A MULTIDISCIPLINARY EXAMINATION OF FAST BOWLING TALENT DEVELOPMENT IN CRICKET

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Biomechanics, cricket, dynamical systems theory, degeneracy, expertise, fast bowling, skill acquisition, metastability, multidisciplinary, talent development, variability.

Abstract

Research on expertise, talent identification and development has tended to be mono-disciplinary, typically adopting geno-centric or environmentalist positions, with an overriding focus on operational issues. In this thesis, the validity of dualist positions on sport expertise is evaluated. It is argued that, to advance understanding of expertise and talent development, a shift towards a multidisciplinary and integrative science focus is necessary, along with the development of a comprehensive multidisciplinary theoretical rationale. Dynamical systems theory is utilised as a multidisciplinary theoretical rationale for the succession of studies, capturing how multiple interacting constraints can shape the development of expert performers. Phase I of the research examines experiential knowledge of coaches and players on the development of fast bowling talent utilising qualitative research methodology. It provides insights into the developmental histories of expert fast bowlers, as well as coaching philosophies on the constraints of fast bowling expertise. Results suggest talent development programmes should eschew the notion of common optimal performance models and emphasize the individual nature of pathways to expertise. Coaching and talent development programmes should identify the range of interacting constraints that impinge on the performance potential of individual athletes, rather than evaluating current performance on physical tests referenced to group norms.

Phase II of this research comprises three further studies that investigate several of the key components identified as important for fast bowling expertise, talent identification and development extrapolated from Phase I of this research. This multidisciplinary programme of work involves a comprehensive analysis of fast bowling performance in a cross-section of the Cricket Australia high performance pathways, from the junior, emerging and national elite fast bowling squads. Briefly, differences were found in trunk kinematics associated with the generation of ball speed across the three groups. These differences in release mechanics indicated the functional adaptations in movement patterns as bowlers' physical and anatomical characteristics changed during maturation. Second to the generation of ball speed, the ability to produce a range of delivery types was highlighted as a key component of expertise in the qualitative phase. The ability of athletes to produce consistent results on different surfaces and in different environments has drawn attention to the challenge of measuring consistency and flexibility in skill assessments. Examination of fast bowlers in Phase II demonstrated that national bowlers can make adjustments to the accuracy of subsequent deliveries during performance of a cricket bowling skills test, and perform a range of delivery types with increased accuracy and consistency. Finally, variability in selected delivery stride ground reaction force components in fast bowling revealed the degenerate nature of this complex multi-articular skill where the same performance outcome can be achieved with unique movement strategies. Utilising qualitative and quantitative methodologies to examine fast bowling expertise, the importance of degeneracy and adaptability in fast bowling has been highlighted alongside learning design that promotes dynamic learning environments.

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List of Abbreviations

BFC	Back foot contact
BR	Ball release
BVE	Bivariate variable error
CE	Centroid error
EMG	Emerging
FFC	Front foot contact
GRF	Ground reaction force
JNR	Junior
MRE	Mean radial error
NAT	National
RE	Radial error

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature:

Date: 3/ 8/ 2011

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Phillips, E., Portus. M., Davids, K., Brown, N., and Renshaw, I. (2010) How do our ‘quicks’ generate pace? A cross sectional analysis of the Cricket Australia pace pathway. In Proc. of *Conference of Science Medicine and Coaching in Cricket*, June 1-3, 2010, Gold Coast, Australia.

Phillips, E., Davids, K., Renshaw, I. and Portus. M. (2010): What the experts think: Fast bowling expertise acquisition and talent development In Proc. of *Conference of Science Medicine and Coaching in Cricket*, June 1-3, 2010, Gold Coast, Australia.

Phillips, E., Portus. M., Davids, K., Brown, N., and Renshaw, I. (2009): Coordination Profiling: Implications for Fast Bowling Research. In Proc. of *Australasian Biomechanics Conference 7*, Nov 30 – Dec 1, 2009, Gold Coast, Australia.

Chapter 1: Introduction

This chapter briefly outlines the background of expertise acquisition, especially in relation to cricket fast bowling (section 1.1). It details the context (section 1.2) of the research and its purposes and relevance in both the academic and applied sports domains (section 1.3). Section 1.4 describes the significance and scope of this research programme and provides definitions of the terms used. Finally, section 1.5 includes an outline of the remaining chapters of the thesis.

This programme of work aims to examine the acquisition of expertise in fast bowling from a dynamical systems approach. Expert performance in sports can be defined as the demonstration of consistently superior athletic performance over an extended period (Starkes, 1993). The programme of research focuses on the acquisition of expertise in players who perform better than their peers during training and competition, and who have the potential to become elite performers in the future (Helsen, Hodges, van Winckel, & Starkes, 2000; Howe, Davidson, & Sloboda, 1998). This conceptualisation of expertise means that the current performance level of youth players is considered important as well as their potential for the future.

1.1 BACKGROUND

At this time, there is no published literature on expertise development in cricket, particularly in fast bowling. However, there has been some research on Olympic champions that has investigated important factors in the development of expertise. These include contextual factors, personality characteristics, training features, competition factors and perceptions (Durand-Bush & Salmela, 2002; Gould, Dieffenbach, & Moffett, 2002). Although there are common factors that appear to underpin the development of expertise, multi-disciplinary models of talent development (e.g., Abbott et al., 2005; and Simonton 1999) predict that there is a range of developmental trajectories and timescales that eventually results in the achievement of sporting expertise. These models provide a criticism of traditional talent identification programmes for overemphasising early identification and the failure to account for variations in maturation rates of adolescence due to the presence of performance *rate limiters* (Abbott et al., 2005). It has been argued that traditional models need to be modified to consider the different rates of development of potentially talented athletes (Abbott et al., 2005). This programme of work aims to provide insights on the development of fast bowling expertise and how each athlete's development may be affected by potential rate limiters.

Historically, research on cricket fast bowling has been focused on injury, rather than on performance and its development. Much of this work has been epidemiological in nature, examining injury occurrence in schoolboys (Dennis, Finch, Elliott, & McIntosh, 2006; Foster & John, 1987) and elite cricketers (Dennis, Farhart, Goumas, & Orchard, 2003; Dennis, Finch, & Farhart, 2005; Gregory, Batt, & Wallace, 2004; Stretch, 2001). Some recent research has examined the relationship between selected anthropometric variables and ball release velocity (Glazier, Paradisis, & Cooper, 2000; Pyne, Duthie, Saunders, Petersen, & Portus, 2006). Much of this work has been descriptive in nature, with some suggestions on how to minimise injury risk, but little evidence provided on ways to improve technique and coaching strategies.

A dynamical systems theory approach will be used to underpin this programme of work, utilising both qualitative and quantitative research methodologies. The qualitative research is exploratory in nature and a grounded theory methodology allows the opportunity to explore the development and interaction of critical components which contribute to each bowler's path to expertise. The path to bowling expertise will be examined as a dynamical system, where individual, task, and environmental factors are continually interacting to shape expertise development and the athlete's developmental pathway (Abbott et al., 2005).

1.2 CONTEXT

The development and maintenance of expert performance in sport has received fragmented attention in the literature, and there has been little work on cricket bowling expertise. Suggested contributing factors include practice, coaching, play, psychological attributes and skills, genetics, movement patterns, physiological attributes, familial support and environmental factors (Phillips, Davids, Renshaw, & Portus, 2010b; Woolmer, Noakes, & Moffett, 2008). Support for the influence of each factor on expertise development varies (Durand-Bush & Salmela, 2002; Holyoak, 1994). The overarching aim of this programme of work is to identify key contributions to the acquisition of fast bowling expertise. This programme of work will increase the understanding of the complexity of fast bowling expertise and the multiple trajectories of development in cricketers, using the Australian performance context as a vehicle.

1.3 PURPOSES

Fast bowling expertise is achieved by very few athletes internationally. If the key components of fast bowling expertise can be identified, such information may be invaluable for talent development and coaching practices. Consequently, the main overarching aim of this research programme is to conduct a comprehensive, multidisciplinary examination of fast bowling talent development in cricket to gain insights into potential determinants of expertise and their identification and development.

The specific aims are:

Aim One: To gather experiential knowledge from elite fast bowlers (past and present) and high level coaches on their perceptions of fundamental factors and skill components that contribute to fast bowling expertise.

Aim Two: To conduct a multidisciplinary examination of a cross-section of the Cricket Australia fast bowling high performance pathway and determine if there are distinct underlying differences in key components of expertise: anthropometric measures from players, movement patterns, ball speed, accuracy, consistency, and adaptability.

1.4 SIGNIFICANCE, SCOPE AND DEFINITIONS

This thesis provides information on the key components of fast bowling expertise and talent development. These findings will be useful to Cricket Australia's Centre of Excellence's talent development programme and coaches at the grass roots level. In the existing body of literature on expertise and its development, there has been little previous work on cricket fast bowling and none that is multidisciplinary in nature. The development of fast bowlers is an important factor for success for international teams; they play a pivotal role in taking wickets in teams, ultimately contributing to the likelihood of success. This research programme will add to the literature by providing a greater understanding of skill components and factors that contribute to fast bowling expertise and its development. This information will help Cricket Australia to understand how to organise future talent identification and development programmes in fast bowling.

1.5 THESIS OUTLINE

To answer the research questions identified, a two-phase programme of research has been developed; phase one containing two studies and phase two containing three studies.

Phase I of the research examines experiential knowledge of coaches and players on the development of fast bowling talent utilising a qualitative research methodology. It provides insights on current and past expert fast bowlers' developmental histories, experiential knowledge and coaching philosophies on the constraints of fast bowling expertise. There is a plethora of research on the acquisition of expertise across domains including sports, highlighting the significant roles of environmental, training, physical and psychological characteristics. However, it is unknown if the same components are essential for the acquisition of fast bowling expertise. Do these themes emerge in pace bowling development trajectories and is there an optimal trajectory or multiple expertise pathways? Study I (Chapter 4) seeks to investigate the developmental histories of expert fast bowlers, past and present, to identify the factors that were perceived to hinder or support the development of expert performance in fast bowling. Study II (Chapter 5) seeks to investigate the perceptions of past and present elite athletes and coaches to establish the key components for fast bowling expertise from a talent development and identification perspective.

Phase II of this research comprises three further studies that investigate several of the key components identified as important for fast bowling expertise, talent identification, and development extrapolated from Phase I of this research. This multidisciplinary programme of work incorporates theory and methodologies from biomechanics, anthropometry, motor control and skill acquisition. This process involves a comprehensive analysis of fast bowling performance in a cross section of the Cricket Australia high performance pathways, from the junior, emerging and national elite fast bowling squads. Previous research on the generation of ball velocity during cricket fast bowling is limited to group performance analysis of bowlers of similar skill levels. It is not understood whether developing, emerging and expert fast bowlers are characterised by similar movement patterns and anthropometric measures, relative to their ability to generate ball speed. Additionally, flexible movement patterning, and the ability to produce a range of delivery types, has been alluded to in fast bowling research, and remains essential at international level competition. The ability of athletes to produce consistent results on different surfaces and environments has drawn attention to the paradoxical nature of consistency and flexibility in skilled tasks; this study will attempt to address how these key components change across the fast bowling developmental pathway.

Study III (Chapter 6) examines the movement patterning and anthropometric variables related to production of high ball speeds in a cross section of fast bowlers in the Cricket Australia high performance pace pathway. Study IV (Chapter 7) will examine the adaptability of performers under different task constraints while maintaining ball speed, a key component underpinning their expertise. Specifically, the chapter seeks to examine whether accuracy and consistency in fast bowling differs between skill levels under three different task requirements (short, good and full length deliveries). It also seeks to examine the relationship between consistency and accuracy in the performance of a complex, multi-articular action and to identify whether bowlers at different skill levels can make adjustments to the accuracy of subsequent deliveries during the performance of cricket bowling skills. Following this, Study V (Chapter 8) examines variability in selected ground reaction force variables in fast bowling in a cross section of individuals in the Cricket Australia high performance fast bowling pathway.

Finally, the results from this programme of research are evaluated and synthesised in Chapter 9. Key research, practical application and recommendations for sport performance research are explored and detailed.

Chapter 2: Literature Review

2.1 INTRODUCTION

Research on expertise and talent identification and development has been dominated by opposing geno-centric or environmentalist positions (Howe et al., 1998). Recently, Dunwoody (2006) has challenged psychologists to look beyond the individual, suggesting researchers have neglected the role of the environment and focused on organism structure and process in isolation. Although there is a need to move away from the cognitive psychology asymmetric–organismic focus (Dunwoody, 2006), the tendency to over-emphasise the role of environmental constraints on expertise acquisition also needs to be eschewed. For example, Ericsson and colleagues (1996) emphasised an environmental perspective, advocating that expertise is acquired as performers specialise at an early age and engage in deliberate practice. Other investigators have associated the hereditary nature of physiological, anthropometric and psychological characteristics with elite performance in sports (Rankinen et al., 2006). For example, early anthropometric research on Olympic athletes advocated a close relationship between physical characteristics and specific Olympic events (Carter & Heath, 1990). This anthropometric evidence has been somewhat over-interpreted, leading to the questionable practice of anthropometric profiling of adolescents to identify potential for early specialisation in a sport. Consequently, anthropometric profiling of physical dispositions has tended to skew the rationale for talent identification models in sport, despite a lack of supportive evidence and the unstable nature of anthropometric and physical parameters during adolescence (Abbott et al., 2005; Vaeyens, Lenoir, Williams, & Philippaerts, 2008).

Recently, there have been proposals to integrate polar perspectives on sports performance and expertise into a multi-disciplinary approach, to enhance understanding of the athlete–environment relationship as exemplifying a complex, dynamical system. A major reason for adopting polarised, mono-disciplinary positions on the acquisition of sport expertise has been the absence of a powerful multi-disciplinary theory to act as an integrative conceptual framework. Although some models have advocated a multi-disciplinary approach to talent identification and development, such as Simonton's (1999) model of talent as a multiplicative, dynamic process and the Differentiated Model of Giftedness and Talent (Gagné, 2004), these approaches tend to be operational and propositional in nature. These models have not provided a detailed, explanatory theoretical rationale underpinning a dynamic and multi-dimensional basis for expertise and how it may support the process of identifying and developing talent.

One suitable theoretical approach to the study of performance, expertise and talent development in sport conceptualises the athlete as a complex, dynamical system. In such systems there is great potential for interactions between system components and the environment, often leading to rich and unique patterns of behaviour. To date, studies of complex system behaviour in sport include match play and behaviour during competitions (Chow et al., 2006; McGarry, Anderson, Wallace, Hughes, & Franks, 2002), decision-making (Araújo, Davids, & Hristovski, 2006; Araújo, Davids, & Serpa, 2005), motor learning (Liu, Mayer-Kress, & Newell, 2006; Newell, Liu, & Mayer-Kress, 2001), coordination (Davids, Renshaw, & Glazier, 2005; Jaitner, Mendoza, & Schollhorn, 2001), human gait and injury (Hamill, van Emmerik, Heiderscheit, & Li, 1999; van Emmerik, Hamill, & McDermott, 2005) and medicine in sports (Davids, Glazier, Araujo, & Bartlett, 2003). In this literature review relevant theoretical concepts and insights from dynamical systems theory, complex systems theory, ecological psychology and evolutionary sciences are identified and their implications for the acquisition of sports expertise and talent development are discussed.

