Filling an important gap in performance analysis literature, this book introduces the key concepts and practical applications of performance analysis for team sports. It draws on cutting-edge research to examine individual and collective behaviours across an array of international team sports. Evidencing the close relationship between coaching and performance analysis, it promotes a better understanding of the crucial role of performance analysis in team sports for achieving successful results.

This book not only presents a variety of different ways to analyse performance in team sports, but also demonstrates how scientific data can be used to enrich performance analysis. Part one delineates the main guidelines for research in performance analysis, discussing the characteristics of team sports, coaching processes, variables characterising performance and methods for team member interaction analysis. Part two drills down into performance analysis across a range of team sports including soccer, basketball, handball, ice hockey, volleyball and rugby.

*Performance Analysis in Team Sports* is an essential companion for any course or research project on sports performance analysis or sports coaching, and an invaluable reference for professional analysts.

**Pedro Passos** is an Assistant Professor in the Faculty of Human Kinetics, University of Lisbon, Portugal.

**Duarte Araújo** is the Director of the Laboratory of Sport Expertise in the Faculty of Human Kinetics, University of Lisbon, Portugal.

**Anna Volossovitch** is an Assistant Professor in the Faculty of Human Kinetics, University of Lisbon, Portugal.
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I dedicate this book to my students.

Pedro

I would like to thank my wife, Carla, and son, Vicente. Without their wholehearted support for my work, and their abundant creation of life affordances, the lucidity and the perseverance to write this book would not have been possible.

Duarte
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**Index** 233
Sports science is awash with data. Waves and waves of statistics to be used to enhance athlete performance. How can we avoid drowning in this ocean of information? This book, *Performance Analysis in Team Sports* by Pedro Passos, Duarte Araújo and Anna Volossovitch, is a timely and well-considered academic endeavour at precisely the moment when the power of digital technologies is advancing rapidly, providing opportunities to record, measure, assess and evaluate performance in many different sports, including team sports. In the past decades the focus within sports science has broadened in scope and turned to exercise science due to massive socio-cultural changes, responding to the need to understand how to design environments that facilitate people’s engagement in physical activity and exercise. Recently the wheels have turned again and sport science dovetails with performance analysis, this time due to the socio-cultural constraints exerted by technological advances. It is now possible to record and measure athlete performance and behaviours during competition, training, practice, recovery and, most recently due to a revolution in apps, at rest. Clearly, it is undeniable that information is needed on performance, learning, training and recovery in sport programmes. But what to do with all these data and, importantly, the opportunities to collect more data? What kind of data are needed by athletes and practitioners? How can we harness the power of large data sets and at the same time avoid the reduction of athletes to marionettes dancing to the tune of a thousand measurements during practice and performance? These, and other related questions, are increasingly being posed in academic circles and sports development programmes, based on concerns about the impact of ‘big data’ or
'datafication' or 'dataveillance' (Williams & Manley, 2014) on athlete behaviours during practice, training and competition, as well as pedagogical practice.

The authors of this book provide a comprehensive response to these concerns by showing that nothing less than an integration of theoretical knowledge, empirical data, and research methodology of a quantitative and qualitative nature, as well as information from pedagogical practice and application, will be needed by the sports pedagogists, practitioners and performance analysts of the future. For the past decade, in my opinion, their group from the faculty of Human Kinetics at the University of Lisboa in Portugal has led the world in enriching performance analysis, moving it from a fundamentally operational approach, dominated by statistical analysis of action frequencies, to a powerfully descriptive and explanatory endeavour in which rich detail is woven into the tapestry of team sports performance. The research programme at both laboratories essentially uses three main types of methodology: (i) experimentation by direct manipulation of constraints on participants and/or the contexts of action, (ii) computerised simulations, and (iii) systematic observations and analysis of behaviours in sports performance settings. Measured variables are typically eco-kinematic, psychophysical, physiological, neuroscientific and notational (in terms of individual and collective behaviours), and these can be mathematically modelled. The equipment used includes GPS, video-based motion analysis, ball projection machines and neurophysiological sensors, which support performance analysis in team sports environments. Additionally this group utilises methods such as interviews, questionnaires and documental analysis to access experiential knowledge of expert performers and coaches.

