle, with the exception of one unintended and subconscious change that resulted in Becker 'signalling' his intentions. But it took a considerable amount of exploration and searching through tapes of Becker's serves before, eventually, Agassi noticed a key difference: prior to tossing the ball, when Becker served down the middle he put his tongue out in the middle of his mouth, whereas, when he served wide he pushed it to the left side. Agassi could now pick Becker's serve at will and went on to win 9 of their next 11 encounters (www.youtube.com/watch?v=3woPuCIk_d8).

Information regulates actions

According to Gibson (1979), information regulates action and one's actions guide the pick-up of information for further behavioural adaptations. This idea implies that information designed into a practice task (e.g. from: gaps, distances, angles, interactions with equipment and obstacles (Figure 2.5), target sizes, surfaces, playing area markings and player numbers in team games) will be used up to regulate an athlete's decisions and actions.

With practice and experience the information in a training context can be coupled to movements in order to modulate, refine and adapt action patterns as they emerge. Does the information need to be *similar* to that which is available in a competitive performance environment? Of course it must, if the information is going to be useful in regulating an athlete's performance behaviours and actions. Does the information need to be

Figure 2.5 Interaction of limb segments, muscles, joints and perceptual systems (visual, haptic, proprioceptive) with important equipment during locomotion on road surfaces and pathways in wheelchair racing.

be *identical* between practice and performance environments? Probably not. Because of the unpredictability of many performance environments, it can be challenging to precisely simulate the exact conditions of a particular performance environment. Practice environments, therefore, can be usefully designed for *simulating* (key aspects of) competitive performance environments. If learning is characterised as the development of effective perception-action couplings, the aim of our practice environments should be to help athletes build these synergies. What determines whether a perception-action coupling is effective? If a coupling between perception and action can help an athlete achieve a performance goal, efficiently, accurately, in a timely manner, and without detriment (e.g. injury), then it is likely to increase an athlete's functionality in performance. This is the crucial point, which is defined by transfer from practice to the

Figure 2.6 With practice, gymnasts become highly attuned to visual, proprioceptive, haptic and acoustic information in their interactions with equipment (pommel horse), objects (balls and ribbons) and surfaces (floor) in their performance routines.

performance environment. Nikolai Bernstein (1967) termed these characteristics of a functional perception–action coupling: *dexterity* in performance, which we discuss in detail later in this section. As a general rule, the more representative a practice environment is, the more likely the perception–action couplings will be able to transfer to a performance environment.

A pause to gather your thoughts: How do you understand practice task designs? Can they be similar or identical to a performance environment? What are the essential aspects of a competitive performance environment that you could seek to design into a practice task? What aspects could you leave out and not impact performance? How far away can you move from the realism of a competitive performance environment without the practice conditions lacking impact on athlete learning?

As will be appreciated, the answers to these questions require some nuanced thinking. Practice simulations may be more and less specific to a performance environment, depending on the nature of the information that a coach wants to design into a practice task. In a constraints-led approach, to ensure that practice tasks specify performance environments, highly specific simulations need to be high in *representative design*. This is a key concept for coaches to understand.

Key concept: what is representative design and why is it important in constraints-led coaching?

The ideas of the ecological psychologist Egon Brunswik (1956) suggest that, for studies of performer–environment interactions (such as those observed in sport performance research), perceptual variables should be sampled from an athlete's typical performance environment, so that they represent the environmental information sources available, and to which behaviour is intended to be generalised. Egon Brunswik (1956) recognised the need to understand behaviour through designing key features of the environment into experiments. He proposed that the 'proper sampling of situations and problems may in the end be more important than proper sampling of subjects' (p. 39).

In science, sampling typically occurs with regards to participants in studies, for example, when seeking correctly categorised samples of elite Paralympic athletes to observe. Representative design emphasises the need to ensure that experimental task constraints represent the task constraints of a performance or training (learning) environment that forms the specific focus of study. In the pedagogical practice of coaches, sports scientists and teachers, experimental design equates to the design of practice tasks and training environments. These ideas imply that, as in experiments, the informational constraints of training and practice need to adequately simulate those of a competitive performance environment, so that they allow athletes to perceive information for affordances and couple their actions to key information sources within specific practice settings. To evaluate the representative learning design of particular practice tasks, coaches and teachers should consider the relevance and usefulness (i.e. *functionality*) of the constraints in supporting performers' perception and action in representative performance contexts. In sport, performers need to cope with a range of information sources in a multitude of noisy, messy, dynamic situations, emerging in a performance environment. Only by representing those irregular and uncertain conditions in practice tasks for an athlete can coaches and teachers discover how he/she can achieve a stable, patterned relationship with his/her environment during performance.