2.2 TRADITIONAL EXPERTISE APPROACHES

As noted, much research has focused on the role of environmental constraints in expertise acquisition, including participation in play and practice activities, and the role of family and environmental contexts (Baker, Côté, & Deakin, 2005; Davids & Baker, 2007). For example, Ericsson and Smith's (1991) expert performance approach explored the contribution to expertise of specific practice environments. Ericsson and colleagues' (1993) deliberate practice approach has highlighted the importance of structured activities involving goal directed skill learning which require effort and concentration. It was estimated that experts spend typically about ten years or 10,000 hours in deliberate practice to attain exceptional performance (Hodges & Starkes, 1996). The uni-dimensional nature of the deliberate practice approach led Starkes (2000) to label it a 'very environmentalist' theory of expertise acquisition, while others (e.g., Araújo, 2007) have proposed it has an organismic bias. Additionally, researchers studying deliberate practice in sport have encountered some incongruities with the theory's main tenets. For example, in contrast to previous findings, many athletes tend to find appropriate practice and training enjoyable and motivating across all development stages (Helsen, Starkes, & Hodges, 1998). Moreover, early specialisation has not been found to be essential for acquisition of expert sport skills in adulthood (Baker, Côté, & Abernethy, 2003; Côté, 1999; Soberlak & Côté, 2003). Time spent in sport-specific training does discriminate between experts and non-experts in some sports, although the relationship between practice and performance is nonlinear (Baker et al., 2005). Further, retrospective analysis of historical data on time spent in practice was unable to clarify differences between experts and novices based on micro-structure of practice activities (Young & Salmella, 2001). For example, Weissensteiner, Abernethy, Farrow and Müller (2008) examined the practice histories of under-15, under-20 and adult cohorts of skilled and less skilled cricket batsmen and found that hours spent in practice explained only a small proportion of variance in the development of anticipation skills. A particular methodological concern in this approach is the proliferation of 'weaker' data from a plethora of cross-sectional studies, relative to the lack of longitudinal research. More evidence on putative benefits of deliberate practice is needed, following cohorts of young athletes through developmental pathways. To summarise, although numerous hours of training are necessary for success in sport at the elite level, research suggests that attainment of expert level is not always accomplished by engaging in deliberate practice alone.

In another polarised approach to elite sports performance, some research has investigated the genetic makeup of individual athletes. Molecular testing has attempted to identify single gene variants deemed ‘responsible’ for performance in specific sports (e.g., a gene responsible for physical power or endurance capacity). This ‘single gene as magic bullet’ philosophy has led to claims that elite performers are born to succeed. For example, there have been attempts to identify sprinters and endurance runners on the basis of differing alleles (i.e., forms) of a single gene known as alpha actinin-3 (Coghlan, 2003; Yang et al., 2003). Besides obvious ethical issues, reports of gene-profiling and gene-transfer technology raise more general theoretical and practical questions about the nature of genetic and environmental constraints on skill acquisition and performance (Stubbe, Boomsma, & De Geus, 2005). Research on human behaviour has yet to reveal that the function of a single gene variant can be inferred from identifying performance phenotypic variance (e.g., power athletes and endurance athletes), supporting the notion of non-specificity of genetic constraints (Greenspan, 2001).

2.2.1 METHODS FOR ASSESSING EXPERT PERFORMANCE IN TRADITIONAL RESEARCH

Empirical expertise research has typically been conducted with two main methods involving: (i) quantitative analyses, which include implementation of multiple test batteries on developing athletes; and (ii) qualitative examination of developmental histories of past or present elite athletes, with methods such as interviews, questionnaires or self-reported, retrospective recall of practice histories.

2.2.2 OUTCOMES OF RESEARCH WITH QUANTITATIVE METHODOLOGIES

Attempts to distinguish athletic expertise based on skills testing have been unsuccessful or have been confounded by the over-riding importance of maturational factors on observed performance (Vaeyens et al., 2008). The over-use of ‘closed-skill drill tasks’ to elucidate athletic potential has been a major weakness in extant research because they lack task representativeness, resulting in a failure to identify skilled players from lesser skilled individuals. For example, Gabbett, Georgieff and Domrow (2007) attempted to assess skills of passing (digging), setting, serving, and spiking as part of a test battery to discriminate between junior volleyball players of different abilities. The only test that revealed differences between selected and non-selected players was passing. This may have been because skills in volleyball (digging, setting, spiking and blocking) are not performed in stable environments but are dynamic and characterised by marked temporal and spatial variability dependent on preceding play (e.g., quality of contact of the ball by teammates and opponents). In other work, Hoare and Warr (2000) assessed talented athletes (non-football players) aged 15-19 years to identify and develop female football players. Initial screening required coaches to grade players by assessing skill performance such as ball juggling, dribbling (around cones) and passing. Players were grouped by performance test scores for playing small-sided games before progressing to full-size games for coach observation and selection. Hoare and Warr (2000) used an innovative quasi-applied research model to identify and develop talent in women’s soccer, and highlighted the need to assess athletes over a longer time period than typical in sport talent assessment, suggesting that two to three months is necessary for coaches to make a valid assessment of athlete potential. They also proposed that components of performance require different weightings since the importance of speed and acceleration was underestimated in their tests. Finally, the need to develop an objective test of game sense was suggested as some athletes performed well on physical tests, but weakly in terms of general tactical understanding.

Other quantitative approaches in empirical talent identification research have attempted to examine sport-specific, relevant performance characteristics, through anthropometric, physical, technical, tactical and psychological testing (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2007; Hoare & Warr, 2000; Morris, 2000; Reilly, Williams, Nevill, & Franks, 2000). In the main, these tests have been limited in utility for identifying talented performers in sport. For example, test batteries focusing on discrete performance measures have provided limited information of athletic potential and adaptability in different performance environments (Abbott et al., 2005; Morris, 2000). Questions on the data of these studies, and the efficacy of traditional talent identification practices, arise due to constraints on individuals like growth, maturation, development and training (Reilly et al., 2000). To exemplify, Elferink-Gemser and colleagues (2007) employed a test battery to examine 30 elite and 35 sub-elite youth hockey players over three competitive seasons. Their research established differences in technical and tactical variables between skill levels at 14 years as well as variations in endurance capacity in the subsequent two years. However, the task demands of the technical test did not provide a valid representation of the competitive performance setting (cf. the importance of representative experimental design in studies of human behaviour) (Araujo, Davids, & Passos, 2007). The use of closed skill proficiency tests, without opposition and in a static environment, and physical performance measures considered in isolation need to be carefully evaluated, because they have a low correlation with the specific demands on an individual during a dynamic competitive situation. Several studies have highlighted the importance of using more sports-specific assessments of tactical and technical competence rather than generic physical measures such as strength or endurance tests (Falk, Lidor, Lander, & Lang, 2004; Hoare & Warr, 2000).

Skill-based differences in perceptual-cognitive skills such as anticipation and decision-making have been successfully identified in a number of studies (see Williams & Ward, 2007). Although several generalised visual training programmes are predicated on the idea that a superior visual hardware system provides perceptual advantages to skilled performers, research evidence does not support this view. Rather it has been argued that expertise advantages emerge as a result of sport-specific practice and experience (Abernethy & Wood, 2001; Williams & Ericsson, 2005; Williams & Ward, 2007).

Despite the large volume of studies examining the role of perceptual-cognitive expertise in sport, there has been some confusion over whether research has actually demonstrated the true extent of expertise. Van der Kamp, Rivas, van Doorn, and Savelsbergh (2008) criticised the lack of precision in perceptual-cognitive research, highlighted the magnitude of errors reported in many occlusion-based studies of anticipation skill, and suggested a weakness in a popular experimental methodology. In a popular approach, liquid crystal spectacles permit information sources available to participants to be manipulated by limiting vision during key moments of performance (Müller & Abernethy, 2006). It was argued that high levels of error observed in these studies may have been due to the failure of the methodology to capture the complementary efforts of the ventral and dorsal cortical visual systems in regulating perception *and* action. This is important since, Williams and Ericsson (2005) indicated, the first stage in determining expertise is that 'performance be observed *in situ* in an attempt to capture the essence of expertise in the domain of interest and to design representative tasks that allow component skills to be faithfully reproduced in the laboratory' (p.286). Van der Kamp et al., (2008) also argued that a weakness of previous work was requiring participants to undertake non-representative actions such as pressing buttons, marking crosses on images of court surfaces, and verbally reporting findings. Another issue associated with the provision of video footage is that it does not replicate the view of performers in action, thereby limiting understanding of the extent of the expert advantage. Some researchers, including Müller and Abernethy (2006), have developed and incorporated what they termed an 'ecologically valid' batting test to measure a batsman's perceptual-action coupling and found skilled players utilised prospective ball flight information to a greater extent than less skilled players.

2.2.3 OUTCOMES OF RESEARCH USING QUALITATIVE METHODS

Qualitative studies on the development histories of elite athletes have been somewhat limited in number, examining physical, psychological, environmental and social factors that shape performance (Durand-Bush & Salmela, 2002; Gould et al., 2002). They have established the importance of environmental constraints including support from family or friends and the opportunity to participate in residency development programmes. A range of individual constraints including mental preparation, focus and commitment, and clear goal setting have been found to contribute to the acquisition of expertise (Abbott et al., 2005). Durand-Bush and Salmela (2002) examined qualitatively the development and maintenance of expert performance in Olympic and world championship competitions. Their data revealed that athletes did not all follow the same pathway to become world and Olympic champions, highlighting how individuals can take different routes to expert status, use various resources and strategies, and be innovative and creative as they develop and maintain their expertise in sport. However, some common factors were observed including: (i) all athletes underwent stages described as the sampling, specializing, investment and maintenance years (Côté & Hay, 2002); (ii) high levels of self confidence and motivation; and (iii) high levels of creativity and innovation during the maintenance years, a continuous drive to learn and improve, and a strong work ethic.

2.3 DYNAMICAL SYSTEMS THEORY AND CONSTRAINTS ON THE ACQUISITION OF EXPERTISE IN SPORT

In contrast to more traditional approaches to studying expertise, a potentially valuable conceptual framework for modelling the acquisition of expertise exists in understanding performers as complex, dynamical systems.

Dynamical systems theory provides a multi-disciplinary framework for understanding the key constraints on the acquisition of expertise in sport and is useful for explaining the specificity of expertise acquisition in different performance domains. This is important because some debate exists over whether a general theory of expertise in sport and motor-skills is feasible (Starkes & Ericsson, 2003). Simon and Chase (1973) proposed the general theory of expertise, suggesting the same basic process mediates all forms of expertise. Their theory was based on an information-processing perspective (Newell & Simon, 1972), suggesting that an individual's amount of experience is related to expertise, and that over time, patterns and chunks of information are accumulated that mediate superior memory. Note that in these cognitive science approaches to expertise acquisition, the emphasis is on the role of organismic (performer) constraints only (acquisition of memories and representations of action), rather than on an improved interaction between performer, environmental and task constraints. In contrast, a multi-dimensional theory of expertise emphasises a broader range of constraints not just one level of performer-related constraints.

Complexity sciences have been used to study and explain the rich patterns formed in complex systems such as animal collectives, weather systems, the human brain and movements in team sports, where patterns emerge from seemly random component trajectories (Bak & Chialvo, 2001; Kauffman, 1993; Sumpter, 2006). From this complex systems description an emerging expert can be viewed as a complex system, composed of many degrees of freedom on many system levels. The potential for interaction between system components provides the platform for rich patterns of behaviour to emerge as individuals interact with dynamically changing environments. This new systems perspective reveals that adaptation in performance occurs as the result of system trade-offs between specificity and diversity of behaviours (Edelman & Gally, 2001). Dynamical systems theory emphasises the influence of interacting constraints on performance and provides a framework showing how expertise can be achieved in diverse ways as individual performers attempt to satisfy the unique constraints on them (Davids et al., 2003).

Some current models of talent development are harmonious with these theoretical ideas, although their tenets are not necessarily predicated conceptually on these insights. For example, Simonton (1999) proposed that talent emerges from multidisciplinary, multiplicative and dynamic processes and is likely to operate as an intricate system beyond the scope of the polar nature–nurture debate. He pioneered mathematical equations to *operationalise* the potential components that contribute to talent development. These components were weighted by relevance and included reference to genetic dispositions (e.g., height or endurance capacity), environmental (e.g., social and familial support) and developmental constraints. Subsequently the model was described as emergenic and epigenetic, comprising components that interact and change with time

(Simonton, 1999). The emergenic aspect proposed that potential talent consists of multiple components, including all physical, physiological, cognitive and dispositional traits that facilitate the manifestation of superior expertise in a specific domain. Beyond individual differences, Simonton's (1999) model captured the dynamics of epigenetics. Epigenetics were seen in the diverse components that make up talent which slowly appear and differentiate over time in an individual and ultimately depend on underlying neurological, muscular, cultural, skeletal, social, psychological, physiological and environmental variables (Obler & Fein, 1988). However, they emerge gradually during the course of long-term interactions between the internally developing organism and appropriate environmental constraints (Simonton, 1999). This system is complicated, as it includes the evolutionary interaction of components, and any examination of talent development that utilises this model needs to be holistic, impartial and sophisticated (Simonton, 1999). Although this mathematical model is a useful starting point for sport scientists since it attempts to operationalise key concepts such as multidisciplinary talent development practices and multiple developmental trajectories towards potential expertise (Abbott et al., 2005), it lacks theoretical power as it is not conceptualized within a theoretical framework. This weakness could be mediated by including dynamical systems theory as a viable rationale for talent development as an emergenic and epigenetic process. Furthermore, on a practical level, adopting Simonton's (1999) model may be extremely difficult as its efficacy is predicated on identifying *all* components that contribute to expertise in any one specific sporting domain. Identification of every component is essential because the model is proposed to be multiplicative, and any score of zero for any specific factor signifies that expertise cannot be achieved.

Vaeyens et al. (2008) provided an insightful talent identification model, capturing the dynamic nature of talent, focusing on the potential for development and inclusion rather than early identification. Such a model can be strengthened with a dynamical system theoretical approach also, and in the next section elucidates key ideas in this framework.

2.3.1 THE ROLE OF NEUROBIOLOGICAL DEGENERACY IN EXPERTISE ACQUISITION

Athletes considered as complex, neurobiological systems are comprised of many interacting parts and levels, which self-organize under constraints (Schöllhorn, 2003). These systems have been conceptualised recently as pleiotropic and degenerate with the ability to adapt to different task and environmental demands (Chow, Davids, Button, & Koh, 2008). Pleitropy provides neurobiological systems with a variety of alternate performance solutions (Davids, Araújo, Button, & Renshaw, 2007). Neurobiological degeneracy refers to the ability of structurally different components to be coordinated together to achieve the same behavioural goal (Edelman & Gally, 2001). At the level of gene networks, degeneracy promotes evolutionary fitness by ensuring that genetic diversity supports functional adaptation to variable environments (Kærns, Elston, Blake, & Collins, 2005). The degenerate relationship between system components and system output in developing experts implies that there are many different pathways to achieving expert performance. Genetic diversity is responsible for a portion of training or performance response differences between individuals, and when there is a favourable interaction with important environmental constraints, performance benefits may be observed. Given differences in genetic contributions, performance variations are more likely to assert themselves under intensive practice regimes.

The characteristics of pleiotropy and degeneracy in athletes highlight the need for a systems-oriented, multidimensional framework (Davids & Baker, 2007). Expertise attainment in a particular sport depends on many additional constraints outside the cognitive domain, including but not limited to genetics, social and physical environment, opportunity, encouragement and the effect of these variables on physical and psychological traits (Wolstencroft, 2002). Mono-disciplinary approaches to the acquisition of expertise fail to capture the complementary nature of the relationship between individual, task and environmental constraints (Abbott et al., 2005; Beek, Jacobs, Daffertshofer, & Huys, 2003; Davids & Baker, 2007). For these reasons, Davids and Baker (2007) highlighted the need for an interactionist explanatory framework to examine performance attainment in sport. As noted in the following sections of this chapter, a dynamical systems theoretical approach provides a viable platform for explaining the dynamic relationship between an individual's genetic disposition and the environment and the acquisition of expertise in sport through variable pathways and processes.

2.3.2 CONSTRAINTS ON ACQUIRING EXPERTISE

In sport, the expression of expertise is limited or shaped by interacting constraints at many system levels. The concept of constraints (boundaries that constrain the interactions of system components) in human movement science was readdressed by Newell (1986). He classified them into organismic, task and environmental constraints (Newell, 1986). Constraints in the expertise acquisition context can be conceived of as the numerous variables that form each individual expert's developmental trajectory, and it is important to identify the range of constraints on the acquisition of expertise. Given that an individual is born with distinguishing physical characteristics (with a degree of genetic influence), expertise research is concerned with how environmental constraints interact to affect the development of skill and the expression of genotypes.