Consequently, the different chapters of the book illustrate convincingly how performance analysts will be required to be conversant in theory, research, measurement and application to practice to provide the type of support needed by elite, sub-elite and development programmes in high-performance sport. The material presented here shows that performance analysts will be required to work in teams with pedagogues, psychologists, skill acquisition specialists, physiologists, biomechanists and engineers to collect and verify, discard and retain, analyse and interpret data collected during different phases of competition, preparation and recovery. The book's main focus is on team sports and each chapter deals with different types of games to engage with specific task constraints encountered. This is important because it has been noted that each type
of (sport) performance environment has a specific ‘form of life’ (as Wittgeinstein noted, predicated on unique patterns of behaviour, knowledge and skills, as well as customs and cultural constraints) (Rietveld & Kiverstein, 2014). It is feasible that performance analysts of the future will need to have a good grasp of a theory explaining how behaviours during competition and practice are organised so that an athlete’s relationship with a particular performance environment is made more functional as a result of the hours spent training. Two fundamental questions will be posed: What is the nature of the performance process, and how should we conceptualise the performer in sport? Answering these questions requires performance analysts to acquire and use a model of (sport) performance and of the performer because without these models (and the same applies for the learning process and the learner) practitioners will simply bob like corks between islands of dry land surrounded by oceans of data. Performance analysis will become very reactive, rather than prospective.

So, what precisely is novel and innovative in this comprehensive text on performance analysis? This book elucidates a powerful theoretical framework which can provide a ‘life raft’ for a performance analyst submerged by a sea of information. It also provides a rationale for coaches wanting to use the methods and the data referenced in the book. The theoretical framework proposed here identifies (cooperating and competing) attackers and defenders in team games as intricate components (degrees of freedom) of a self-organising system linked by informational fields which surround them – e.g., acoustic and visual. Thus, in team sports considered as complex adaptive systems, the individual performer is conceptualised as the base unit degree of freedom. Team sports are dynamic, complex performance environments because of the continuous changes in the location, positioning and movements of competing and cooperating players. Due to the highly interactive nature of the performance environment in team sports, opportunities for action are constrained in time and space. These affordances or invitations for action emerge from a process of co-adaptation among individuals. Co-adaptation can emerge in many different forms, including interpersonal coordination, which provides a platform for performance in all sports, at elite and sub-elite levels and even subconsciously (Varlet & Richardson, 2015). In team games, co-adaptation has been shown to result in the continuous emergence and dissolution of spontaneous pattern-forming dynamics among system degrees of freedom (athletes) during performance. Like organisms in other complex adaptive systems, such as schools of fish and flocks of birds, individual athletes in sports teams use fairly
simple local behavioural rules to create rich structures and patterns at a collective level that are much more nuanced than the behaviour of any single individual playing in the team. This is known as the ‘complexity from simplicity’ model for understanding behaviours of complex adaptive system. Research has shown how local rules for interactions among single system components can lead to the emergence of sophisticated ‘macro-states’ of organisation in a global system. What is needed are non-linear methods of analysis of patterns of emerging behaviours among individual athletes. This book discusses a range of such methods for understanding how sophisticated attacking and defending patterns of play in team sports emerge from continuous attacker–defender interactions. It clarifies how the constraints of a competitive environment in team sports force performers to continuously co-adapt to behaviours of teammates and opponents, typically in close proximity to specific locations of a playing area (such as the goal or sidelines). Important performance variables like relative angles among competing individuals, values of interpersonal distances between an attacker and a defender, and the relative velocity of two moving competitors have been empirically verified as relevant variables for understanding interpersonal coordination tendencies of team sports players as agents in a complex adaptive system. Additionally, variables capturing the shape of attacking and defending sub-units or formations, such as team centroids (a variable showing the centre of performance gravity of a team) and surface areas, as well as width and length, provide information on the coherent patterns in sports teams during performance. These behaviours emerge from processes of co-adaptation in team sports performance, providing working materials for coaches, teachers and practitioners. Finally, the book proposes that a major task for pedagogues during practice is to create small-sided and conditioned games that provide informationally constrained dynamic interactions created in space and time by changes in the relative positioning of attackers and defenders in many different team sports.

In conclusion, the many chapters of this book outline in fine detail a rich mix of theory, as well as non-linear and other methodologies for analysing performance behaviours over time; data from well-controlled empirical investigations in studies of athlete behaviours during different sub-phases of team sports performance; and applications for coaches, teachers and sport scientists. This rich integration of necessary information hands a veritable ‘life raft’ to the reader, and I consider that it has the potential to take sport science and performance analysis in a new direction.