These ideas suggest that athletes, coaches, sport scientists and performance analysts need to understand what information sources are used in sport performance to support opportunities for action. These most important perceptual variables need to be designed into practice tasks for learners to use.

The ideas also raise questions over: when, how and why coaches should use grids, cones, ball projection machines, and a whole range of artificial aids as information which constrains actions in learners.

These ideas imply that it is most important to carefully design task instructions (e.g. for directing the athletes' search for perceptual information) and task constraints in practice to help athletes discover and exploit information–action relationships, which underpin successful performance and development (across the whole performance career from novice to expert). During practice, stable couplings will be formed with sources of information that are present in the environment (e.g. climbing only on indoor wall surfaces (Figures 2.7 and 2.8), dribbling around cones, training in a swimming pool, or batting against a ball projection machine in cricket). The question arises whether such practice environments adequately simulate performance. Table 2.1 provides examples of a range of task goals and compares traditional practice methods with alternative RLD-enhanced practice design. A recent real-life example of the limitations of traditional practice to enhance performance was observed in the series of T20 and One Day Internationals (ODIs) between England and India in the English summer of 2018. In the first T20 international, England were soundly beaten mainly due to the efforts of a new Indian wristspin bowler, Kuldeep Yadav. Vadav is a rarity in international cricket as he bowls left arm wristspin. Consequently, many of the England batsmen were unable to 'pick' him (i.e. they could not identify the direction he was spinning the ball) and he picked up three wickets in one over, sending back Morgan (7), Bairstow (0) and Root (0) and creating a collapse from which England never recovered. Kuldeep returned with figures of 5 for 24 and became the first left-arm wrist spinner to pick up 5 wickets in a T20 international. To address this significant challenge to their future success, England resorted to using a special bowling machine, that 'simulates' spin bowling. The views of journalists covering the story, was that this ingenious training aid should make Kuldeep's task much harder in the future with an expectation that the batters would be able to pick up the cues telling them which way the ball was going to spin (see below for a summary).

Jos Buttler [one of the England players] told a Cricket Australia website:

> Kuldeep will have his task cut out with England batsmen now banking on Merlyn – a bowling machine, equipped to simulate any kind of variations, including swing, spin and bowling angles.
>
> One thing we can do is with Merlyn, to replicate the angle. It's a very good machine to get used to that. But it was the first time some guys have faced Kuldeep and it may take one or two games, plus video.
>
> It's about understanding that you shouldn't get too flustered. With spin it can all happen quickly, suddenly you have faced a few balls and aren't off the mark, so it's not allowing that to affect you. You have to get used to the action and once you have faced them a bit more it gets easier. You have a bit more, trust and might pick up a few cues.
>
> Jos Buttler has been assigned to supervise the practice session with Merlyn as he was the only one who seemed to have some clue against Kuldeep.

(www.wahcricket.com/en/news/to-counter-kuldeep-england-adds-merlyn-ahead-of-2nd-t20i-62805)

In contrast to the journalists, anyone who had a background in CLA in cricket might have predicted that Merlin might have had limited impact as there was no opportunity to learn to attune to the specifying information present in the spin bowler's action (Renshaw & Fairweather, 2000). In fact, the impact of using Merlin could have been said to be non-existent, as just two games later, Kuldeep terrorised the England team during the first ODI, with the left-arm spinner finishing with figures of 6–25 from his 10 overs. Obviously, as highlighted by Buttler (the only England player who played him effectively) in the article above, the ideal scenario for England, would be to get some time facing Kuldeep; however, this requires them to stay in! A more effective solution may have been for England to find a high standard left-arm wristspin bowler and face him in simulated game scenarios. For those players who are struggling to 'pick' his action, a constraint could be added in, to direct search to the key information sources within the bowler's action (i.e. the wrist position at ball release). For example, the back of the hand and fingers could be 'painted' with different coloured stripes or he could be asked to bowl with a modified ball (i.e. a two-coloured ball or one with a painted seam) to help the players learn to attune to the key informational cues provided by the bowler. This example highlights that athletes may need to form new couplings during competition, *if* existing perception–action couplings formed in practice environments do not functionally transfer to performance environments. What does this idea imply for the design of training tasks to transfer skill from practice to competitive performance?