Performance emerges from the intrinsic dynamics of experts, the preferred behavioural tendencies which arise from the interaction of environmental, task and organismic constraints (including development, experience, genes and learning of each performer) (Kelso, 1991). Kelso (1991) proposed that intrinsic dynamics reflect the organisational tendencies of an individual. Thelen (1995) referred to intrinsic dynamics as "the preferred states of the system given its current architecture and previous history of activity" (p.76). The intrinsic dynamics of each individual are unique and shaped by many constraints including experience, learning, development, morphology and genes which interact to shape performance and the acquisition of expertise in sport (Davids, Button, & Bennett, 2008). In developing experts, these contributions can lead to significant variations in performance solutions. The manner in which each developing expert attempts to satisfy constraints during performance and learning is determined by the matching of his/her intrinsic dynamics with the specific task dynamics (Corbetta & Veriejken, 1999). By knowing an individual's intrinsic dynamics one can specify what in the performance repertoire actually changes due to environmental, learned or intentional influences (Zanone & Kelso, 1992).

Due to variations in intrinsic dynamics, expert performers are able to generate different types of functional performance solutions. The ideal of multiple movement patterning fits with data in cricket fast bowling reported by Pyne, Duthie, Saunders, Petersen and Portus (2006) who examined the relationship between junior and senior high performance athletes' anthropometric and strength characteristics and bowling speed. They observed differences in the variables and strength of correlation of predictors of peak ball speed between age groups and suggested growth and biological maturation largely accounted for greater peak ball speed in seniors. Maturation differences proposed by Pyne and colleagues (2006) could be followed by a comprehensive performance analysis including technical/coordination variants under a variety of conditions, such as different delivery types, to gain an understanding of the relationship between the intrinsic dynamics and performance solutions of individuals across developmental groups.

Therefore, understanding the nature of each individual's intrinsic dynamics is central to understanding how expert performance develops in sport. Due to different relationships between an individual's intrinsic dynamics and a set of task dynamics, each athlete may harness system variability in a different way implying that expertise may develop in quite unique ways. As individuals progress towards a state of expertise and explore different performance solutions, their intrinsic dynamics will alter and diversify. If the behavioural requirements of a task provide a close match with the pre-existing intrinsic dynamics of an individual learner, the rate of expertise acquisition is likely to be enhanced. The matching of intrinsic and task dynamics may explain precocial behaviour in sport when some athletes can perform incredibly well from an early age and forms the basis of talent transfer in sport. In contrast, acquiring task dynamics which are dissimilar to those of a previously learned task (e.g., tennis and squash movement pattern dynamics) may lead to a longer process of learning because the specific learner's intrinsic dynamics may need to be significantly re-shaped (Renshaw, Davids, Shuttleworth, & Chow, 2009).

These ideas in dynamical systems theory have important implications for understanding the development and maintenance of expert performance. How the intrinsic dynamics of developing experts are continually shaped by genetic and environmental constraints needs to be understood. The effects of environmental constraints on phenotypic gene expression suggests that athletes with what may be perceived as less favourable genetic dispositions may still achieve expert levels of performance given an appropriate skill acquisition environment (Baker & Horton, 2004). Alternatively, genetically gifted athletes may fail to achieve expert status without an environment that allows rich interactions for acquiring and practising skills (for a discussion of rich learning environments see ideas of Hammond and Bateman, 2009). Rich learning environments provide many opportunities to engage in continuous interactions with skilled peers, mentors, skilled coaches and supportive parents as athletes acquire movement skills and knowledge in specific sports. In Australia, Abernethy (2005) discussed the disproportionate success of athletes from rural locations as the 'Wagga-effect'. Wagga Wagga is a rural town with a population of 46,735 people (Australian Bureau of Statistics: Census QuickStats, 2006), where children typically play many different sports, often engaging in senior or adult competition prior to specialisation. It has produced an inordinately high number of international and professional athletes, more than any other urban conurbation in Australia. Côté, Macdonald, Baker, and Abernethy (2006) speculated that smaller cities (defined as having populations <100, 000 people) provide advantageous opportunities for talent development, because the populace is large enough to support the need for facilities, different sporting codes, club networks and competition infrastructure, and allows early exposure to adult competition. Côté et al. (2006) referred to the 'birthplace effect' where the quality and quantity of play and practice interactions afforded by the physical environment of smaller cities is favourable for talent development. These data highlight the need to undertake more research examining appropriate environmental cultural constraints underpinning development of expertise.

The range of unique constraints on athlete performance and behaviour have made predictions of expert performance difficult due to the dynamic nature of sport performance contexts (Davids & Baker, 2007).

To summarise so far, it seems unlikely that a singular common optimal pathway to performance expertise exists because of the degenerate neurobiological system characterising each individual performer and the effect of interactions between environmental and personal constraints on the intrinsic dynamics of each learner. Expert performers are able to generate different types of functional performance solutions, depending on differences in their intrinsic dynamics. Future research needs to provide a more comprehensive examination of influential constraints including technical/coordination variants under a variety of tasks' demands. For example in cricket fast bowling, investigating different delivery types, would allow greater insight into the individual dynamics and movement solutions of such a group (e.g., varying ball speed or type and line and/or length in cricket fast bowling).

2.4 A COMPLEX SYSTEMS APPROACH TO TALENT DEVELOPMENT

Conceptualising expertise acquisition as a complex system has several implications for talent development programmes. First, the aim of talent development is to aid individuals in gaining the expertise needed to satisfy the unique constraints impinging on them in specific performance domains. Assistance with expertise acquisition can be achieved by deterring intrinsic dynamics of each individual athlete, identifying key constraints on him/her and facilitating development by manipulating these constraints to encourage exploration of movement solutions (Davids et al., 2008; Handford, Davids, Bennett, & Button, 1997; Thelen, 1995; Thelen & Smith, 1994). Second, talent development programmes can harness existing system nonlinearities by developing strategies to induce phase transitions in individual performers. Understanding how to force individuals into the meta-stable region of the perceptual-motor landscape of practice may provide information on catalysts of expertise acquisition, where a strategy of co-adaptation can underpin the emergence of creative behaviours (typical of the profile of expert performers in line with the findings of Durand-Bush and Salmela, 2002). Meta-stable regions of a performance landscape are areas where the system is poised in a state of dynamic stability which allows it to rapidly undergo phase transitions to new, functional states of organisation as constraints change. If this strategy were aligned with observations of critical developmental periods in young athletes, abrupt phase transitions in expertise and performance may be induced. An implication of this approach for coaches is to incorporate tasks that promote adaptability and creativity in performers. In cricket, performance adaptability could be tested through the implementation of carefully designing games that require batters to probe the boundaries of their skill set and force co-adaptive behaviours in learners as long as the design of game tasks are based on grounded principles of the game (Renshaw et al., 2009). Third, these ideas signify the nonlinear nature of expertise acquisition. Traditional models of talent development need to be adjusted to consider the different rates of development of potentially talented athletes (Abbott et al., 2005). Sub-system behaviours continually shape an individual athlete's intrinsic dynamics. Because of variations in each athlete's intrinsic dynamics, individual rates of skill acquisition are likely to progress at different time scales (Liu et al., 2006). Talent development models need to take into account the different rates of learning and growth and maturation processes experienced by individuals on their pathway to expertise (not least it must take into account the relative age effect to maximise the available talent) (Cobley, Baker, Wattie, & McKenna, 2009). These different rates of learning can be influenced by key constraints which act as 'rate limiters' causing systems to find new functional performance solutions (Handford et al., 1997). Rate limiters can be defined as system controllers, that is components or sub-systems which limit the development of an individual in sport (Thelen & Smith, 1994). For example, children's strength in key muscle groups may act as a rate limiter which inhibits them from demonstrating the skills that they have acquired already through practice and experience in sport. An important task for coaches and practitioners is to identify the rate-limiting constraints which are acting on an expert system in order to manipulate them and facilitate transitions to a new performance level.

2.4.1 THE ROLE OF META-STABILITY IN ACQUIRING EXPERTISE

Two important characteristics of complex systems mentioned already include meta-stability and co-adaptation. These features are important for talent identification and development but need to be conceptualised in the sport performance domain. Emerging expert athletes exhibit complexity and meta-stability due to the potential for interaction between their sub-systems. In this way, the whole dynamical landscape of expertise can suddenly change with small variations in responses to constraints impinging on the developing athlete. Critical periods have been identified as brief windows of time and space during which a complex system's organisation is most open to modification from external and internal constraints. It has been argued that motor learning can be enhanced when developing athletes are located within these critical periods (Anderson, 2002).

The challenge for coaches and sport scientists is to identify when individual athletes enter meta-stable regions and/or critical periods while developing their expertise levels so that performance paradigm shifts in expertise and skill acquisition might be triggered, as exemplified in this chapter. For the individual to utilise technical and cognitive variability and find new performance solutions and cope with instabilities (meta-stability) requires complementary cognitive attributes (e.g., confidence, sacrifice, dedication, and perseverance). By ensuring exposure to meta-stable regions of the performance landscape during development, experts can discover new modes of behaviour to satisfy interacting perceptual, affective and task constraints. These new modes of performance are likely to emerge as novel solutions to performance problems as developing athletes co-adapt their responses to challenging constraints imposed by opponents, coaches or performance environments.

Co-adaptation is an evolutionary strategy that has implications for the way that constraints can influence the process of talent development by forcing the developing expert to find new functional performance solutions. It may represent a useful expertise development strategy for practitioners, as different performers and/or technologies attempt to pressurise individuals to seek unique performance solutions. Furthermore, the process occurs naturally as a sport develops (i.e., through movement pattern changes, rule changes or equipment change or as athletes pose each other new performance problems). New solutions to performance problems emerge as talented individuals learn how to assemble creative movement solutions during practice.

In cricket, fast bowlers can make the ball “swing”, which is the curved trajectory of the ball’s flight path, thereby making the task of hitting the ball more difficult for the batter. A cricket ball will swing when asymmetrical aerodynamic forces are acting on the ball, conventionally achieved by angling the ball’s seam obliquely to its direction of travel and caring for the ball so that one side is shiny and smooth and the other dull or rough. A more modern variant of this flight characteristic is “Reverse swing”, which originally gained prominence in Pakistan in the 1970s, with the success of players such as Sarfraz Nawaz, Imran Khan, Wasim Akram and Waqar Younis. These players experimented with ball care and grips and found they could achieve reverse swing, by focussing less on keeping the ball smooth and shiny on one side, and bowling the ball with the rough side forward (rotating the ball 180^{o} from the traditional position for swing bowling) (Mehta, 2000). The prominence of this technique in Pakistan has been attributed to the specific environmental conditions such as hard dry grounds resulting in balls enduring greater wear and tear at a faster rate (Mehta, 2000). Reverse swing fast bowling is now considered one of the most potent forms of attacking bowling in cricket, seldom mastered but often aspired to in elite level fast bowling.

In other sports, performance paradigm shifts have been created by:

I. equipment changes (e.g., the change from bamboo to fibre glass pole vaults leading to the World record increasing from around 4.5m to 6.14m in a vault by Sergey Bubka in 1993);

II. changes to playing surfaces (such as international hockey matches on artificial turf instead of grass), which may explain the ebb and flow of current performance standings and international rankings between countries; and

III. rule changes, such as the turn-over law in rugby union or the distance of the three-point line in the Olympics versus the NBA.

In elite sport, the drive for success means that performers are being challenged constantly to co-adapt to succeed. Through co-adaptation, players need to add new skills or strategies in the off-season in order to continue to challenge opponents with new problems (Cowdrey, 1974). Essentially, players have to constantly re-invent themselves or demonstrate an ability to adapt to the strategies developed by opponents. A good example of this adaptation was observed in 2008 in cricket when the use of ‘switch hitting’ by Kevin Pieterson (a current English test batsman) was first formalised. He developed a strategy of changing his stance (from his typically right-handed position) as a bowler was in the process of delivering a ball, by ‘jumping’ into a left-handed stance in order to overcome the restrictive field placings of opponents in one-day cricket.

The idea of sub-systems co-adapting to constraints imposed by other sub-systems of the body is influential in a dynamic systems analysis of motor development across the lifespan (Thelen, 1995). For example, during children’s motor development, dynamic systems analysts emphasise the idea that specific behaviours may not have yet appeared in developing children, because specific sub-systems act as system ‘rate limiters’ and are ‘lying in wait’ for another critical sub-system to reach a critical level (e.g., changes in the muscle to fat ratio in infants to enable upright postural control). In the performance of specific sports, various sub-systems could be critical to the performance development in athletes, such as strength, speed, mobility, or game understanding as a result of numerous experiences.

2.5 THE CASE OF FAST BOWLING EXPERTISE ACQUISITION

Historically, cricket fast bowling research has been focused on injury, rather than performance and skill development. Much of this work has been epidemiological in nature, examining injury occurrence in schoolboys (Dennis et al., 2006; Foster & John, 1987) and elite cricketers (Dennis et al., 2003; Dennis et al., 2005; Gregory et al., 2004; Stretch, 2001). Recent research has examined the relationship between selected anthropometric variables and ball release velocity (Glazier et al., 2000; Pyne et al., 2006; Stuelcken, Pyne, & Sinclair, 2007). Typically this research has been descriptive, with some suggestion on how to minimise injury risk, but with little consensus or evidence provided on ways to improve coordination and coaching strategies. Multi-articular movement tasks such as fast bowling in cricket provide valuable research vehicles to examine the role of adaptive movement behaviours in expertise development in complex performance environments. In cricket fast bowling the paradoxical relationship between stability and variability explains why skilled athletes are capable of both consistency and adaptability in goal orientated movements (Glazier, Davids, & Bartlett, 2003). From a dynamical systems approach movement variability is functional and a central feature of expert performance, providing flexible coordination solutions which adapt to changing sport environments and demands (Williams, Davids, & Williams, 1999). Traditional cricket expertise research tends to be mainly mono-disciplinary (biomechanical or psychological) in nature.

2.5.1 TECHNIQUE FACTORS AND INJURY IN FAST BOWLERS

The high incidence of injury in fast bowlers across all ages has pushed much of the research toward injury mechanics associated with different movement patterns. Fast bowlers are subject to great internal and external loads to produce ball velocities of between 30-45 m/s^{-1} in competition. High ball release velocity is achieved initially through a substantial run-up followed by a bound to put the body into the correct alignment and position for the individual's delivery phase; between back foot contact and front foot contact (and ball release), the transfer of energy from the ground and production through musculo-skeletal torques to ball release velocity is achieved through a combination of complex and often unique intersegment motions. During this transfer of energy through the kinetic chain, the trunk goes through hyperextension, flexion, lateral flexion and axial rotation (Burnett, Barrett, Marshall, Elliott, & Day, 1998; Elliott, 2000).

Early research on injury occurrence in fast bowlers suggested that high bowling workloads, increased ball release heights and counter rotation of the shoulders were statistically related to lower back injuries in adolescent fast bowlers (Foster, John, Elliott, Ackland, & Fitch, 1989). Subsequent research has focused on shoulder counter rotation, finding evidence associated with stress fractures and lower back injuries (Burnett et al., 1996; Burnett, Elliott, & Marshall, 1995; Elliott & Khangure, 2002; Elliott, Davis, Khangure, Hardcastle, & Foster, 1993; Elliott, Hardcastle, Burnett, & Foster, 1992; Foster et al., 1989). Shoulder counter rotation can be most easily explained as the rotation of the shoulder away from the batter to its maximum point, between back foot contact and front foot contact.

The position a bowler adopts at back foot contact has been used to classify their movement pattern. Bowlers who counter rotate their shoulder to re-align the shoulders to the hips are classified as having a mixed technique. Three main techniques have been established (Elliott, Foster, John, Ackland, & Fitch, 1989; Stockill & Bartlett, 1992). However, because of the degeneracy associated with fast bowling techniques, no clear boundaries between the techniques exist and classification occurs along a movement pattern continuum rather than within rigid categorization parameters (Bartlett, Stockill, Elliott, & Burnett, 1996). The three main techniques are the side-on technique, the semi-open technique and the front-on technique.

Researchers have related the position a bowler adopts at back foot contact to injury (Portus, Mason, Elliott, Pfitzner, & Done, 2004; Portus, Galloway, Elliott, & Lloyd, 2007; Ranson, Burnett, King, Patel, & Sullivan, 2008), with agreement that mixed action and counter rotation of the shoulder is related to lumbar spine injuries and abnormalities. However, the exact mechanics of injury have not been established (Bartlett, 2003; Elliott, 2000). Portus and colleagues (2003; 2004) have shown that a more front-on trunk alignment and larger pelvis-shoulder separation angles at back foot contact and a more extended pelvis lumbar angle at front foot contact have been linked to increase shoulder counter rotation. The kinematic differences between fast bowling movement patterns will likely result in multifaceted injury mechanics. The methodological progression toward three-dimensional modelling analysis has greatly advanced understanding of the intricateness of trunk mechanics (Burnett et al., 1998) and modelling issues associated with the upper body, specifically the shoulder joint and elbow angle (Elliott & Alderson, 2007; Elliott, Wallis, Sakurai, Lloyd, & Besier, 2002; Elliott, Alderson, & Denver, 2007; Lloyd, Alderson, & Elliott, 2000).