Keith Davids, Nether Edge, Sheffield, June 2015
REFERENCES


CHAPTER 1

PHYSICAL AND INFORMATIONAL CONSTRAINTS CHARACTERISE TEAM SPORTS

Leading author: Duarte Araújo

INTRODUCTION

Performance analysis is concerned with the analysis, design and evaluation of sport systems. These systems are complex, and the distinction between analysis, design and evaluation is an abstraction and does not capture the actual practice of sport scientists and coaches. If sport systems are to be built in an integral fashion, then all three activities must be intimately intertwined and mutually informing each other. A sport system is composed of several layers. Traditionally, many disciplines like physiology, biomechanics, psychology, pedagogy or sociology have viewed their technical core as comprising the entire system. For example, the definition of ‘sport science’ for the Encyclopedia of International Sport Studies (Bartlett et al., 2006) does not include sociology, whereas ‘training science’, in the same encyclopedia, is mainly derived from physiology, and the entries ‘practice’ and ‘practice structure and organisation’ are mainly informed by psychology. A new layer of complexity appears when the discussions around how technical and tactical aspects of a sport should go beyond task characteristics and considering the players constraints (e.g., Davids et al., 2008). But this is not the whole story. The social-organisational level also plays a crucial role in the sport system. For example, the management changes implemented in a Team Sport Club may have consequences in terms of the performance of the professional team. Finally, environment also affects a sport system. The national football championships in Europe and in Asia greatly differ in terms of the competitive level of the teams, audience participation, economic management and the physical environment.
Any analysis of performance in a given sport is based on a certain set of assumptions about the performance that is intended to be analysed. For example, counting frequencies of a certain event in a match assumes both that the event is relevant, and that counting frequencies is informative. Rather than making those assumptions implicitly, the design of information systems for performance analysis should be based on an explicit model of performance in a given team sport. Since performance analysis is not an end in itself but rather a means to derive implications for sport training and competition, it is important to have an explicit understanding of what a sport system is, such as a competitive match.

CHARACTERISTICS OF SPORTS

Sport is a human activity characterised by a particular organisation and functioning in a given context. The ecology of sport is not only distinguished by the physical characteristics, where the activity of the players happens, but also by its social and cultural aspects. Given all the physical and social constraints, the sport activities explore the competition of players. The factor of interest for the sport audience is precisely to observe which are the players or the teams that succeed in a competition, characterised by a complex interaction of physical (e.g., gravity) and social (e.g., rules) constraints specific to each team sport. Specifically, the aim of a team is to score more points/goals than the other team. This implies an initiative to score (attacking), and also prevent the other team from scoring (defending). This distinction between attacking and defending is an oversimplification because there are team sports where a team can be defending when in possession of the ball, and the team without the ball may be attacking the space and the ball carrier of the other team to re-gain ball possession. It may be more appropriate to talk about team offense and defence (Mateus, 2005). In any case, a specific feature of team ball sports is the flow of interactions between cooperating and competing players, with or without the ball, to achieve the aim of each team for the match (Mateus, 2005). The aims of the teams are thus mutually exclusive during a match. This way, each team tries to avoid the implementation of the strategic plans of the other team, as well as thwart their tactical actions (Davids et al., 2005). The result is a complex, emergent behaviour of players and teams.

Complexity is, in general, a multidimensional concept and sport matches are not an exception (Davids et al., 2014). Some complex sport systems
such as team games are characterised by direct interaction among players and their opponents (e.g., a volleyball match), or by collaborative interactions among players competing with another group of collaborative players (e.g., a basketball match). The following list of interrelated characteristics is intended to be broad enough to encompass the different types of complexity that we can find in a team sport system (see Vicente, 1999), such as a competitive match:

1. **Large problem spaces.** Sport matches tend to be composed of many different elements and forces (Gréhaigne et al., 2011; McGarry et al., 2002). As a result, the number of potentially relevant factors that coaches and players need to take into account can be enormous. For example, in a soccer game the possibilities of combinations of players’ actions in a team are unlimited. Large problem spaces also create difficulties for coaches, who ensure that the training sessions they develop allow athletes to deal with the entire array of possibilities without exceeding their resource limitations.