Table 2. Examples of traditional and alternative RLD-enhanced practice design

Task goal	*Traditional method*	*Alternative RLD enhanced practice design*
Mountain climbing	Indoor climbing wall	Real mountain
Dribbling in team games	Dribbling around cones	Dribbling in a directional practice around an area with other players moving and dribbling
Swimming practice	Swimming circles with other swimmers in a lane	Swimming against others in different lanes. Use of handicapping to experience swimming when leading or trailing
Batting against a spin bowler	Facing the Merlin bowling machine in a net	Facing real spin bowlers in simulated game scenarios
Practising athletic run-ups	Run-throughs (no jump)	Running up to jump in a simulated competition
In play basketball shooting	Unopposed, repetitive, static shooting	Dynamic shooting with the presence of defenders

Figure 2.7 How well does practice on an indoor climbing wall simulate the performance environment mountain climbing? How specific is transfer?

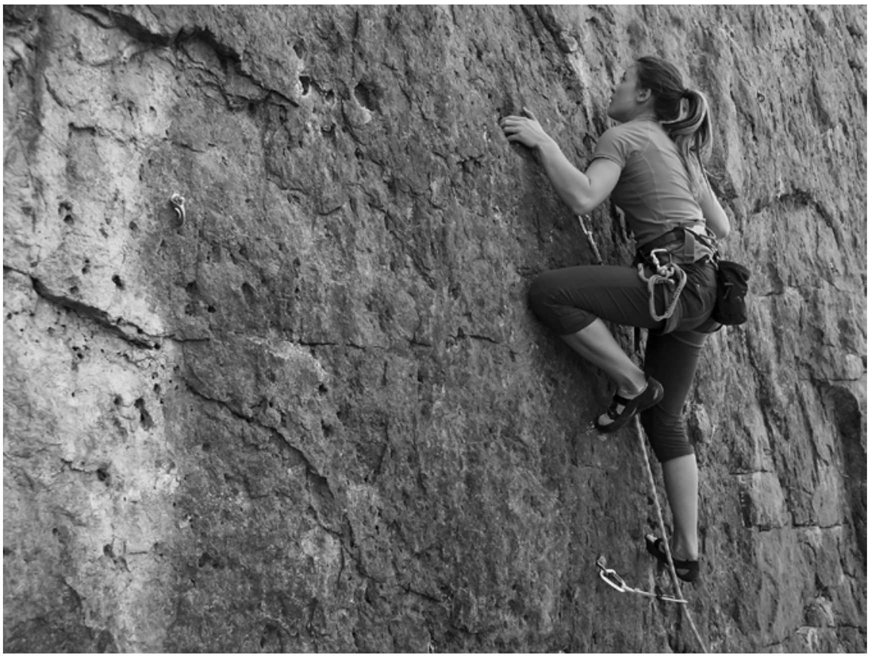

Figure 2.8 What effects on skill could we expect from undertaking an indoor climbing programme? Coordination of actions with respect to the environment.

Ecological dynamics focuses on the importance of *coordination*. This is another important idea promoted by the eminent Russian physiologist Nikolai Bernstein (1967), who placed this concept at the forefront of understanding how humans organise the vast number of system *degrees of freedom* (roughly speaking, motor system component parts such as muscles, joints, limbs and bones). Bernstein's ideas suggest that each individual learner could be conceived as a movement system comprising many interacting *degrees of freedom*. The aim of learning is to ensure that such a complex, multi-component system becomes functionally organised (more efficiently coordinated) as a result of training and practice in sport. This process involves the (re)formation and control of coordinated patterns or synergies between relevant system components, groupings of neurons, muscle complexes and limb segments, during sport performance. The process of synergy formation would be most daunting if it were not for the 'self-organising' tendencies that are intrinsic to complex adaptive systems. In the human body, the self-organising process of synergy formation exploits similar principles that guide flocking tendencies in fish, insects and birds (as we discuss in Chapter 3). Simple rules guide the interactions between individual system components, whether it is a muscle, bone or limb segment. These inherent self-organisation tendencies can be exploited as humans learn to coordinate their actions. Coordination of these motor system degrees of freedom is paramount in achieving specific task goals like jumping into a tucked position in a springboard dive (Figure 2.9) or landing on one leg before springing out into an aerial position in a gymnastic routine.