There has been conflicting evidence published on the correlations between movement patterning parameters and both injury and ball speed, with regards to run-up velocity (Burden & Bartlett, 1990; Glazier et al., 2000; Hanley, Lloyd, & Bissas, 2005) and front limb functionality during impact (Portus et al., 2004). One potential explanation for these conflicting mechanisms is the use of discrete values and the grouping of bowlers of different movement patterns into the same sample group. Alternatively, studies that have limited groups based on specific criteria have used different classification movement patterns, as different standards of classification exist between fast bowling research groups. Movement pattern differences have led to problems with inconsistent cohorts based on these diverging classifications and may explain potential inconsistency in both determents of injury and ball velocity (Salter, Sinclair, & Portus, 2007).

2.5.2 PHYSIOLOGY AND ANTHROPOMETRY RESEARCH ON CONSTRAINTS ON FAST BOWLING

Existing research has failed to establish a clear consensus on which physical factors contribute most strongly to ball release speed (Bartlett et al., 1996; Hanley et al., 2005). There are weak correlations between ball release speed and physical characteristics in senior bowlers. These include: chest girth and composition and body composition (Portus, Sinclair, Burke, Moore, & Farhart, 2000), static jump ability (lower body strength) and arm length (Glazier et al., 2000; Pyne et al., 2006; Stockill & Bartlett, 1994). In junior bowlers, static jump, bench throw, body mass, percentage muscle mass and height have been identified as important factors contributing to ball speed (Pyne et al., 2006). Hanley et al., (2005) examined the relationship between ball speed and 74 variables based on a systematic review of the literature. Only five variables showed a significant relationship with release velocity, none of which were found in the earlier studies of fast bowling (for review see Bartlett et al., 1996). These were run-up velocity, trunk angular displacement, shoulder angular displacement, angle of bowling arm and alignment of the feet. Conflicting literature results suggest that grouping bowlers of varying movement patterns may not provide insight into the relationship with an individual's bowling speed and that valuable information may be lost in non-individual analysis (Salter et al., 2007).

More recent research has profiled anthropometric measures of elite Australian male fast bowlers (Pyne et al., 2006; Stuelcken et al., 2007). Stuelcken et al. (2007) found that Australian fast bowlers were predominantly characterised by mesomorph somatotypes, similar to the South African bowlers examined by Stretch (1991). However, significant differences were found between the muscularity of male and female participant groups. Typical male, elite fast bowler somatotype characteristics included a well-developed chest and upper arm, and a relatively short trunk (Stuelcken et al., 2007).

Pyne and colleagues (2006) examined the relationship between strength alongside anthropometric variables and ball release speed in junior and senior first class fast bowlers. They found the main discriminator between the two groups in the production of ball speed was mass and upper body strength. However, in junior but not senior fast bowlers, body mass and percentage muscle mass were predictors of ball release speed, explaining 74% of the variation in ball release speed. In senior bowlers, arm length, chest depth and lower body strength were predictors of ball release speed, explaining only 54% of the variation in ball release speed. This low predictor value supports previous suggestions that coordination and additional factors play a critical role in ball speed production, and talent identification based on physical characteristics alone is unwarranted. These findings suggest that early maturation may lead to performance enhancement in the junior (14 + 1.3 years) age group. However, results from the senior group suggested that these factors were not uniquely important throughout development and that movement pattern and general strength should remain the focus of fast bowling development squads (Pyne et al., 2006).

2.5.3 MOVEMENT PATTERNS, COORDINATION AND BALL SPEED

Cricket research has failed to establish a clear consensus on which technical factors contribute most strongly to ball speed (Bartlett et al., 1996; Wormgoor, Harden, & McKinon, 2010), with weak correlations being shown between ball release speed and specific movement pattern variables. These include front leg knee angle (Burden & Bartlett, 1990; Portus et al., 2000), shoulder rotation (Hanley et al., 2005) and alignment (Portus, 2001) and horizontal velocity (Glazier et al., 2000). Limited research has been published on the coordination of segments and the fundamental mechanisms associated with faster ball release speeds (Bartlett et al., 1996). Research has examined technique factors associated with higher ball release speeds in junior and senior bowlers and has not established exclusively consistent correlates. A moderately significant relationship has been established between faster bowlers and higher peak ground reaction force at front foot contact (Portus et al., 2004; Portus, Rosemond, & Rath, 2006). This finding suggests that the mass of the bowler combined with the run-up velocity may be important components of ball release speed when combined with the braking action of the front knee, sequential transfer momentum onto the trunk and then forearm and wrists at ball release in both age cohorts. In junior bowlers greater trunk flexion range of motion and rate of flexion, as well as pelvis-shoulder separation angle, range of motion and pelvis-thorax lateral flexion during delivery were also positively correlated with higher ball release speed (and potential injury risk). In senior bowlers, the opposite was true; less trunk flexion range of motion and a lower rate of flexion between back and front foot contact were associated with higher ball release speed (Portus et al., 2006). These differences in release mechanics indicated the functional adaptations in movement patterning as bowlers' physical and anatomical characteristics changed during maturation, highlighting the difficulty in determining the potential of junior athletes.

In the existing research, there are discrepancies and contradictions involving mechanical factors associated with ball release speed. For example large shoulder rotation range of motion (Portus et al., 2004) and small shoulder rotation range of motion (Portus et al., 2006) have been observed during the delivery stride, and the role of the front lower limb at contact has been reported to brace, collapse, or extend (Burden & Bartlett, 1990; Portus et al., 2004). These discrepancies have been explained in several ways including erroneous methodology, which has been improved with the use of three-dimensional motion analysis, the use of discrete maximal data analysis, differences in technique classifications and inappropriate use of between-bowler methodology. Between- bowler methodologies average data between bowlers, where key individual information may be lost, especially when very few trials are used (one in some cases) as representative of 'typical' movement patterns (Elliott et al., 2007; Portus et al., 2004; Salter et al., 2007). Inconsistencies with experimental task requirements have also been an issue, with some studies only recording the fastest ball delivery without reference to task outcomes (e.g., accuracy of delivery). A more comprehensive analysis would involve analysis of several performance trials, where the researcher can observe movement coordination patterns in relation to achievement of task outcomes. The adaptability of fast bowlers to bowl different type of deliveries and adapt their movement patterns to different pitch conditions, given the global nature of the game is an important consideration for future research.

Glazier and colleagues (2000) conducted a biomechanical examination of medium fast bowlers using the kinetic chain principle to underpin the analysis. This phenomenon has previously been used to examine other over arm actions including baseball, javelin, throwing and the tennis serve (Bartlett, 2000). Glazier et al. (2000) identified a proximal-to-distal linkage system in right-handed bowlers with a sequential increase in peak linear speed from the right hip, seventh cervical vertebra, right glenohumeral joint, and right elbow to the right wrist. Through this linkage system, energy and momentum were transferred sequentially, reaching greatest magnitude in the end segment speed (Fleisig, Barrentine, & Escamilla, 1996). The initial acceleration of the large muscle groups and segments with large moments of inertia facilitates distal muscles, which contract over joints with increased energy, creating greater forces in the distal muscles (Morriss & Bartlett, 1996). Although the action of the run-up, hip and trunk is important in fast bowling, this study found greater variance in peak linear speed in the more distal points of the kinetic chain (Glazier et al., 2000).

There are a number of research groups examining fast bowling movement patterning factors related to ball release speed and injury in cricket. However, there remain numerous unknown mechanical factors behind higher release velocities. Portus et al. (2004) were able to account for 68% of ball variance and suggested the remaining determinant to be linked to run-up speed, transfer of momentum, anthropometry and physiological determents. In a review of biomechanics in fast bowling, Bartlett (1996) suggested more research is needed on segmental contributions to ball release speed, particularly energy transfer and segment kinetics. As highlighted in this chapter, future research needs to explore intra-individual analyses or more appropriate analysis methods in fast bowling. The constraint-led approach (Davids et al., 2008) strongly supports the use of individual analyses, such as coordination profiling, since an individual bowler’s optimal movement pattern will be determined by the interaction of the performer, environmental and task constraints. Performer constraints include physical factors such as height, weight, limb length, arm speed, athleticism, flexibility, strength and power. Discrepancies of technique classification across research and inappropriate analyses groupings of fast bowlers have led to discrepancies and non significant findings in parameter - skill mechanisms in fast bowling skills.

A major limitation of previous fast bowling research has been the number of trials analysed, the classification of skill level and differing task conditions. Sports performance research under the biomechanics umbrella faces a predicament between controlled research environments due to traditional engineering frameworks and modelling limitations, and the need for greater task representativeness in creating rich environments, which are close to performance contexts so that experts are challenged to demonstrate their expertise, particularly in dynamic multi-articular actions. This has led to some criticism academically and commercially. Davids and Button (2004) described this challenge as a false dichotomy alongside recent advances in sports science with the integration of ideas from dynamical systems theory. Glazier and colleagues (2003) suggested movements such as cricket fast bowling should include multiple-individual analyses to better characterize the role of intra- and inter-individual variability of movement in relation to the purpose of the movement (Newell & Slifkin, 1998). Bartlett (2006) suggested technique classification in cricket fast bowling may be fuzzy not crisp, due to the complexity of multi-articular actions in expert systems. He advocated the use of Kohonen mapping and artificial neural networks in the examination of expert systems. With advances in technology, biomechanics automatic marker-tracking systems allow greater and more accurate expert movement data to be collected, which could lead to the use of fuzzy expert systems for diagnosis of weaknesses in sports movement patterns (Bartlett, 2006).

The mono-disciplinary nature of previous fast bowling research discussed in this chapter highlights the need for a multidisciplinary framework for the investigation of fast bowling performance and skill acquisition. The lack of research on skill acquisition in fast bowling provided a valuable context to advance the understanding of coordination in this task. Obvious but uncharted in previous research is the degeneracy in the search for a movement solution. From a dynamical systems approach, fast bowling provides a valuable task because of the numerous unique constraints on athlete performance and the unstable nature of sporting competitions and required movement solutions. The task is highly degenerate in the sense that many different movement patterns can elicit similar ball speeds and accuracy. The athletes and the environment are treated as an inseparable system. The athlete’s behaviour emerges out of the dynamics of this system, and the system provides enough information to make adaptive behaviour possible (Duchon, Kaelbling, & Warren, 1998).

The acquisition of motor expertise involves the interaction of numerous neurobiological system components and their adaptation over time when exposed to different learning experiences. As such, the component interactions will always be specific to a domain of interest or specific sport skill and it may not be appropriate to draw conclusions from research in other expertise domains. Expertise development in cricket fast bowling is unique and very little can be understood by the study of other multi-articular actions in sport (e.g., throwing or running towards a target). Indeed, as mentioned earlier, recent work examining multi-articular actions in sport suggests that tasks are highly degenerate in the sense that many different arm movement patterns can elicit identical acceleration of an object, for example (i.e. a ball) (Liu et al., 2006). Similarly the existence of a common optimal pathway to performance expertise within cricket fast bowling is unlikely to exist because of the degenerate neurobiological system characterising each individual performer.

2.5.4 METHODS FOR STUDYING EXPERTISE IN FAST BOWLING FROM A DYNAMICAL SYSTEMS PERSPECTIVE

The functional role of variability in expert performance has important implications for the study of expert skill acquisition in fast bowling. Morriss and colleagues (1997) examined variability of men's javelin throwing in the world athletics championships. They found the finalist from the event exhibited a range of movement solutions which they based on the reliance on different upper body contributions to ball release speed. The silver medallist demonstrated linear shoulder movements (shoulder horizontal flexion and extension), whereas the winner of the event utilized the shoulder rotation movements combined with elbow flexion (which had a velocity of 18% greater than any competitor) and throwing styles. The other finalists used variations of these movement patterns, supporting the notion of degenerate movement solutions reliant on the self organization process (Bartlett & Robins, 2008). However, the two dimensional nature of the data collection methods due to the constraints of biomechanical analysis in match situations questions the validity of shoulder and elbow movements reported, considering the issues of crosstalk and long axis rotation in throwing tasks. Overarching the skill itself, variability in neurobiological systems also has implications for the formation of talent development programmes.

Conceptualising expertise development as a complex system has numerous implications for talent development programmes. The aim of talent development is to aid skill acquisition and mastery in challenging environments. Providing environments that allow individuals to move into a metastable region to allow phase transitions in performance to occur should be a focus. This requires a comprehensive understanding of the intrinsic dynamics of each individual. Talent development programmes can harness these nonlinearities by developing strategies to induce phase transitions in individual performers; this might be best achieved by understanding how to force individuals into the metastable region where a strategy of co-adaptive moves can underpin emergence of rich behaviours. Co-adaptive moves is a strategy that harnesses constraints as a process of developing talent, forcing the learner to find new movement solutions (Kauffman, 1995; Kauffman, 1993). This is a useful coaching strategy but also occurs naturally as a sport develops (i.e. skill levels change and athletes pose each other new performance problems) and new solutions to these problems emerge as talented individuals learn how to access creative movement solutions during practice. For example, in high jump early athletes use a scissor technique to jump with first the inside leg and then the other leg in scissoring motion. The scissors then progressed to the western roll and finally the Fosbury Flop. This technique took advantage of the raised, softer landing areas in modern times, by directing the body over the bar head and shoulders first, then sliding over on one’s back, which would have likely led to injury without modern landing mats. Talent development programmes should aspire to promote the movement of individuals into a metastable region. This can be achieved by identifying key constraints on each individual and facilitating development by manipulation of these constraints to encourage exploration of coordination.

2.6 CONCLUSION

A comprehensive examination of expertise involves understanding the intrinsic dynamics of each individual and the specific rate limiters and constraints that shape their behaviour. Each individual athlete comes to a performance context with a particular set of intrinsic dynamics that has already been shaped by genes, development and early experiences. These constraints are shaping the intrinsic dynamics along different timescales. Individualised pathways to expert performance are expected because of the unique interacting constraints on each individual. The concept of degeneracy supports different ways of attaining the same outcome across expert performers, and underlies expert behaviour; as such it should be a central focus in future expertise research.

Traditional talent development processes have been challenged (Abbott & Collins, 2002; Simonton, 1999) due to the emergence of nonlinear development, as maturing athletes satisfy key constraints on them, and shift the system to a new organizational state as required. Historically, expertise research has typically focused on the role of either nature (genes) or nurture (environment) as mechanisms for understanding how experts emerge in performance domains such as sport. This dualist approach has failed to emulate the complementary nature of the relationship between individual and environmental constraints. Although numerous hours of training are needed at the elite level, attainment of an expert level of skill is not accomplished by hours of deliberate practice alone. Similarly, the importance of an individual's genetic make up has been accentuated with biased interpretation of genomic studies (Davids & Baker, 2007). In recent years sport performance research has encompassed a move toward multi-dimensional models of performance and learning in sport, with significant implications for understanding processes of expertise and talent development. In this chapter it has been demonstrated that dynamical systems theory and the complexity sciences might provide the basis of an interactionist perspective on expertise acquisition in sports.

Dynamical systems theory is an appropriate functional framework for expert performance research because it can be used to consider developing athletes as nonlinear, complex neurobiological systems. It avoids the organismic asymmetry that can be observed in traditional models of expertise acquisition and talent development, addressing questions that other frameworks do not have the language and tools to pose. This chapter has highlighted several concepts with important implications for expertise and talent development researchers, including the concepts of self-organisation under constraints; emergence; meta-stability, creativity; degeneracy; and system stabilities and instabilities over different timescales. Within this overarching theoretical framework it could be argued that the same performance outcomes can be achieved in diverse ways as individual performers attempt to satisfy the unique constraints on them (Davids et al., 2003). Evidence from biomechanical fast bowling research presented in this chapter suggests individuals' unique movement solutions may produce desired high ball speeds. Genetic diversity may be responsible for a small part of training or performance response differences between individuals, and only when there is a favourable interaction with important environmental constraints are performance benefits observed. Phenotypic expression of behaviour might be best understood at the level of individual interactions with key environmental and task constraints. Given differences in genetic contributions, performance variations are more likely to assert themselves under intensive practice regimes. Common optimal pathways to performance expertise are not expected because of neurobiological degeneracy characterising each individual performer and the effect of interactions between environmental and personal constraints on the intrinsic dynamics of each learner.