2. **Social complexity.** Sport complex systems are usually composed of groups of people who must work together to make the overall system function properly. This creates a strong need for clear communication to effectively coordinate the actions of the various parties involved (Araújo et al., 2015; Mateus, 2005). For example, a rugby club can’t provide the most effective care for its players unless there is good communication between directors, coaches, parents, sponsors, journalists, doctors, sport psychologists and other staff.

3. **Heterogeneous perspectives.** The people involved in a sport context frequently come from different cultural and social backgrounds and thus represent the potentially conflicting values of a diverse set of origins. Consequently, the social negotiation process becomes more difficult by the fact that different values have to be adjusted to achieve a common goal (Kleinert et al., 2012).

4. **Distributed.** The demands associated with social coordination can be complicated by the fact that the people involved may be located in different places (e.g., different areas of the football pitch). It is difficult to get people located in different places to communicate clearly and coordinate their actions and decisions when trying to achieve a goal (Duarte et al., 2012; McGarry, 2005).

5. **Dynamic.** Complex sport systems are usually dynamic and can have long-time constants: it can take seconds to score a goal and hours or days to overcome a negative result. In a team, because the effects of
players’ actions in training are delayed, players have to anticipate the future state of the game and act accordingly (Davids et al., 2005, Mateus, 2005; McGarry, 2005).

6 Hazard. There is also a high degree of potential hazard in certain types of competitions because inappropriate beliefs or actions can have catastrophic consequences (e.g., an offensive gesture by a player to the opponent’s spectators), jeopardise public safety (e.g., initiate violence among rival spectators outside the sports facilities), or have economic consequences (e.g., disinterest of the sponsors due to losing a major international competition). This is particularly critical in abnormal or unusual situations (Vicente, 1999); for example, an elimination match of a championship, or an international match played after the threat of a bomb. Moreover, coaches cannot afford to rely on trial-and-error approaches. Because of the potential hazard involved, there is very strong requirement to try to ‘get it right the first time’.

7 Coupling. Complex sport systems also tend to be composed of many sub-systems that are highly coupled (i.e., interact). This makes it very difficult to predict all of the effects of an action, or to trace all the implications of a disturbance of the adversary because there are many, perhaps diverging, possible outcomes (Davids et al., 2014; Mateus, 2005). Acting in a highly coupled sport competition puts a great burden on all those who are involved because of all the factors that need to be considered at the same time.

8 Uncertainty. There tends to be uncertainty in the data that are available to players (i.e., imperfect evaluation of the performance of the other team, the contribution of the substitute players, the strategic moves of the opponent’s coach). Because of this lack of total information, the actual state of the competition is never known with complete certainty (Davids et al., 2005; Mateus, 2005). Furthermore, players must distinguish changes that are caused by events in the match from those that are caused by random drift. Thus, there may be a need for problem solving and inference (i.e., to ‘go beyond the information given’) (Eccles, 2010).

9 Disturbances. Finally, athletes are also responsible for dealing with unanticipated events (e.g., two players with a red card; the other team scored in the first minutes of the game). They must improvise and adapt to an unanticipated event quickly to maintain team productivity. Therefore, players’ training can’t be solely based on expected or frequently encountered situations (McGarry, et al., 2002; Travassos et al., 2012). Instead, complex sport systems must also
operate effectively under idiosyncratic events – that is, events not anticipated by players or coaches.

It is important to emphasise that not all team sport matches rate high in all these dimensions. There are important differences across sports (e.g., football vs. volleyball), so some dimensions may not even be particularly relevant for some matches, and some may not be exclusive for team sports. Nevertheless, all team sport competitions will rate highly in at least some of these dimensions, and will also usually exhibit several other dimensions of complexity albeit to a lesser extent. These dimensions should be analysed in order to see how they constrain the effectiveness of the player or the team. Effectiveness criteria are of different kinds in different sports, but productivity (i.e., goal achievement), safety (i.e., not getting injured) and satisfaction (i.e., motivation to continue) should be considered.