A springboard diver has to (re)organise motor system degrees of freedom in four different movement sub-phases from the hurdle step, take-off, aerial phase (pictured in Figure 2.9) to water entry. This involves coordination of relevant body parts and use of information from proprioceptive (awareness of body parts in space), haptic (feeling from the soles of feet on the springy take-off board), visual (sighting the end of the board and landmarks in the pool area, as the surface of the pool) and acoustic (sound of the board movement) sources.

It is worth remembering that learners will always attempt to adopt the most functional co-ordination pattern at any moment in time in order to meet their goals and a key role of a coach is to support their search for this solution. Sometimes these goals may be in line with those of a teacher or coach, but at other times, they may be below (or above) the level expected. For example, when first learning to play badminton, the goal of the coach may to develop an overhead hitting action that enables the player to hit the shuttlecock to the back of the court (i.e. a *clear* shot). For this reason, coaches may demonstrate a 'correct' overhead hitting technique recommended

Figure 2.9 Perception-action coupling in springboard diving.

in most coaching manuals and textbooks. The ‘clear’ requires a significant coordination from several body parts (degrees of freedom), including the legs and trunk as well as the arms and wrist. For the novice, these complex coordination requirements are often beyond their capability and attempts to co-ordinate them all frequently results in complete failure, with ‘air shots’ that miss the shuttle. Consequently, young players soon modify their own intentions and set their initial goal as simply hitting the shuttlecock and getting it over the net. To do this, they often modify their hitting action using just the forearm to develop a ‘tapping’ action (see Figure 2.10). This performance solution solves the co-ordination problem by reducing (freezing) the degrees of freedom that need to be organised in action.

Scott Kelso (1995) drew attention to the coordination principles that underpin behaviours of complex systems throughout the whole of nature (from waterfalls to flocks of animals to the brains and behaviours of individual organisms). His ideas on *coordination dynamics* have been influential in understanding organisation in many different systems, whether chemical, physical, neurobiological, or a mix of all features. Kelso (1995) showed that the key principles of coordination dynamics include tendencies for cooperation and competition between system components, often simultaneously, as well as inherent propensities for pattern

Figure 2.10 Beginner badminton players often freeze up the degrees of freedom to simply ‘tap’ the shuttlecock back over the net, irrespective of the coach’s goal of developing a ‘clear shot’, where the overhead hitting action enables the player to hit the shuttlecock to the back of the court.

formation and self-organisation of system components under constraints. For example, in an invasion game, players on the same team co-operate by creating adaptive interactions as they move with or off the ball. Conversely, the actions of players on opposing teams are coupled together in a competitive way as they co-adapt in attempts to achieve their respective goals. In sport performance, principles of coordination dynamics imply that athletes and sports teams are highly integrated collective systems (e.g. a group of athletes collectively focused on competing in a league). The deeply entwined nature of such systems means that coordination of the vast number of system parts can emerge from continuous changes and interactions between key system variables. Analysis of sports performance through a coordination dynamics perspective seeks to understand how continuous interactions between microscopic elements of a system (e.g. in team games, competition and cooperation of players) result in emergence of macroscopic patterns of behaviour (i.e. global collective patterns of play). In team games this is exemplified by the rich, sophisticated and highly coordinated patterns of movement behaviours in attack or defence shown by performers adhering to simple principles of play such as: advance up the field with the ball, exploit width to increase and exploit space between and behind opponents, and maintain depth to cover space between and behind teammates (Figure 2.11).