The acquisition of expertise is domain specific and involves adaptation to performance environments through satisfying unique constraints which impinge on each developing expert. Expertise acquisition emphasizes the changing nature of the performer-environment relationship through development, and gaining experience through training, practice, coaching and competing. A comprehensive examination of expertise involves identifying the intrinsic dynamics of each individual and the specific rate limiters and constraints that shape their behaviour. Each individual athlete comes to a performance context with a particular set of intrinsic dynamics that has already been shaped by genes, development and early experiences. Individualised pathways to expert performance are expected because of the uniqueness of these dynamics constraints.

This chapter has outlined expertise acquisition drawing on evidence and theoretical advances across a range of domains. However, due to the domain-, sport- and skill-specific nature of expertise, and the unique constraints associated with fast bowling also discussed in this chapter, an in-depth examination of fast bowling development, exclusively, is required. The first phase of this research in chapters 4 and 5 examines experiential knowledge of Australian expert fast bowlers and coaches, where a wealth of knowledge explored the remarkable developmental trajectories, challenges, as well as fast bowling talent development and coaching philosophies. The following chapter outlines the qualitative methodologies used in the first phase of the research.

Chapter 3: Qualitative Methods

3.1 INTRODUCTION

The first phase of this thesis included a series of interview-based data recording sessions. This chapter outlines the details of the rational for using a grounded theory methodology, interview protocols, data coding, interpretation and processing. Details specific to each study can be found in each associated chapter.

3.2 QUALITATIVE METHODOLOGY

Grounded theory is an interpretative research methodology used to examine social phenomena, from a symbolic interactionist viewpoint (Cutcliffe, 2000). From this perspective individuals construct reality and meaning in situations from their interaction with events, people, happenings and objects (Morse & Field, 1995). Researchers utilising a grounded theory methodology aim to understand social patterns that exist as a function of human and group interactions and may formulate a concept from the emergent relationships (Strauss & Corbin, 1994).

Grounded theory is a descriptive and exploratory methodological framework, with two main purposes: 1) the aim of generating a theory that is grounded in systematically gathered and analysed data; and 2) to act as a possible elaborator and modifier of existing theories (Strauss & Corbin, 1994). One strength of this methodology is the systematic data collection and analysis procedures which allow the development of theory utilising constant comparative analysis methods allowing the emergence of themes throughout the research process (Glaser & Strauss, 1967). Specific use of these procedures is outlined in the following sections, with reference to the current programme of research.

3.3 INTERVIEW PROTOCOL

Participants were contacted through a letter of invitation in cooperation with Cricket Australia. The researcher began building a rapport with participants via phone calls to organise meeting times and venues. During this period potential participants were informed of the purpose and potential benefits of the study, and given details of their expected involvement and interview content. Pilot work consisted of semi structured interviews with two elite fast bowlers outside the precise inclusion criteria for the main study. Pilot interviews were conducted to review and refine interview content, semantics and order of questions for the interview guide, which was adapted to the cricket fast bowling context from previous expertise and talent development research in sport (Côté, Ericsson, & Law, 2005; Weissensteiner, Abernethy, & Farrow, 2009) (See Table 3.1). All semi-structured qualitative interviews were conducted by the primary researcher, all occurring face-to-face except for one which was completed on the telephone. All interviews were recorded on an mp3 storage device and lasted between 40-70 minutes. This study was approved by the human research ethics committees of the Australian Institute of Sport and the Queensland University of Technology. Participants signed a written consent form before participating in the project.

3.4 DATA COLLECTION

At the onset of interviewing, participants were reminded of the purpose of the inquiry and signed a consent form. A general outline of the semi structured interview is displayed in Table 3.1. Specific topics of investigation included: (a) identification of significant others contributing to experts' development; (b) engagement in physical activities apart from cricket; and (c), identification of potential 'rate-limiters' or specific factors which hindered or aided the development of fast bowling and cricket skills. After rapport building conversations and broad questions to familiarise them with the inquiry theme, participants were asked about their developmental experiences and factors believed to hinder or contribute to their own fast bowling development. Following grounded theory practices, self-reported data were collected in an open-ended way without prescribing categories for describing how participants might have become expert. Probe questions were used to encourage participants to expand on responses and provide depth to articulated perceptions.

Table 3.1. Fast bowling expertise interview content guide

A. DEVELOPMENTAL HISTORIES

(1) Identification of significant people who made a contribution to their development.

When did you first play cricket?

Describe your family background in relation to participation in sport?

Where there any specific people who influenced you fast bowling from child to adult?

> *As a child were you involved in rec, club or school cricket and other sports?*
> *How did you become passionate about fast bowling (opportunities easily available)?*
> *Who support/influenced your game (sibling, family, coach and community involvement)?*
> *Parental support, fun and involvement Vs pressure and expectation*
> *Did you move clubs or city in your youth and through your career? (Location and movement of childhood sporting experiences)*

(2) Engagement in Various Sports/Physical Activities

How would you describe your involvement in sports and physical activity outside of cricket?

> *How would you describe the structure? (Organised vs spontaneous)*
> *Others involved/support?*
> *Level of competition/motivation/ physical effort/ concentration involved/fun.*
> *Do you think this was important for your cricket skills? (How did this effect your cricket development (time restrictions Vs transfer)*

(3) Physical Activity Cricket-Related Activities

Can you describe your early involvement in cricket + the factors which you think were important for your development of fast bowling and cricket skills?

> *Physical development issues (maturation rate, height and weight changes).*
> *Psychological issues (motivation concentration, focus, anxiety, coping).*
> *Coach environment, relationship with captain, CA pathway.*
> *Mentors?*
> *Significant memories of experiences which may have shaped your values in areas such as sportsmanship.*
> *Exposure quality environments and opportunities and location.*

How would you advise aspiring pace bowlers to balance their training workload? *Did you always bowl fast?*

Can you describe your early involvement in cricket + the factors which you think hindered your development of fast bowling and cricket skills? (If not already mentioned)

> *Injury (describe the nature and duration of any injuries and to provide a rating of overall health.)*
> *What where the important factors which contributed to your comeback and return to playing cricket for Australia.*

B. EXPERTISE DIMENSIONS

(1) Expertise Components

Could you give me an overview of what you do when you coach developmental athletes?
How does this contrast to what you do when you coach elite athletes?
What factors do you think characterise someone who has the potential to become elite?
Do you see any common trends for reasons why promising bowlers do not advance?

What are the stages that someone has to go through to progress from novice to elite in cricket? What do you do at each of these stages?
Could you tell me about the complexity of what you are trying to do at each stage?
What categories or component do you think about when you are coaching in terms of talent development or identification?

(2) Developmental rate limiters or catalysts
Does Cricket Australia offer clear guidelines as to the levels/skills etc. expected by each stage?
How effective do you think current talent development processes are in cricket?
Can you describe how you would improve this and what you would consider best practice for the CA FB Pathway?

Coaching environment and structure (adolescent c/f adulthood)
Life balance, how is this learned is it important.
Weightings of different dimensions (socio-development, physical maturation, deliberate, play) at different stages.

3.5 DATA ANALYSIS

All interviews were transcribed verbatim with grammatical changes to improve the flow of the text if needed. A copy of the interview transcripts was emailed to each participant to authenticate that the information accurately reflected their perceptions (Miles & Huberman, 1994). Participants were asked to provide their written comments directly on the transcripts.

Data were analysed by the main researcher in NVivo software (QRS NVivo 8) using inductive reasoning. Open coding of each participant's transcript allowed concepts and themes to emerge from the data (Côté, Salmela, Baria, & Russell, 1993). Ideas or concepts were coded and used to conceptualize categories and/or sub-categories. Once a new theme or concept had emerged from a transcript, the remaining transcripts were deductively analysed for the same theme. Themes expressed by two or more participants were considered significant. This coding process was flexible so that categories could be adjusted and refined during analysis, until theoretical saturation occurred and the themes conceptualized all of the data (Strauss & Corbin, 1998).

In line with recommendations of Miles and Huberman (1994), procedures used to maximize reliability and control research bias included: (a) engaging in peer concept mapping sessions with co-authors; and (b), verification of data by participants, who were emailed interview transcripts and asked if they were in agreement with the content and to make amendments if needed. Triangulation of data was implemented with the use of public document analysis (e.g., scrutiny of authorised autobiographies) and the perception of participant coaches where possible (Miles & Huberman, 1994).

Chapter 4: The Development of Fast Bowling Expertise in Australian Cricket

4.1 ABSTRACT

In this chapter, key concepts from dynamical systems theory and complexity sciences are presented to exemplify constraints on talent development in a sample of elite cricketers. Eleven international fast bowlers who cumulatively had taken more than 2,400 test wickets in over 600 international test matches were interviewed using an in-depth, open-ended, and semi-structured approach. Qualitative data were analysed to identify key components in fast bowling expertise development. Results revealed that, contrary to traditional perspectives, the athletes progressed through unique, nonlinear trajectories of development, which appears to be a commonality in the experts' developmental pathways. During development, individual experts encountered unique constraints on the acquisition of expertise in cricket fast bowling, resulting in unique performance adaptations. Specifically, data illustrated experts' ability to continually adapt behaviours under multifaceted ecological constraints.

Keywords: expertise, skill acquisition, dynamical systems theory, talent development

4.2 INTRODUCTION

As noted in the previous chapter, in sport the probability of an individual achieving expert levels of performance has traditionally been regarded as dependent on either innate talent or prolonged exposure to environmental stimuli promoting learning and development (Howe et al., 1998). Expertise and talent development research has traditionally been dominated by the nature (biological) and nurture (environmental) debate, a dialogue crossing many domains in science (for a review see Davids & Baker, 2007). More recently, these polar perspectives on sports performance have become entwined, with suggestions that genes and environments have co-varying and interacting effects (Baker & Davids, 2007). The perception that universal correlates of expert performance exist has come under increasing criticism (Durand-Bush & Salmela, 2002). Although there are some common factors that appear to underpin development of expertise, multi-disciplinary models (e.g. Simonton, 1999) have highlighted talent development as a nonlinear process and predict that a range of developmental trajectories over different timescales can lead to achievement of sporting expertise. These models have criticised traditional talent identification programmes for overemphasising early identification and for not considering variations in maturation rates of developing performers (Abbott et al., 2005).

To exemplify, a multi-disciplinary, emergenic and epigenetic model on talent development was proposed by Simonton (1999). He suggested that talent emerges from multiplicative and dynamic processes and is likely to operate as an intricate system beyond the scope of the polarised nature–nurture debate. His mathematical equations formally *operationalised* how potential components might contribute to talent development. As discussed in Chapter one, such formalisms were conceptualised within the sports expertise domain from a dynamical systems theoretical perspective (Phillips et al., 2010b), capturing expertise acquisition as a messy, noisy, unpredictable and nonlinear process. The dynamical systems theoretical model proposed expert skill acquisition as emerging from an interaction between constraints related to the specific individual, task and environment. Individual performer constraints included personal factors such as psychological, physiological and anthropometric characteristics. Task constraints were considered specific to the sports discipline for each developing athlete and environmental constraints included socio-cultural factors, such as family support, access to facilities and cultural trends in sport participation. It was argued that the range of interacting constraints impinging on each athlete is unique and shapes the acquisition of expertise in sport, resulting in the expectation of varying developmental pathways between individuals. Several key features of the model require empirical investigation including constraints on rates of expertise acquisition and the notion of individual development trajectories in expert athletes. This chapter examines development trajectories of elite fast bowlers in cricket to consider the model's efficacy. It was expected that performance solutions emerging from developing expert fast bowlers would be shaped by the confluence of interacting personal, task and environmental constraints. The ability of the developing athlete to adapt to constraints, and produce functional performance solutions will affect their rate of learning and development.

Complex dynamical systems are highly integrated and can be exemplified by an individual athlete as well as the athlete-environment relationship. These systems can transit between different organisational states (the dynamics), as internal and external constraints, operating at different time scales and described by the same physical principles, change (acting as information for the system). This process of development and change can be observed to occur within systems at different levels (e.g., in an expert individual when 'rate limiters', such as cognitive and physical sub-systems, become mutually entrained to drive the system to new states of organisation [expertise]). It can also occur between systems and the environment (e.g., distinct constraints leading to the emergence of different behaviours in individual experts as they co-adapt to each other's performance innovations) (Phillips et al., 2010b). Through a process of entrainment, like co-adapting biological organisms seeking to optimize their relative 'fitness' on an evolutionary landscape, rate-limiting sub-systems of performers can become dependent on what is occurring in other key sub-systems. A phase transition in expertise levels of athletes might, therefore, be facilitated by a change in the relationship between an athlete's sub-systems or with other performers. This change may emerge as a result of development, experience and physical or mental practice/training, which might push the whole system to a state of non-equilibrium. In nonlinear dynamics, if a system is driven to the edge of its current basin of attraction, the probability of a new state of organization emerging (e.g. a new level of expertise) increases, due to a breaking of symmetry in initial system structure. This occurrence exemplifies the process of 'self-construction' that Kauffmann (1993) defined in systems that evolve over time. In Chapter 1 it was highlighted how expert skill acquisition can be promoted by exploiting dynamical tendencies within athletic systems and between athletes, by creating diverse learning environments, encouraging late specialisation into sport (e.g. from approximately 13-15 years of age (Côté, Baker, & Abernethy, 2007) and facilitating discovery learning processes (Phillips et al., 2010b).

A significant first step in investigating the nature of interacting constraints that have shaped performance development in individuals is to study the experiential knowledge of current experts in a selected sport and assess how the data fit the model of interacting constraints on performance development. This interactionist approach requires a case study methodology which enables a deep analysis of individual performers' developmental histories. Some previous research has attempted qualitative analyses of elite athletes to identify physical, psychological, environmental, and social factors that constitute elite performance (Weissensteiner et al., 2009). Favourable factors included: extensive mental preparation, focus and commitment, clear goal setting, support from family or friends and opportunities to participate in residency programmes. An important observation related to similarities and differences in the athletes' perceptions. Without providing a detailed theoretical interpretation of these factors, Weissensteiner and colleagues (2009) proposed the existence of different pathways and strategies as they developed towards expertise (Durand-Bush & Salmela, 2002).

The current chapter raises questions on the dynamics of expertise acquisition and the developmental trajectories of expert athletes. The purpose of this chapter was to investigate the utility of a multi-dimensional model of expertise development using the sport of cricket as the task vehicle. The developmental pathways or trajectories of elite cricketers, specifically Nationally selected and established fast bowlers in Australia, were explored to identify the major constraints perceived by them to be important in the development and maintenance of expert performance. To achieve the aim of studying developmental trajectories of expert fast bowlers, it was decided to focus on experiences of the most accomplished experts. Such an approach needed to include analysis of their achievements at the highest level of performance and to explore the potential basis of performance longevity. Open-ended interviews have been previously used to examine competencies among elite performers to derive factors associated with the development and maintenance of success in a skill (Durand-Bush & Salmela, 2002). Allied to this method of obtaining information, grounded theory allows exploration of concepts as they emerge, and inductive hypothesizing of theory relating to the acquisition of expertise (Glaser & Strauss, 1967).

4.3 METHODS

4.3.1 PARTICIPANTS

Eleven past or present Australian international elite fast bowlers who had taken more than 2,400 international test wickets in over 630 international test matches were interviewed. Participant demographics are shown in Table 4.1[1]. Specifically, the fast bowlers satisfied the predetermined criteria of: (a) capability of producing an average bowling speed of > 130km/hr or classification as fast or fast-medium bowlers by members of the Cricket Australia Technical Fast Bowling Group; (b) having taken at least 75 international test wickets; and (c), having bowled in at least 20 international test matches.

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[1] Specific details and statistics of each individual are not reported to protect the anonymity of participants.