**PHYSICAL AND INFORMATIONAL CONSTRAINTS CHANNEL**

**INDIVIDUAL AND TEAM BEHAVIOUR**

As can be understood from these characteristics, team sport competitions can be considered as complex dynamic systems composed of many interacting parts (e.g., Davids et al., 2014). A dynamic systems approach to sport studies describes how patterns of coordinated movement come about (‘emerge’), persist and change. It builds on the insight that social systems (e.g., teams) consist of a large number of interacting parts, endowing them with the capacity of spontaneous pattern formation or self-organisation. The spontaneous creation of coherent macroscopic patterns (e.g., team coordination) is important scientifically because it allows for studying the resulting macroscopic patterns in terms of the dynamics of one or a few collective variables (e.g., the centroid of a team), without having to know all the microscopic states of the individual parts (e.g., the movement of each player) (Kelso, 1995). Conversely, when the dynamics of macroscopic phenomena have been identified, the contributions of relevant dynamic components (e.g., the movement of certain players) to the overall dynamics may be investigated in a top-down fashion.

Performers can generate behavioural patterns that are tightly coordinated with the environment (e.g., the match configuration), in the service of achieving a specific goal. In team sports, athletes are surrounded by physical (e.g., gravity, altitude) and social (e.g., audience, rules of the
constraints and continuously interact with each other to achieve performance goals. Successful performance in sport is predicated on an individual’s perceptual and action capabilities, and is grounded in the information used for action selection and goal achievement (Araújo et al., 2006). The view of the performer–environment relationship is central to performance analysis, but it is here usually assumed to follow the post-Cartesian paradigm, whereby the performer is regarded as the active agent and the environment as something that only supports the actions of the individual or provides the source of stimuli (Araújo & Davids, 2011).

According to the view of the organism–environment system, the environment is not just a passive scene in the background of the acting players but an active part of the system making specific results of behaviour possible (Gibson, 1979; Järvilehto, 2009). This means that the structure and physics of the environment, the biomechanics of the body, perceptual information about the state of the performer–environment system, and the demands of the task all serve to constrain the performance (Turvey, 2009). One consequence of this account is that behaviour can be understood as self-organised, in contrast to organisation being imposed from the inside (e.g., the team captain) or the outside (e.g., the coach). Performance is not prescribed by internal or external structures, yet within the given constraints there are typically a limited number of stable solutions that achieve the desired outcome.

From the player’s point of view, the task is to exploit physical (e.g., the pitch characteristics as determined by the rules) and informational (e.g., the movement of other players) constraints to stabilise the intended behaviour. Constraints have the effect of reducing the number of configurations available to a dynamic system at any instance. In a team sports match, coordinated patterns (individual or collective) emerge under constraints as less functional states of organisation are dissipated. In its most general meaning, a constraint can be defined as a limitation on the available states of a system being studied. Every team sport presents its own set of constraints, which helps define its functioning. For example, the offside rule in association football implies specific training tasks for the players as a whole be perceptually attuned to this physical constraint – i.e., this configuration of the match, which has tremendous impact on how attacking and defensive team actions can be played.

Aligned with these notions of physical and informational constraints, a Constraints-Led Approach has been promoted as a theoretical framework for understanding how players perform and learn in sport (see Davids
et al., 2008; Renshaw et al., 2015). Developing a sound theoretical understanding of the major constraints on performers in sport could provide a strong basis for performance analysis and coaching at introductory as well as advanced levels of training and practice.

**CONSTRAINTS-LED APPROACH TO PERFORMANCE IN TEAM GAMES**

Actions in sports differ in the nature of the constraints imposed on performers. The characteristics of each sport as indicated by the sport's rules and competition goals, the characteristics of the players, as well as the characteristics of the environment define the broad categories of constraints (Davids et al., 2008). Despite the huge variety of influential factors or constraints imposed by team sports, one thing they all share is a requirement for highly coordinated actions and perfectly timed movement sequences. A Constraints-Led Approach emphasises the study of coordination and how it changes with learning and development and attempts to categorise the many constraints of different sports, as well as the individual differences that each performer brings to practice and training environments (Davids et al., 2008). Importantly, coordination can be seen at an intra-individual level (e.g., during a basketball shot), between the performer and an external object (e.g., kicking a moving ball), or between two or more performers (e.g., playing football and basketball). Individual and team coordination are therefore a key issue in team sports, and they are highly sensitive to the characteristics of each sport – i.e., to the physical and informational constraints that channel the coordination pattern (behaviour).