So what, 3: it is advantageous for practitioners to adopt a *systems* lens when coaching invasion games

A practitioner will facilitate the creation and application of attacking and defensive systems in a group of players. The role of a defensive system (formation, shape and principles) is to coordinate and organise against any instability caused by the opposition's attacking system. Furthermore, a defensive system may also be designed to cause instability in the opposition's attacking system and facilitate a transition of possession in a more advantageous field position. The team members involved in the system will, via multiple layers (from macro to micro) of perception-action, co-adapt, collaborate and coordinate to achieve their goal-directed behaviours. Practitioners must have the required invasion game knowledge to provide learners with instabilities in practice environments to develop this coordinated organisation.

Michael Turvey (1990) also focused attention on coordination, especially the dynamical interactions between parts of the body that involve two integrated dimensions: (i) the process of organising the functional relations between parts of the body to achieve a task goal (e.g. changing coordinated relationships between relevant parts of the body (e.g. between the hip, knee and ankle to transition from walking to running); and (ii), (re)organising parts of the body with respect to environmental objects, surfaces,

Figure 2.11 Perceiving a gap between defenders and coordinating action accordingly in team games.

implements, other people, spaces, gaps, terrains and so on (Figure 2.12). His research shows how perception is needed to regulate our actions, and we act to perceive, because information about the world and the body facilitates emergence of adaptive, functional behaviours in performers to satisfy changing task and environmental constraints.

A pause to gather your thoughts: Turvey's focus on coordination emphasised the importance of understanding how processes of perception and action are highly integrated. Turvey pointed out the challenge for scientists and practitioners in designing experiments and practice tasks, respectively, by pointing out that (1977, p. 211):

> it is curious that theories of perception are rarely, if ever, constructed with reference to action. And, while theories of perception abound, theories of action are conspicuous by their absence. But . . . perception and action are interwoven, and we are likely to lose perspective if we attend to one and neglect the other; . . . After all, there would be no point in perceiving if one could not act, and one could hardly act if one could not perceive.

So what, 4: practitioner should encourage self-organisation

This understanding often leads practitioners to direct a learner's attention within the environment, informing them of where and what to perceive (in information terms). For example, it is important for practitioners to help learners with 'where to look', but not restrict their search strategies by being overly prescriptive and telling them 'what to see'. This approach is useful with different sources of perceptual information such as proprioceptive, haptic and acoustic information. The environments that practitioners design will allow learners to self- organise and attune to the relevant energy flows.

> Experts . . . encounter an environment overflowing with opportunities, and they single out from among the available opportunities just those that are relevant to their interests, preferences, and needs in the specific situation.
>
> (Rietveld & Kiverstein, 2014, p. 341)

It is the role of the practitioner to facilitate and encourage this process through the application of a CLA.

Skill acquisition is better framed as skill adaptability as it involves forming more functional relationships with a performance environment.

Figure 2.12 Turvey (1990) emphasised the importance of the perception–action relationship in coordinating parts of the body with respect to movements of other people and objects in a dynamic environment.

In ecological dynamics, the term skill acquisition refers to the process of acquiring an increasingly functional (more efficiently coordinated and effective) relationship with a particular performance environment. The large number of motor system degrees of freedom available for an athlete can be considered a ‘blessing’ since it is a rich and wonderful resource to be exploited when adapting actions to dynamic, information-rich environments. For this reason, *skill adaptation* would be a better term to describe the process of an athlete becoming more skilful in a sport. This subtle change in emphasis would avoid the idea that ‘acquiring skill’ involves the personal acquisition of an ‘entity’ (i.e. skilled behaviour) or a status (i.e. high skill level) by an individual. Skill adaptation is essentially defined as enhancing one’s functionality in a performance environment, which can continually be improved (Araújo & Davids, 2011a). Captured this way, learning is a process by which an athlete’s behaviour becomes better adapted to a specific performance environment. By increasing or reducing the involvement of motor system degrees of freedom, the athlete can temporarily assemble stable, flexible and functional actions (a process known as ‘*soft assembly*’). This idea signifies that these synergies emerge under constraints and are not permanently hardwired into the skeletomuscular system to help them achieve their intended task goals.