Table 4.1: Participant Demographics (Mean ± s)

Age (years)	Test Wickets	Test Matches
44.0 (10.6)	222.4 (135.1)	55.7 (28.4)

4.3.2 DATA COLLECTION AND ANALYSIS

Participants were contacted through a letter of invitation in cooperation with Cricket Australia. They were informed of the purpose and potential benefits of the study, and given details of their expected involvement and interview content. All semi-structured qualitative interviews were conducted by the primary researcher, with ten occurring face-to-face and one by telephone. All interviews were recorded on an mp3 storage device and lasted between 40-70 minutes. Pilot work consisted of interviews with two elite fast bowlers outside the precise inclusion criteria for the main study. Pilot interviews were conducted to review and refine interview content, semantics and order of questions for the interview guide, which was adapted to the cricket fast bowling context from previous expertise and talent development research in sport (Côté et al., 2005; Weissensteiner et al., 2009).

At the onset of interviewing, participants were reminded of the purpose of the inquiry and signed a consent form. Specific topics of investigation included: (a) identification of significant others contributing to experts' development; (b) engagement in physical activities apart from cricket; and (c), identification of potential 'rate-limiters' or specific factors which hindered or aided the development of fast bowling and cricket skills. After rapport building conversations and broad questions to familiarise them with the inquiry theme, participants were asked about their developmental experiences and factors believed to hinder or contribute to their own fast bowling development. Self-reported data were collected in an open-ended way without prescribing categories for describing how participants might have become expert. Probe questions were used to encourage participants to expand on responses and provide depth to articulated perceptions.

All interviews were transcribed verbatim with grammatical changes to improve the flow of the text if needed. A copy of the interview transcripts was emailed to each participant to authenticate that the information accurately reflected their perceptions (Miles & Huberman, 1994). They were asked to provide their written comments directly on the transcripts. Only a few minor changes were made to the transcripts.

Data were analysed by the main researcher in NVivo software (QRS NVivo 8) using inductive reasoning. Open coding of each participant's transcript allowed concepts and themes to emerge from the data (Côté et al., 1993). Ideas or concepts were coded and used to conceptualize categories and/or sub-categories. Once a new theme or concept had emerged from a transcript, the remaining transcripts were deductively analysed for the same theme. Themes expressed by two or more participants were considered significant. This coding process was flexible so that categories could be adjusted and refined during analysis, until theoretical saturation occurred and the themes conceptualized all of the data (Strauss & Corbin, 1998).

In line with recommendations of Miles and Huberman (1994), procedures used to maximize reliability and control research bias included: (a) engaging in peer concept mapping sessions with co-authors; and (b), verification of data by participants, who were emailed interview transcripts and asked if they were in agreement with the content and to make amendments if needed. Triangulation of data was implemented with the use of public document analysis (e.g., scrutiny of authorised autobiographies) and the perception of participant coaches where possible (Miles & Huberman, 1994). Only minor changes to the transcripts of two participants were made.

4.4 RESULTS

Data revealed that a significant commonality expressed in the perceptions of the group of experts were nonlinearities in development trajectories and their unique adaptations to constraints during expertise acquisition. The existence of numerous different trajectories to expertise was highlighted. Experts came from a range of social backgrounds and expertise evolved under unique, interacting task, individual and environmental constraints. Here a number of specific emergent themes are discussed and participant observations and comments are provided as exemplar evidence:

4.4.1 SIGNIFICANT OTHERS CONTRIBUTING TO EXPERTS' DEVELOPMENT

Support Networks. From adolescence onwards, support networks, including family members, coaches, and team mates, were perceived as important. Parents and siblings were supportive in many different ways. Some parents preferred to play a less dominant role, adopting more of a facilitating role such as with transport assistance. Some family members had little or no knowledge of cricket, but sought involvement with their children in a common activity, while other experts formed relationships with teachers at school providing coaching and support throughout early development:

> *"Oh look certainly my dad. He was the one that would always take me up to the nets. He'd bowl to me for hours on end and then I'd bowl to him for hours on end. He said he noticed a big difference as I was getting older he was finding it harder and harder to face me because I was getting quicker and quicker and it got to the point where he couldn't face me anymore. So that was a good gauge for me."*

Seven experts had parents who were actively involved in sports themselves. There was also a range of family interest in cricket, with some individuals coming from strong sporting families, with parents actively competing themselves:

> *"I never really realised how important sport was as far as a support structure to me, considering that my mother brought us up on her own, the three boys on her own. And it really taught me the lessons in discipline and values, in teamwork and all these things that I think it helped me out in that situation."*

Senior Team Mates and Competition. All participants stressed the importance of opportunities to play with older cricket players, and the increased level of challenge in this environment. They felt the club structures protected them when required but also gave them the opportunity to play a more challenging level of cricket both in big cities and smaller locations. Many declared there was no specific fast bowling coaching available, so often senior team mates filled this gap, acting as coach-mentors:

> *"Playing senior cricket and being around blokes that knew certainly enhanced it. So to come back to [small home town] and not play junior cricket where you're just eligible to continue to play senior cricket. I just think that the higher level you play at an earlier age the more chance you've got to improve. Whereas if you stay in under fourteens till you're old then the under sixteen's till you're too old and then just start playing senior cricket, the guys that do that, their development just seems just a little bit slower."*

National Idols. Nine fast bowlers spoke of the role of idols in attracting them to cricket and providing motivation. The importance of cricket as an Australian way of life meant there were strong TV role models, with high participation and play rates seen as normal.

"You know the Australia cricketers mean so much. Dennis Lillee was my favourite player by a mile. So I think he had a huge impact on me, you know he was a great bowler, great charisma, it was when it started to get marketing."

4.4.2 ENGAGEMENT IN PHYSICAL ACTIVITIES

The role of unstructured practice activity in available spaces. All experts mentioned the importance of "backyard" cricket in their development (for additional insights in cricket see Cannane, 2009). Backyard cricket activities were often undertaken with siblings and friends, in an unstructured environment allowing skill development in all aspects of the game, and with a strong focus on enjoyment, participation and competition:

> *“The primary school was about four doors down; all the kids in the neighbourhood would just play cricket at every opportunity. So I think that unstructured play is very important as well.”*

Multiple Sports Involvement. Ten of the eleven experts called themselves ‘sporting kids’, two focused on one winter and one summer sport only, while the remainder tried every sport they were allowed to. Several participants reached state representative level in more than one sport, including basketball, athletics, tennis, AFL and Rugby:

> *“I played a fair bit of rep. tennis throughout NSW, travelling around, was never that good, but it was always something I enjoyed. I play a little bit of golf, well quite a bit of golf when I was younger, just locally, and then I played a lot of rep. When cricket took off, I was also playing a lot of rep. basketball and travelling around. I guess I was always pretty competitive by nature and played different types of representative sports”.*

Late Specialisation. Some experts were not involved in structured cricket until late in their teens, typically viewing this experience as beneficial to their development. Eight out of eleven experts did not specialise as fast bowlers until late in development and considered themselves all-rounders (batters and bowlers), while others always classified themselves as fast bowlers and felt the desire to bowl fast:

> *“I can honestly say I didn’t come into cricket as a kid saying ‘I want to be a fast bowler,’ it just sort of happened because you know I had talent both bat and ball but I didn’t really sort of start to bowl fast so to speak until I sort of got to about 16, 17 when I really sort of shot up, grew about four or five inches, very quickly filled out a bit and all of a sudden bowled a yard or two quicker than I did the year before.”*

> *“Yeah, I was always a fast bowler. I used to bat a little higher up in the country, you know. But, yeah, I loved bowling, being a fast bowler, and that was what I always was.”*

4.4.3 RATE LIMITERS AND CATALYSTS FOR VARIABLE TRAJECTORIES IN FAST BOWLING SKILL DEVELOPMENT

Locality of Development. In line with previous research (Côté et al., 2006), birthplace effect data revealed experts from small cities and rural settings were over-represented in the group (shown in Table 4.2). This is of significant interest in the group, as most of the population, sporting opportunities and resources are concentrated in a few urban centres in Australia. Five of the participants grew up in rural towns or small cities, providing strong support for the view that smaller conurbations may provide better opportunities for talent development in sport than larger cities. Fast bowling experts felt the smaller communities provided them with more space for physical activities.

Table 4.2: Fast Bowling Experts Sampling Years Locality

Number	Town/City Population
3	< 50, 000
2	< 300, 000
6	> 1,000,000

However, experts who grew up in the city also had access to open spaces to develop their skills, including local parks, school grounds, and backyard facilities:

> "*Oh look I think I did what every other kid did, play you know like backyard, front yard, bowling at the garbage bin. I remember setting up under our house where I grew up drawing some stumps on the brick wall paint and just bowling for hours and hours at it. I didn't know any different."*

Sibling competition was noted as important in some, but not all cases. Often community neighbours or friends were involved in backyard cricket and numerous hours of play:

> *"He's [brother] only 18 months older than me, so we played lots of sports together. Competing in the backyard, he was always better than*

> *me, he was always faster. I think I may have got a competitive outlook on life from trying to beat my older brother all the time."*

> *"We would go down the park; we took things pretty seriously in the park. We would always pick up teams and play test matches and things like that so that would be after school, or on the weekends whenever we could."*

4.4.4 SEEKING OUT NEW CHALLENGES: THE EVOLVING ATHLETE

Experts actively sought out challenges to optimise their development. This tendency to seek new challenges formed the basis of adaptivity and longevity, requisite for maintaining expertise in later life. Experts sought new challenges in a variety of ways, the more obvious being movement between clubs and cities. Smaller cities may have less structured and more spacious, safe sports environments which may facilitate development in junior sport. However, in the sample, all athletes from smaller cities either commuted or eventually moved to larger cities to increase the competition and chance of future success. For two participants this move occurred during high school years and they remained in the city once they had finished high school and had left home.

> *"I knew that to further my cricket I couldn't stay down [there] and that's no disrespect to the level I was playing or the team I was playing for. I knew that if I wanted to get better I had to go down and play in Sydney."*

Some athletes moved states to attend university or to further their career at this stage. It was felt that some states had too many bowlers, or bowlers were labelled as not being able to get any further or make state representative squads, thus experts moved locations to make opportunities for selection:

> *"I was twenty-four and I'd developed a reputation in district cricket here, but I didn't seem to be able to get to the next level but I just seemed to be a district cricketer and people just thought 'oh he can bowl fast but they're not going to play him.' So I went across there and that's where I got the opportunity. I think you find a lot of people change states."*

Coaching and Individual Learning. Through self report participants alluded to personal characteristics that helped to shape their performance during early development. Being independent and always being open to new ideas and striving to learn and improve were seen as critical throughout the fast bowling development pathway. Being from a country background was believed to lead to greater hardiness and toughness by a number of the participants:

> *"I think growing up in the bush makes you a little bit tougher too. Working on the land, driving the tractor and putting crops in when I was nine and ten years of age, and I think the other thing [was that] I didn't mind being by myself, I was happy with who I was. I think the most important thing was I was just enjoying it; going out and having fun and just being relaxed. I think, you know maybe playing in the bush and travelling so far [to play cricket] you have got to be prepared to sacrifice a few things."*

While fast bowlers mentioned a lack of coaches, they also spoke of continued learning based on experiences and self discovery:

> *"I always found that I learnt best by doing something and learning, having the kinaesthetic process of doing something for me to learn. Yeah, to feel it so that if it was a mistake then I'd change it and I always felt that like whether it's swinging the ball or correcting technique and relying on instinct to do that. And I think for me that suited me and helped me a lot through that process, there wasn't anyone directing saying, you've got to do this, this is the way to bowl and this is the way you fix that and do that."*

Often individual constraints such as height, percentage of fast twitch fibres, and style of bowling and specific experiences resulted in the emergence of different types of fast bowler style. Experts expressed the importance of building movement patterns based on their own unique intrinsic dynamics (i.e. a system's unique dispositions for behaviour shaped by interactions of genes, development, and learning experiences). For many of the experts, the lack of formal coaching at youth level helped this exploratory process as it enabled coordination to emerge through discovery learning without over-prescriptive coaching.

> *"The thing the bowlers [have] got to realise is that no one's got the same bowling action, everyone is unique and that's the greatest thing about sport. So to me, what a coach should be doing is actually encouraging them to be themselves; bowl the way they should ... Don't try and bowl like [several Australian Fast Bowlers], bowl the way that you've been brought on earth to bowl., You know, bowl your normal action but do everything you possibly can to make sure that's taking as much stress of your back as you possibly can."*

At older ages when players were at a more advanced stages of learning, refinements in movement patterning could be made by more expert coaches at the cricket academy level. A number of participants expressed the importance of the Cricket Australia Academy. The importance of this development programme was captured by access to mentors, learning about what it meant to be a professional cricketer, training ethics, understanding movement patterns, game tactics, and discovery learning. Retrospectively experts highlighted the importance of 'knowing your body' and how to balance workload issues, particularly during adolescence:

> *"Before going to the cricket academy, training was basically non-existent. I would just turn up and roll my arm over in the nets or have a hit, no real clear plan; it was just something you had to do to play on the weekend. I guess going to the cricket academy really showed me what I had to be prepared to do, training-wise. You know: have plans and goals and set things like that, whereas beforehand there was not too much thought to it."*

Additionally, experts highlighted that one important role of the academies was to provide access to their idols, iconic ex-professional players and coaches who could pass on experiential knowledge to developing players.

Psychological attributes and dealing with injury. Psychological attributes were highlighted: intrinsic motivators, strong work ethic, sacrifice, resilience, self-confidence, passion as well as athletic skill, development of pre-ball and pre game routines, game tactics, dealing with pain and pressure.

> *"To be successful, I think at a higher level it's all about attitude, and the guys that are prepared to work harder, prepared to listen, always looking to learn, I think, will always have more potential."*
>
> *"I loved it [pressure]. I always felt my strength in the game was the mental side of the game. I felt I was mentally strong, I was happy with who I was and could handle things pretty well. When I played my first game for New South Wales I was just loving it, I wasn't nervous I didn't put any pressure on myself, I just went out there and enjoyed it as much as I could."*

Injuries were a prominent hurdle for aspiring bowlers to overcome and often contributed to the reasons why some athletes took time out from bowling. Several spoke about the determination it took to come back from injuries:

> *"The doctor told me when I was 18, you know you have got a complete fracture through your lower back. You know you won‟t be able to bowl fast again, you will be actually lucky to run properly without pain, you might want to work on your batting or you might want to choose another sport. And I was like, this is what I was thinking to myself, I don‟t buy that. .... So I said to the doctor, look I will be going away and doing everything that you ask me but I will see you when I‟m playing my first test match for Australia, and left it like that.."*

4.5 DISCUSSION

The developmental trajectories of expertise acquisition can be conceptualised in a framework including dynamical systems theory and the complexity sciences as highlighted below. In this chapter, it was evident from the data that the unique constraints impinging on numerous facets of the system can be looked at on many levels (including differences in familiar support, birthplace locality, specialisation late in sport, formal development programme support, different rates of maturation), resulting in varying nonlinear pathways to fast bowling excellence. A key role was identified for unstructured practice activities in optimal learning. Experts surrounded themselves with strong support networks advantageous to cognitive, physical and emotional development, and the importance of key cultural constraints was exemplified. The level and type of support required changes at different timescales and is unique to each individual. Developing experts resembled complex evolving systems, by harnessing nonlinear transitions in performance, through seeking out new challenges, exposure to optimal learning designs, self discovery and rich support networks in the acquisition of expertise.

4.5.1 DEGENERACY UNDERPINS ADAPTABILITY AND NONLINEAR TRAJECTORIES OF EXPERTISE ACQUISITION

Degeneracy suggests that structurally different components can be coordinated together to achieve the same goal (Liu et al., 2006). This concept underpins the adaptability and nonlinear trajectories of expertise acquisition. Sub-system interactions continually shape each individual athlete’s intrinsic dynamics or dispositions for behaviour. Because of variations in each athlete’s intrinsic dynamics, individual rates of skill acquisition are likely to progress at different time scales (Liu et al., 2006). In the data, different time scales were observed in different stages of specialisation and involvement in numerous sports until late in adolescence (e.g., Vayeens et al., (2009). The different rates of learning were influenced by key constraints which acted as ‘rate limiters’, causing systems to find new functional performance solutions (Handford et al., 1997). Rate limiters can be defined as system controllers, i.e. components or sub-systems which limit the development of an individual (Thelen & Smith, 1994). For example, in cricket, going through a growth spurt may act as a rate limiter both psychologically and physically, which inhibits athletes from demonstrating the skills that they had already acquired through practice and experience. Performance decrements may in turn affect motivation and performance opportunities (associated with non selection). An important challenge is to create talent development programmes which consider the effects of different rates of learning and growth and maturation, and identify the rate-limiting constraints which are influencing each specific expert system in order to manipulate them and facilitate transitions to a new performance level (Cobley et al., 2009).