Dynamic sport systems exhibit several important characteristics that are useful for our understanding of coordination. First, they have many independent degrees of freedom which are free to vary. The term ‘degrees of freedom’ refers to the number of potential configurations available to the many independent parts of a system (e.g., the players in a team). So, for example, a player is free to move in a pitch, but his/her degrees of freedom are reduced if he/she is marking, and therefore constraining, another player. A social system such as a competitive match has an abundance of degrees of freedom (e.g., players actions, trajectories of players and ball displacements, etc.), which is a rich resource to exploit in coordinating interpersonal actions to achieve a goal. Second, dynamic movement systems have many different levels (e.g., individual,
intra-group, inter-group, social-organisational). The contribution of each level needs to be considered as coaches attempt to understand the constraints on behaviour. Third, the huge number of sport system degrees of freedom (e.g., players) has the potential to interact, resulting in non-linearity of behaviours emerging from the system (e.g., apparently unpredictable peaks and troughs in the performance, ‘highs’ and ‘lows’ of an inconsistent sports team). Finally, dynamic systems have the capacity for stable and unstable patterned relationships among system parts (e.g., stable and unstable collective behaviours, such as attacking) to occur as the sport system components (such as players) spontaneously adjust and adapt to each other, a process called self-organisation.

What does the idea of self-organisation imply for our understanding of individual and team coordination? It appears that dynamic systems such as teams are able to exploit the constraints that surround them in order to allow functional patterns of behaviour to emerge in specific contexts. Large-scale coordination patterns (e.g., tactical configurations) occur among the vast number of small-scale degrees of freedom or component parts (e.g., players). Self-organisation of a particular system into different states occurs when the many micro-components (e.g., players) interact and begin to seriously influence each other’s behaviour. These micro-level dynamics typically lead to no large-scale changes in system behaviours, merely a lot of underlying fluctuation, which mildly perturbs system stability – for instance, when defenders need to adjust relative positions due to attackers’ attempts to get closer the goal. However, key events – for example, a defender breaking through the adversary defence with the ball – can alter the whole system structure, leading to macroscopic-level changes and reorganisation into a different state (Araújo et al., 2015). Self-organisation in dynamical systems is not a random or ‘blind’ process in which any pattern can result. Typically, a dynamic system only takes on very few states of organisation (e.g., having possession of the ball, not having possession of the ball, as well as transitions between these states). The type of order that emerges is dependent on initial conditions (existing match conditions) and the constraints that shape a system’s collective behaviour (Davids et al., 2012).

**Constraints and performance**

These ideas of order emerging under constraints have some important implications for understanding how players learn coordination patterns.
Ecological dynamics views influential factors within the practice environment as constraints on performance development. It is proposed that performance emerges under interacting constraints, which harness the body’s degrees of freedom during learning. Due to the abundance of mechanical degrees of freedom available in the human motor system, the main problem for the learner is to convert the complex human movements to a more controllable, stable system (Bernstein, 1967). What happens is that, with learning, functional groupings or coordinated states emerge from the available degrees of freedom, which stabilise the motor system from the random fluctuations that can occur between system components. The same process happens in a sports team. The difference is that while for the player the parts (e.g., limbs) are physically constrained (linked), in a team the parts (players) are linked by information (Schmidt et al., 1999).

According to Newell (1986), constraints can be classified into three distinct categories to provide a coherent framework for understanding how coordination patterns emerge during goal-directed behaviour (Figure 1.1). It is important to clarify that the constraints are not negative influences on behaviour, like ‘oppressors’ or ‘punishers’, which take away freedom. Instead, constraints are seen as the way the components of a system are linked, forming a specific type of organisation. It would be strange to consider that the wheels of a car have lost their freedom because they are constrained by the axis. A good driver is aware of these constraints and explores them, and he/she does not decry the absence of freedom of the wheels. Moreover, the particular ways the components of a car are linked (constrained) together comprise a vehicle. The separate unassembled components of a car do not constitute a vehicle.

**Performer constraints**

These constraints refer to characteristics of individual athletes, such as genes, height, weight, muscle–fat ratio, connective strength of synapses in the brain, skill level and readiness to learn, as well as psychological characteristics such as thoughts, motivations and emotions. Some of the most important constraints on motor performance involve the neuroanatomical design of the muscles and joints of the human body. For example, Carson and Kelso (2004) showed how flexor muscle groups have structural characteristics and cortical connections that provide greater stability in sensorimotor coordination compared to extensor muscle groups. It appears that performers can counteract this feature of neuroanatomical