Skill adaptation implies that performance goals can still be achieved, as athletes learn to vary their actions according to the information that emerges in unpredictable performance contexts. Adaptation provides a functional relationship between *stability* (i.e. persistent behaviours) and *flexibility* (i.e. variable behaviours) during performance. Highly skilled performance is characterised by stable and reproducible movement patterns, which are consistent over time, resistant to perturbations. Bernstein (1967) showed, with his work on hammering a nail, how skilled individuals do not achieve consistency through repeating an *identical* movement pattern time after time. Their actions are reproducible only to the extent that a *similar* movement pattern may be re-organised under the same task and environmental constraints. Skilled athlete’s exhibit stable patterns of behaviour when needed but can vary actions (subtly or not) depending on the demands of dynamic performance conditions. That is the basis of dexterity according to Bernstein’s (1967) proposal, which we mentioned earlier in this section as the basis of the effectiveness of a perception–action coupling strengthened in practice. Athletes’ actions become more stable and economical with experience and practice. Yet stability and flexibility are not opposing characteristics of skilled performance. Flexibility should not be construed as a loss of stability, but as a sign of skill adaptation, as motor system degrees of freedom are continually re-organised to achieve specific performance goals, solve problems and satisfy the demands of competition. This is a key idea for coaches as learning designers. It implies that variability needs to be designed very carefully and thoughtfully into practice tasks to enhance athlete skill adaptation. By designing learning environments in which each learner is continuously challenged to adapt to varying task constraints, coaches and teachers can support learning, psychological preparation and conditioning for sport performance. Here we need to go back to the questions of: *why*, *when*, *how*, *what* and *whom*, during manipulations of task constraints. The answers to these questions are developed with an understanding of the end in mind, namely *optimal grip.*

The enhancement of expertise in different sports domains through implementation of a constraints-led methodology is characterised by an individual having an *optimal grip* over the field of affordances (Bruineberg & Rietveld, 2014). Skilled performance is also predicated on context-sensitive actions. This notion stretches our understanding of what the learner is searching for as they self-organise during practice – that is, they are searching for an optimal grip. Similar to a player trying to (re)organise their biomechanical degrees of freedom, a player is also searching for optimal grip on the field of affordances. Skilled *intentionality* is what an individual exhibits when acting skilfully in a familiar situation or as characterised by Bruineberg and Rietveld (2014) – the tendency toward an optimal grip on a field of affordances.

> A pause to gather your thoughts: These ideas on flexibility, stability and skill adaptation seem to be modern insights promoted by ecological dynamics, but they are remarkably aligned with ideas of Bernstein (originally proposed in the Russian language in the first half of the last century, but translated into English in 1967, p. 228): Dexterity is: '*the ability to find a motor solution for any external situation, that is, to adequately solve any emerging motor problem correctly* (i.e. adequately and accurately), *quickly* (with respect to both decision making and achieving a correct result), *rationally* (i.e. expediently and economically), *and resourcefully* (i.e. quick-wittedly and initiatively)' (italics in the original).

The concept of degeneracy: a platform for skill adaptation

Practice task design could incorporate variability into learning contexts to encourage athletes and teams to seek different solutions to the same performance problem, as well as requiring athletes to explore a variety of related task problems to find the same performance solution. In neurobiology, this is known as exploring system *degeneracy*. Degeneracy is another technical term that needs to be understood in its strict scientific sense. In a complex adaptive system, degeneracy has been usefully defined by Edelman and Gally (2001) as '. . . the ability of elements that are structurally different to perform the same function or yield the same output' (p. 13763). In movement behaviour, system degeneracy supports the great flexibility, adaptability and robustness needed for an athlete's functionality during performance. Functionality of athletic performance in skilled athletes is exemplified by coordinative structures assembled to achieve a particular task goal in different ways (Figure 2.13). Degeneracy in the movement system supports the interchange of different sub-structures in achieving a task goal. In an individual athlete, degeneracy involves the (re)organisation of different muscle groups, joint combinations and limb segments (motor system degrees of freedom) to coordinate actions to achieve the same task goals. For example, in relatively stable performance environments, like archery or shooting, performers can exploit system degeneracy to constrain their actions, depending on subtle changes in influential variables like wind direction or strength, ambient temperatures or the layout of the competition venue. In more dynamic performance environments, degeneracy can be harnessed for reassembly of the same motor system degrees of freedom to achieve different performance outcomes. In a sports team, this process refers to the rotation of roles between players and the interchange of players in different sub-phases and tactical patterns during performance. The actions of individual performers can be constrained by co-positioning and re-alignment of movements of teammates and opponents, as game events emerge, field surfaces change due to weather conditions, or properties of the ball or projectile alter with humidity and presence of moisture, or due to sudden changes in opposition strategies and tactics.