Results provided strong support for previous research highlighting the importance of unstructured practice activities, such as ‘backyard’ cricket (Cannane, 2009; Weissensteiner et al., 2009). Unstructured activities were encouraged by cultural constraints where backyard cricket often occurred daily in Australian neighbourhoods over the summer months, providing experts with the capacity to adapt movements to emerging task and individual constraints. Unstructured play was also important for promoting enjoyment, participation and competition at various stages of development. These early experiences shaped the intrinsic dynamics and movement patterns of developing experts, as they naturally discovered creative movement solutions in unstructured play.

Abundant beneficial cultural constraints were identified by experts, such as the ease of access to playing fields and the accommodating climate in Australia which encourage skill development. The importance of cricket in many Australian families meant that numerous hours of play and practice were effortlessly accrued, particularly during adolescence. The sheer number of children participating in sport, the excellent television coverage, and support networks within local sports and school communities, all aided development of sporting and cricket skills on many levels.

While deliberate play (in the form of less structured practice activities) was found to be important, early deliberate practice in fast bowling specifically did not gain the same support from the sample. In fact, the majority of experts did not specialise in fast bowling until their late teenage years. Several experts were not even involved in structured cricket until late in their teens. Because of the high injury rates associated with workload issues endured by fast bowlers during maturation, many reported late exposure to structured cricket to be beneficial. This perception directly contrasts with the notion of the need for early deliberate practice, highlighted as important in other sports (Côté et al., 2007).

The existence of strong support networks was evident in all experts, although the sources of support varied, as did the level of dependency of the expert. Sources varied but included siblings, parents, extended family, neighbours, community, teachers, coaches, team mates, best friends and senior players. The dynamics of the support system were unique to each individual. Some parents, particularly fathers, were very ‘hands on’ in their support of cricket development, even those without coaching or cricket experience. Others had little or no involvement and, in these cases, experts formed relationships with teachers at school, peers or senior club players providing coaching and support at various stages of their development.

All participants stressed the importance of opportunities to play with older cricket players, and the challenge of this environment. The practice and performance environments ensured that players were continually challenged and always on the edge of stability, forcing them to constantly adapt their behaviours and increase their level of performance. They also felt that the club structures protected them when required but also gave them the opportunity to play a more challenging level of cricket, both in big cities and smaller locations. Many affirmed there was no specific fast bowling coaching available, so often senior team mates filled this gap. These ideas bring into question the relevance of birth date effects by arguing that these constraints on expertise could be manipulated, depending on the dynamics of the development environment, where backyard, and structured cricket programmes are not necessarily age-specific. Qualitative data suggested that introducing younger players to play with older, more experienced players may create a controlled, supportive, mentored learning programme.

In the sample, all athletes from smaller cities either commuted or eventually moved to larger cities to increase the competition and chance of future success. This movement identified in the data raises questions on the putative ‘place of birth’ effect in the literature (e.g., Côté, et al, 2006), suggesting that ‘place of development’ may provide a more powerful constraint on expertise development. For two participants this move occurred during high school years and they remained in the city once they had finished high school and had left home. Experts were born in very different localities, but they all sought to optimise learning by partaking in high levels of competitive cricket, often associated with playing with seniors in larger conurbations. Several experts felt the benefits of smaller cities included earlier access to competition, and all saw the potential benefit of moving to larger cities to increase competition post-school years. These movements suggested the need to examine place of development effects in conjunction with birth place effect, as these interact and effects many constraints of performance development.

Support for the experts' drive to optimise learning was evident in the search for advantages even outside training or games. Many players became students of the game, seeking knowledge through various sources including: biographies, watching television, reading books, listening to coaches and/or idols. This information provided the basis of their profound domain-specific, adaptive 'game' intelligence. Additionally the prominence of certain psychological characteristics, including commitment, self confidence, work ethic, resilience, determination and sacrifice, supports previous research (Holt & Dunn, 2004; Weissensteiner et al., 2009).

4.6 CONCLUSION

In this chapter, strong support for previous theoretical models has been presented (Abbott et al., 2005; Phillips et al., 2010b; Simonton, 1999) proposing that expertise acquisition can be construed as a messy, noisy, unpredictable and nonlinear process. It was evident that the unique interacting constraints impinging on numerous levels of complex, athletic systems resulted in varying nonlinear trajectories to fast bowling expertise. The key role of unstructured practice activities, optimising learning processes, strong support networks, and effects of cultural constraints were highlighted in fast bowling development. The difference between 'place of birth' effects and 'place of development' effects were discussed, suggesting the need for a more complex analysis of developmental histories. Additionally, birth date effects may have been mediated by opportunities for younger players to play with older, more experienced players (in a supportive environment). This experience creates a controlled, supportive, mentored learning programme, dissimilar to a ‘survival of the fittest’ situation as might currently be perceived to exist in youth sport, which may facilitate talent de-selection rather than development (Abbott et al., 2005). While this work has provided support for the values of experiential knowledge in developmental history research and provided insight into the nonlinear nature of the acquisition of expertise in fast bowling, further work is needed to elucidate the key components from a talent development perspective. The next chapter endeavours to identify the potential components of expertise, to enhance understanding of the rich interacting personal, task and environmental constraints that shape expertise acquisition. This information would be of great value for fast bowling talent development programmes.

Chapter 5: Experiential Knowledge of Expert Players and Coaches Reveals the Dynamics of Fast Bowling Expertise in Cricket

5.1 ABSTRACT

Experiential knowledge of elite athletes and coaches was investigated to reveal insights on expertise acquisition in cricket fast bowling. Twenty-one past or present elite cricket fast bowlers and coaches of national or international level were interviewed using an in-depth, open-ended, semi-structured approach. The importance of intrinsic motivation early in development was highlighted, along with physical, psychological and technical attributes. Results supported a multiplicative and interactive complex systems model of talent development in fast bowling, in which component weightings were varied due to individual differences in potential experts. Data are consistent with a dynamical model with numerous trajectories for talent development. Dropout rates in potential experts were attributed to misconceived current talent identification programmes and coaching practices, early maturation and physical attributes, injuries and lack of key psychological attributes and skills. Further work is needed to relate experiential and theoretical knowledge on expertise in other sports.

Keywords: expertise; talent development; experiential knowledge; dynamical systems; cricket

5.2 INTRODUCTION

In the previous chapter multiple pathways were identified in achieving expert performance in fast bowling. However, the key components required to be an expert were not examined in detail; these will be explored in this chapter. In sports science an important challenge is to identify components contributing to the development and maintenance of expertise (Abbott et al., 2005; Gould et al., 2002; Morgan & Giacobbi, 2006; Soberlak & Côté, 2003; Vaeyens et al., 2008). For example, qualitative analysis has revealed several psychological (e.g., mental focus, goal-setting and self-evaluation), socio-cultural (e.g., community and family support, cultural influence), physical (e.g., strength, height) and environmental (e.g., access to facilities and climate) constraints on successful Olympian development (Abbott et al., 2005; Durand-Bush & Salmela, 2001; Gould et al., 2002). However, the influence of these factors is likely to be sport specific due to different task constraints and the changing nature of the performer–environment relationship through practice, coaching and competing (Vaeyens et al., 2008).

Recently, Dunwoody (2006) criticised the over-emphasis on the individual in cognitive psychology explanations of behaviour. He eschewed a humano-centric approach, suggesting that traditionally psychologists have neglected the role of the environment and over-emphasised the role of organismic structure and processes in isolation, a tendency he termed ‘organismic asymmetry’. Although there is a need to move away from an asymmetric–organismic focus on expertise acquisition captured by genocentric explanations (Davids & Araújo, 2010), the tendency to over-emphasise the role of environmental constraints on expertise acquisition also needs to be avoided (Phillips et al., 2010b). For example, Ericsson and colleagues (Ericsson, 1996) advocated that expertise is acquired only when performers specialise at an early age and engage in deliberate practice (Rankinen et al., 2006). Ericsson and colleagues (1993) highlighted the importance of structured practice involving goal-directed skill learning requiring effort and concentration. It was estimated that experts need to typically spend about 10 years or 10,000 hours in deliberate practice to attain exceptional performance (Hodges & Starkes, 1996). Time spent in sport-specific training has been shown to discriminate between experts and non-experts in some sports, although the relationship between practice and performance is nonlinear (Baker et al., 2005). The uni-dimensional nature of the deliberate practice approach has been criticised as ‘environmentalist’ (Davids & Baker, 2007; Phillips et al., 2010b; Simonton, 2007) and researchers studying deliberate practice in sport have encountered some incongruities with the theory’s main tenets. For example, early specialisation has been deemed inessential for acquisition of expert sport skills in adulthood (Baker et al., 2003; Côté, 1999; Soberlak & Côté, 2003). Further, Weissensteiner and colleagues (2009), studying cricket batting in Australia, found that talent development may be facilitated by early unstructured play termed ‘backyard cricket’ (see Cannane, 2009) and other rich practice experiences, a wide range of sport experience during development, and early exposure to playing with senior players as discussed in the previous chapter (Phillips, Davids, Renshaw, & Portus, 2010a; Weissensteiner et al., 2009). The benefits of playing a range of sports has much anecdotal support in sporting cultures such as in Australian cricket. Interestingly, a recent analysis of Olympic athletes in Europe provided field-based data suggesting that earlier and extended involvement in institutional talent promotion programmes is poorly correlated with future success in senior international elite sport (Vaeyens et al., 2009). In fact, not being selected for such programmes may be a blessing in disguise as world-class athletes were often inducted into talent development pathways at a significantly later age than their less successful peer group. A potential reason for the later emergence of these future experts was as a result of their greater involvement in secondary sports. Vaeyens reported a higher proportion of the world-class athletes trained (60.9% vs. 48.3%) and competed (47.2% vs. 37.2%) in other sports beyond their current individual main sport and they invested significantly more training time in other sports. Additionally, they performed approximately every second training session up to 10 years of age and every third training session from 11 to 14 years in other sports, and the total training frequency accumulated during childhood and youth was over

50% larger than among national-level athletes (Vaeyens et al., 2009), p.1,372).

Therefore, it seems apparent that expertise attainment in a particular performance domain depends on many constraints including, but not limited to, genetics, social and physical environment, opportunity, encouragement and the effect of these variables on physical and psychological traits (Abbott et al., 2005; Beek et al., 2003; Davids & Baker, 2007). Mono-disciplinary approaches to the acquisition of expertise have failed to capture the complementary nature of the relationship between these individual, task and environmental constraints (Abbott et al., 2005; Phillips et al., 2010b; Simonton, 1999; Vaeyens et al., 2008). For these reasons, in sport there has been growing awareness of the need for an interdisciplinary and interactionist theoretical framework to examine expertise attainment (Phillips et al., 2010b).

Recently a number of multidimensional models of talent development have begun emerging in the literature. For example, Simonton's (1999) multidimensional, epigenetic and emergenic model has operationalised the process of talent development, comprising all physical, physiological, cognitive and dispositional traits that further the acquisition of expertise in a specific domain. The potential in each component is individually assessed on a ratio scale or weighting. Although some common factors appear to underpin the development of expertise, multi-disciplinary models of talent development have highlighted talent as a nonlinear process, predicting that a range of developmental trajectories over different timescales would lead to achievement of sporting expertise.

One problem with some current multidisciplinary approaches to modelling expertise and its components is that the models tend to be operational and propositional in nature (Phillips et al., 2010b). For example, Simonton's (1999) model of talent as a multiplicative, dynamic process and the Differentiated Model of Giftedness and Talent (Gagné, 2004) have yet to provide a detailed, explanatory, theoretical rationale underpinning a dynamic and multidimensional basis for expertise and talent development (Phillips et al., 2010b). As introduced in the previous chapters, recently it has been argued that key concepts from dynamical systems theory and complexity science can provide a compelling theoretical explanation for the complex nature of talent and its development (Phillips et al., 2010b). This framework characterised expertise acquisition as a messy, noisy, unpredictable and nonlinear process which emerged from an interaction of constraints related to the specific individual, task and environment. It was argued that the range of interacting constraints impinging on each athlete is unique in shaping acquisition of expertise, resulting in the expectation of varying developmental pathways between individuals and a variety of contributing expertise components across sporting domains. Viewing talent development from a dynamical systems theoretical approach enables researchers to develop a more principled examination of expertise processes of how elite athletes might emerge. For example, one challenge of the implementation of models such as Simonton's is that *all* components of talent need to be identified. Due to the multiplicative nature of the weighting system in the model, a score of 'zero' for any one individual factor would logically preclude an individual from becoming 'expert'. The problem is that identification of the many components of talent, although highly sought after, has yet to be achieved within specific sports (Phillips et al., 2010b).

One strategy that could be used to catalogue all the key components of talent in a sporting domain could be to analyse the experiential knowledge of true experts in sports (athletes and coaches). Sampling opinions and perceptions of experts by tapping into their vast experiential knowledge on the dynamics of development in elite performance environments as demonstrated in the previous chapter (Phillips et al., 2010a) may enable identification of key constraints on talent and potential, and the factors related to athletes' differing levels of achievement. Open-ended interviews with expert athletes and/or expert coaches have been previously used to examine competencies of elite performers to derive factors associated with success (Durand-Bush & Salmela, 2002; Holt & Dunn, 2004), allowing exploration of concepts as they emerge, and inductive hypothesizing of theory relating to the development and constraints on expertise.

In this chapter the efficacy of a multi-dimensional theoretical framework of expertise is examined through experiential knowledge of expert players and coaches. This is a rich sample group who have experience as player, coach, supporter and practitioner for fast bowling expertise. Additionally, components of fast bowling expertise in cricket are identified. In cricket, this theoretical framework suggests that the components of expertise are likely to have different rates of expression and potential weightings, as the developmental trajectories of expert fast bowlers are shaped by a specific confluence of interacting personal, task and environmental constraints. Currently, the factors contributing to the acquisition of expertise in cricket fast bowling have not been identified in empirical research or from experiential knowledge of elite performers/coaches. Therefore the following research aims will be the focus of the study in this chapter:

I) Identifying components considered critical for fast bowling talent development by elite performers and coaches.

II) Understanding relative weightings of talent components in fast bowling proposed in experiential knowledge of elite performers and coaches.

III) Identifying interactions and development of fast bowling talent components as specified by elite performers and coaches.

5.3 METHODS

5.3.1 PARTICIPANTS

The cohort was composed of two groups: athletes and coaches. The athletes consisted of the same 11 past or present Australian international, male, elite fast bowlers sampled in Chapter 3. These fast bowlers had taken in total more than 2,200 international test wickets in over 570 international test matches. They were classified as fast or fast-medium bowlers by members of the Cricket Australia Technical Fast Bowling Group: (a) having taken at least 100 test wickets each at international level; and (b) having bowled in at least 25 test matches at international level. In addition to the athlete group examined in Chapter 3, a coach group was also sampled and included. The coaches' group consisted of 10 past or present Australian and State level head coaches and fast bowling coaches.

Participants were contacted through a letter of invitation in cooperation with Cricket Australia, were informed of the purpose of the study, and given details of their expected involvement and interview content. All semi-structured qualitative interviews were conducted by the primary researcher and recorded on an mp3 storage device, lasting between 40-70 minutes each. Pilot work reviewed and refined interview content, semantics and order of questions for the interview guide.

5.3.2 DATA COLLECTION AND ANALYSIS

At the onset of interviewing, participants were reminded of the purpose of the inquiry and signed a consent form. The interview guide (see Chapter 3) was based on previous expertise and talent development research in sport (Côté et al., 2005; Miles & Huberman, 1994). After rapport building conversations and broad questions to familiarise them with the inquiry theme, participants were asked about specific factors which they believe are identifiers of fast bowling expertise potential. Of specific interest was the relative importance of each potential component of fast bowling expertise and how components interacted with other factors and developed over time. Self reported data were collected in an open ended way without prescribing categories for describing expertise components. Probe questions were used to encourage participants to expand on responses and provide depth to articulated perceptions.