So what, 5: examples from sport

In the Atlanta Olympics in 1996, Australian hockey coach, Rick Charlesworth developed an approach that enabled his team to play at a much higher tempo than other teams. Charlesworth worked out that the humidity in Atlanta would result in teams playing slower than normal. To counter this, he developed a policy of rotating his players to keep them fresh. To do this he needed players to be able to play more than one position, ensuring that his team were highly adaptable. The tactics worked, with Australia winning the gold medal. System degeneracy provides each athlete with opportunities to exploit the deeply intertwined relationship between their cognitions (i.e. specific patterns of thinking, ideas, intentions, beliefs and desires), perceptions and actions. It underpins the stability and flexibility of coordination patterns used by each athlete in competitive performance. The degenerate architecture of athlete movement systems provides a platform for creativity, innovation and adaptability during learning and performance. The take-home message here is that learners need to be provided with practice task constraints that allow them to explore dexterity in their interactions with the performance environment. Exploration and, ultimately, exploitation of inherent *degeneracy* is a major goal for learners during continuous interactions with key features of a practice environment, which coaches need to emphasise in their learning designs.

From a practical perspective, these ideas imply that coaches need to ensure that athletes have plenty of opportunities for continually adapting their actions (re-organising their motor system degrees of freedom) to achieve same/different task goals under varying performance conditions. This is what athletes and sports teams need to excel at during their constant repetitions during training and practice. The continuous reorganisation of system components during learning to achieve the same or different task goals is aligned with Bernstein's (1967) proposal for practice to consist of 'repetition without repetition'. His ideas suggest that repetitive practice should not merely consist of repeating the same movement pattern time and again, (i.e.

Figure 2.13 Humans can show wonderful adaptability and flexibility by exploiting inherent motor system degeneracy. Athletes can use different coordination patterns and parts of the body to achieve the same task goal, here striking a ball with a bat.

repetition *afte*r repetition), for example, when trying to reproduce a 'classic' forehand drive in tennis or in replicating the 'ideal' textbook stance in archery. Rather, due to changing performance conditions, learners should be challenged to repeat the process of solving the same performance problems under varied practice task constraints.

This conceptualisation of how to design practice tasks and programmes fundamentally opposes the traditional view of creating conditions for constant *reproduction* of an ideal movement so that specific neural pathways in the nervous system are strengthened, or traces in an internal movement representation are refined. Traditional pedagogical practices also tend to: (i) meticulously structure detailed learning tasks into isolated sub-phases, (ii) elaborate tasks into progression-drills, often in static and unopposed contexts, and (iii), are typically decomposed into manageable sub-movements for repetitions. This traditional approach is exemplified by the assumptions behind the popularity of spring board divers practising separated movement sub-components in isolation away from the pool in a 'dry-land' facility using foam pits, or batters in cricket and baseball rehearsing aspects of their 'technique' against a ball projection machine. The ideology behind this traditional way of practising separate task components is based on the assumption that separately practised sub-components can be successfully re-integrated into the whole diving or batting action.

There is no question that using the traditional approach requires a coach to be highly organised. However, this approach often involves methods of *task decomposition*, which can lead to the decoupling of information and movement, for example, when a learner practises dribbling around static objects like cones, instead of passive (and then active) defenders in small-sided and conditioned games. This atomised approach helps guide learners vertically through progression-drills. These strategies, based on whole-part task training, guided by verbal instructions/feedback, have the unfounded assumption that performing components of a task, in isolation, will unproblematically lead to successful performance of the entire task when parts are re-integrated. This traditional pedagogical approach follows a logical progression from known to unknown, simple to complex and easy to difficult, as task components are 'mastered' in isolation (Figure 2.14).

Figure 2.14 Practising in the dry-land area of a diving programme. Here, athletes practise tasks that are decomposed to emphasise the hurdle step and preparation for take-off phase separately from the aerial and landing phases (for safety reasons).

The assumption of additive part–whole learning is a long-held idea, whose proponents argue that skills where the parts 'remain the same' are best suited to the task decomposition approach as it allows 'stable schemas for movement sub-components' to be developed and then put together. For example, tennis serving is proposed as one such task where there is 'clear evidence that practicing the subtasks in isolation can transfer to the total task' (Seymour, 1954 cited by Schmidt & Young, 1986, p. 23). The underlying assumption behind application of this idea to pedagogical practice is that the sub-tasks are essentially independent activities and there is little difference in performing them apart or as a coordinated whole action, since tennis serving is considered to be made up of two separate motor programmes that run sequentially (i.e. the ball-toss backswing as the first programme and the second programme that produces the hit) (Schmidt & Young, 1986).

However, there is limited evidence in support of this theoretical explanation with empirical research questioning the efficacy of additive approaches in skill acquisition. A number of studies have shown that breaking actions down to improve modules or sub-phases leads to limited transfer when moving back to performance of the whole task. However, in tasks such as tennis or volleyball serving, coaching manuals have tended to follow the motor programme model of part–whole learning emphasising that a consistent ball

Figure 2.15 Volleyball serve on the ‘readying’ phase unopposed.

toss is crucial to the success of the serve. This approach has resulted in coaching practice that focusses on developing a stereotyped ball toss in isolation from the ‘hitting action’. It is common practice for coaches to place a small hoop or chalk a circle on the court surface and require players to practise throwing the ball up to land inside the small area. Only when consistency is achieved in this task sub-component do coaches then ‘add in’ the hitting sub-phase of the serving action. However, expert tennis and volleyball players do not actually achieve invariant positioning in the vertical, forward-back and side-to-side toss of the ball. Handford (2006) examined the serves of senior international players performing the volleyball serve and found that the only invariant feature of their serving action was the vertical component of the toss, with the forward-back and side-to-side dimension showing high levels of adaptive variability. It would appear that the server only aimed to create temporal stability in terms of the time from the peak height (zenith) the ball reached and the time required for the forward swing of the hand to contact the ball (Figure 2.15). Interestingly, in a study to compare the ball toss characteristics in part and whole tasks, the variability of the peak height of ball toss when undertaking part practice separately and the mean value for peak height *was much greater* than in the whole condition. It would appear that decomposing the task led to movement patterns that were dysfunctional for performance. The key to learning to serve is to link perception to action together to effectively support performance.

Breaking up a movement into separate components for isolated practice therefore fails to recognise how separate parts of a multi-articular action are co-dependent on each other for successful performance. Such complex coordination patterns are difficult to decompose because of the information that establishes ‘coherent integration’ between parts during performance. Practice strategies should typically avoid undermining the deep relationship between parts of a coordinated action through task decomposition. Rather, parts of a synergy needed to achieve a performance goal need to be kept together during practice. Scaling or simplification of an action for an athlete, rather than decomposition during practice, would be an ideal way to help athletes seek functional performance solutions, while allowing conditions to vary. Many elite sports coaches and practitioners intuitively understand this key idea.

A pause to gather your thoughts: Pep Guardiola, one of the best football coaches in the world, noted that: ‘Football is the most difficult game in the world because it is open, and every situation is completely different, and you have to make decisions minute-by-minute.’
(Pep Guardiola, 2016: www.theguardian.com/football/2016/oct/07/pep-guardiola-exclusive-interview-johan-cruyff-unique).

The dynamic nature of the ecological constraints of competitive performance dictates that practice needs to involve ‘repetition without repetition’ in many different sports, regardless of whether their ecological constraints are more or less static or dynamic. In the context of sport practice, ‘repetition without repetition’ refers to the need for learning designs to place athletes in dynamically varying contexts where they have to repeat problem solving and find a way to achieve a specific task goal or realise a particular intention. This principle of practice involving ‘repetition without repetition’ applies to many different sports like archery, gymnastics, climbing, springboard diving and shooting, not just team games like basketball and the many codes of football. The emergence of behaviours under manipulated constraints is a key idea that needs to underpin the design of practice tasks that require athletes to solve performance problems with their actions. In adapting to changing interactions of constraints, athletes can learn to exploit adaptive variability to maintain the functionality of their performance behaviours.