All interviews were transcribed verbatim with grammatical changes to improve the flow of the text if needed. A copy of the interview transcripts was emailed to each participant to authenticate that the information accurately reflected their perceptions (Strauss & Corbin, 1998). Only a few minor changes were made to the transcripts. Data were analysed by the main researcher in NVivo (QRS NVivo 8) using inductive reasoning. Open coding of each participant's transcript allowed concepts and themes to emerge from the data (Miles & Huberman, 1994). Ideas or concepts were coded and used to conceptualize categories and/or sub-categories. Themes expressed by two or more participants were considered significant. This process was flexible so that categories could be adjusted and refined during analysis, until theoretical saturation occurred and the themes conceptualized all of the data (Tesch, 1990). In line with previous work by Miles and Huberman (1994) procedures were used to maximize reliability and control research bias, including engaging in peer concept mapping sessions and verification of data by participants.

5.4 RESULTS

Experts believed that early in development the primary focus should be on three common emergent themes of fun and enjoyment (100%), participation (85.7%) and general skill development (71.4%) in cricket. Those who showed a true passion for the game were suggested to be most likely to continue into the investment phase. Additionally, coaches were cautious about the merits of early talent identification programmes:

> *"You can see talent in kids. But to see talent in a 12 year-old kid, mate talent's one thing but how far they are going to go is probably parental wishing is that they want their kids to go as far as they can. I'm of a different view; we'll just wait and see."*

Later in development, fast bowling experts expressed a range of factors which they felt were important for identifying expertise potential in developing bowlers. Eighty-four raw data themes and associated general themes that emerged from the analysis of components that comprise expertise potential are presented in Table 5.1. These components of expertise could be broken into the following categories: (a) personality characteristics; (b) psychological skills; (c) physical competencies; (d) technical skills; and (e) other. The most prominent perceived requirements for fast bowling skill were pace, technique fundamentals, skill, coordination, good attitude, motivation and training ethic. The importance of these key components of fast bowling expertise was interrelated and also varied across individuals:

> *"Mark and Steve Waugh are two good examples; one guy with so much natural ability and one guy with so much self belief and self determination. To be successful, I think at a higher level it's all about*

> *attitude, and the guys that are prepared to work harder, prepared to listen, always looking to learn, I think, will always have more potential. I think the guys that have the right attitude with the skills as well; you still have to have a certain skill level to perform at this level. Attitude to me I think is more important than actual, natural ability to a certain degree."*

Table 5.1: Raw, general and emergent themes of components of potential talent in fast bowling and number of expert sources

Raw Themes by category	**General Sub Theme**	**Emergent Theme**
Personality Characteristics: Coachable(6), competitive(16), self belief(6), dedication(6), determination(6), desire(6), discipline(10), fun/enjoyment (8), fast bowing personality(4), knowledge(6) good head(8), good heart(4), listener(8), mental strength (13), motivation(18), open to change(5), passion(12), persistence(5), planning(3), priorities(8), right attitude(17), sacrifice(4), hard work ethic(16).	1.Motivation 2.Love of the game 3. Dedication 4. Good work ethic	Highly motivated (1 and 2) Strong work ethic (3 and 4)
Psychological skills: Goals setting(6), mental focus(15), technical focus(4), pre-ball process (4), dealing setbacks(4), learner(7)	5. Mental toughness 6. Deal with setbacks 7. Willing to learn/change	Mental Strength (5 -7)
Physical: Strong glutes (4), athletic ability(16), abdominals, coordination(14), dealing with injury/load(18), fast twitch fibres(4), fast arm(8), good runner(8), pace off 2 step(4), height (-ve6,+ve8), strength(12), throwing ability(4), longevity (4), speed (12), rhythm (12)	8. Athletic ability 9. Dealing with load 10. General coordination 11. Stature 12. Strength, endurance	Physical capacity (8 – 12)

Technical Skills: True pace (19), good action (4), repeatability of action (6), bounce(7), swing(6), change of pace(8), variation(7), technique fundamentals(18), advanced level of skill(16), accuracy/bowling straight(12) repeatability or control(6), tactics (6), coordination(14)	13. Tech fundamentals 14. Pace 15. Rhythm, coordination 16. Control 17. Variation	Pace (14,15) Technical Excellence (13, 15 -18)
Other: General sporting background (15), genes (12), link between mental and physical (7), life balance (4), experience (4), point of difference (13), timing (8), individual (16), taking opportunity (12), innate (18)	18. Genetics 19. Mental - physical link 20. Taking opportunity	

Individual differences were considered important in fast bowling expertise due to the existence of different types of fast bowlers and unique components of talent. A common perception was that experts are able to make up for weakness in some components (i.e. height) in other components or areas (i.e. physical strength), and that these alter with development:

> *"The thing that I will say is that what works for me won't work for everyone, and that's very important. The way that I train, the things that I do prior to a game is what I know works for me as a person. A guy like Mitchell Johnson might be slightly different; Shaun Tait might be slightly different again."*

Several reasons were proposed to set experts apart from their peers or talented athletes who do not progress to the elite level. The most prominent issues associated with drop out factors included: (a) psychological attributes: self doubt, lack of motivation or drive, general attitude, lack of dedication, not prepared to do hard work; (b) physical: different rates of maturation (early

TID), injury, workload demands, genetics; (c) technical: lack of athleticism or ability, lack of fundamental skill; and (d) other: bad timing, limited sports, other sports (Australian Football), lifestyle choices (diet, alcohol), lack of support network. One interviewee commented:

> *"I think the main one is injury. If you're continually injured, if you're not physically strong enough, then you are going to struggle."*

Issues with skewed early talent identification programmes were identified as reasons for drop out in perceived fast bowling talent, emphasising different rates of maturation and development across individuals:

> *"Well I think there are a lot of things going on and it depends on each athlete. I think often its very good young fast bowlers who are successful in terms of how people perceive them, their results and so on, are sometimes generated from the fact that they're actually physically big compared to the rest of their age group. A couple of things happen with that type of athlete; often, everybody else catches up to them so they can't dominate the way they did at a younger age. So they and possibly the people around them, meaning their parents, generally find that difficult to deal with or understand. The other side to that is that generally because they have dominated coaches or teachers or parents haven't worried too much about them technically, their skill set, because they're going so well and what happens a lot of times is that their skill set remains at that level, whereas others apart from catching up physically in size have also learnt a few other skills along the way."*

Given the multitude of key themes identified and the range of pathways to expert performance in fast bowling, several underlying themes presented themselves. Although obvious, the ability to generate fast ball speed, which requires technical skill and athletic ability, was of primary importance. Second to this was the ability and control to put the ball where required in order to take wickets.

5.5 DISCUSSION

The study reported in this chapter attempted to expand understanding of the acquisition of fast bowling expertise by drawing on experiential knowledge of expert fast bowlers and coaches in cricket. From one-on-one interviews expert perceptions and opinions were gained on: (a) the components that might identify potential in fast bowling expertise; (b) the relative importance and interactions of these components; and (c) identification of factors leading to drop out of potential experts.

The experts articulated a number of factors as comprising expert performance and potential talent in fast bowling. Within the psychological domain high levels of motivation, competitiveness, mental strength and focus, a good work ethic and a positive attitude were essential for success. Experts noted the important role of mental strength and physical skills since fast bowlers have to perform under pressure, often experiencing physical and psychology fatigue due to the long duration of cricket matches. The psychological skills and attributes of experts have been well explored, utilising experiential knowledge of expert athletes, coaches, and their families (apart from cricket fast bowling). Research on the developmental experiences of elite athletes (Baker et al., 2005; Bloom, 1985; Côté, 1999; Ericsson et al., 1993; Gould et al., 2002) has identified them as being very focused, spending copious hours of domain-specific time-on-task, and having supportive environments (e.g., quality coaches and encouraging parents). Other work has suggested that a relationship between several different personality traits and performance might exist (Gould, Eklund, & Jackson, 1993).

Conversely skill and physical attributes have not received much attention in the qualitative literature on sport performance and expertise. Fast ball projection (~150km/h) with high accuracy is the desired performance outcome of fast bowling skill, requiring a high level of proficiency in fundamental movement patterning. In this chapter, some underlying physical demands and fundamental skills were identified as being required by aspiring fast bowlers. The generation of ball velocity is a complex skill governed by the laws of physics; the physical aspects of the system can be optimised, including lever length, muscle strength, flexibility, coordination of the system, release height and point of release. Experiential knowledge of experts acknowledges that individual differences existed in the ability to physically create pace. Key attributes were also identified as being optimal, such as height for creating bounce:

> *“Tall is a must. If you’re not… well it’s not a written rule but if you’re not over six foot you’re struggling to become a good fast bowler. There’s been a couple obviously that have done really well, but the real good ones are up around the six three plus mark, just for getting bounce. And again the guys that are really good are tall and athletic.”*

However, these attributes were described as useful, but not essential, weapons in the pace bowler’s artillery. A base line of physical demands was suggested to not only produce ball velocity within the range classified as fast bowling (>130km/h), but also survive the large workloads placed on elite pace bowlers in all forms of the game. It was noted that workloads (number of balls bowled per game/training etc.) increase with level of competition at domestic and international elite level competition. Experts spoke of the importance of skill proficiency and having control of movement patterns and coordination as vital to expertise:

> *“You know, you’re not going to always survive if you’ve only got just run in and bowling a good length. It worked for Glenn McGrath, but he’s got a lot of tricks. ... He doesn’t look on the TV as though he’s got a great bag of tricks, but if you really analyse every ball that comes out of his hand, he does try a lot of different things – but he’s trying to still bowl a ball in a good area. So for the young guys I’m just trying to up-skill them as much as I can on swinging the ball, seaming the ball, bowling slower balls, bowling bouncers, playing around with where it’s hitting the crease, maybe where you angle your run-ups.”*

The concept of innate talent was also expressed as a predominant component of expertise. Probe questions allowed the innate talent components to be expanded and explained by expert athletes and coaches, and often these factors were related to environmental constraints such as early developmental experiences and training effects. Hyllegard and colleagues (2001) attributed this to a lack of direct knowledge of the history of athletes which may have resulted in confusion of effects of early training and development with assumed or innate talent. Further clarification is required with regards to perceptions of the role of innate genetic characteristics compared to the concepts of innate talent (Howe et al., 1998; Hyllegard et al., 2001). Deliberate practice has been criticised for its dismissal of the role of genetic or innate factors and talent development (Baker, 2007; Simonton, 2007), individual differences and creativity (Coleman, 2007).

Experts were in agreement that an athlete's developmental experiences might result in a range of different weightings on expertise components, and it is likely that these interact with dispositional constraints in complex and unique ways. Therefore, it is believed that unique development pathways, achievement and solutions result in different types of fast bowlers. These views are harmonious with recent suggestions of a more integrated approach to talent development discussed in Chapter 1 (Phillips et al., 2010b), capturing expertise acquisition as a messy, noisy, unpredictable and nonlinear process. Here key features of this model are investigated, including constraints on rates of expertise acquisition to complement previous research on fast bowling development trajectories in expert athletes (Phillips et al., 2010a), supporting the notion of fast bowling expertise as a complex, nonlinear process. Previous talent development research utilising an interactionist approach (Bloom, 1985; Côté, 1999; Durand-Bush & Salmela, 2002; Gould et al., 2002; Morgan & Giacobbi, 2006; Singer & Janelle, 1999) has reported how an efficacious relationship between perceived genetic dispositions, practice, situational factors and mental characteristics has facilitated and nurtured talent development in athletes. These ideas were summarised by Martindale and colleagues (2005), who recommended promoting appropriate talent development rather than detection systems, individualised training programmes and flexibility in talent development programmes (Martindale et al., 2005).

The study in this chapter advances these ideas with reference to an analysis of the opinions of expert fast bowlers and coaches. A specific issue related to perceptions of the factors that are involved in identifying talent potential in fast bowlers and the factors related to athletes' differing levels of achievement. Statements by this group of experts generated several components that they felt identified potential talent, differentiating elite and non-elite athletes. Reasons for drop out were linked to prominent components of expertise as identified in the data set:

> *"If you're mentally not tough enough, then you are going to struggle. Guys that lacked a bit of self belief or didn't learn from their mistake would only reach a certain level."*

The majority of experts spoke of the importance of understanding one's movement pattern and even sporting situation. Unique differences in an individual's intrinsic dynamics (broadly speaking the performance dispositions of an individual informed by genes, learning and past experiences) suggests that elite performance can be achieved in different ways, as athletes experience a unique set of constraints in development. Key components identified were common across groups. However, the importance of different types of fast bowler and how individual components may change over time and to different degrees across experts, emphasized systemic interaction among factors over time, as individuals utilized specific intrinsic dynamics and available resources as operationalized in Simonton's (1999) model. The data are harmonious with views of expert athletes as exemplifying a dynamic complex system, in the systemic degenerate nature of the components and their interactions. This systemic conceptualization is congruent with other research, (Johnson, Edmonds, Jain, & Cavazos, 2010; Simonton, 1999); the athletic, dynamic and complexity of requisite movement patterns in cricket results in a large weighting on key physical and skill components. Still these factors were always concurrent with the relevant psychological skills to perform at an international level, since athletes without some level of talent in physical, skill and psychological components were felt likely to not progress to international level.

The experiential data obtained suggest that future research needs to adopt a multi-disciplinary framework to study expertise acquisition in sports. Unique interacting constraints emphasise the likelihood for individualised pathways to expertise due to degenerate skill acquisition processes.

Specifically, longitudinal, individualised, multidisciplinary research programmes would allow detailed examination of the key influences shaping each athlete’s intrinsic dynamics and the different rates of expression of expertise components across time.

5.6 CONCLUSION

Analysis of experiential knowledge of elite athletes and coaches revealed that expertise acquisition is a nonlinear process, which fits with key concepts of dynamical systems theory applied to the performance context of sport. Experts’ insights highlighted the importance of appropriately designed talent development programmes that attribute significance to the role of adaptability in expert performance. Other important insights of expert cricketers concerned the reality of different rates of athlete development and variations in expressions of components of expertise which shaped individual development trajectories. The data suggest that more attention in talent development programmes needs to be paid to emphasising the multidisciplinary nature of talent. The data also suggested that the objective of such programmes should be talent development, rather than talent selection. Experiential knowledge of experts in sport was revealed as a source of information that could complement empirical knowledge of expertise acquisition.

5.7 RESEARCH LINK

5.7.1 QUALITATIVE PHASE TO QUANTITATIVE PHASE TRANSITION

In chapters 4 and 5, strong support for proposing that fast bowling expertise acquisition can be construed as a messy, noisy and nonlinear process was presented (Abbott et al., 2005; Phillips et al., 2010b; Simonton, 1999). Additionally, this work has provided support for the value of experiential knowledge in developmental history research and provided insights into the unique interacting constraints impinging on numerous levels of complex, athletic systems. The data suggested that more attention in talent development programmes needs to be paid to emphasising the multidisciplinary nature of talent and that the object of such programmes should be talent development, rather than talent selection. Experts' insights highlighted the importance of appropriately designed talent development programmes that attribute greater significance to the role of adaptability in expert performance. The key role of unstructured practice activities, optimising learning processes, strong support networks, and effects of cultural constraints were highlighted in fast bowling development. Specific talent components identified included the ability to generate high ball speed and control (and adaptability) in performance outcomes, although methods for attaining these components were unclear. The remaining chapters in this thesis examine selected key talent components identified by expert fast bowlers as key to fast bowling expertise. Chapter 6 outlines the methods and protocols used in these studies, and Chapter 7 examines in detail how developing, emerging and national pace bowlers generate ball speed using three-dimensional motion analysis technologies. Chapter 8 examines the accuracy and consistency in this same group of high performance players, to establish whether they are able to perform specific skills on demand and if adaptations occur during performance of a validated fast bowling skills test.

Chapter 6: Methods

6.1 INTRODUCTION

The second phase of this thesis included a series of laboratory based collection sessions. This chapter outlines the details of the testing protocols, biomechanical modelling, and data processing. Details specific to each study can be found in each associated chapter.

6.2 EXPERIMENT DESIGN

Before data collection, the test protocols were explained and each participant undertook a brief familiarisation session as part of a warm up. This warm up involved the performance of all bowling tasks. This study was approved by the human research ethics committees of the Australian Institute of Sport and the Queensland University of Technology. Participants or parents signed a written consent form before participating in the project.

Participants completed an adapted version of the Cricket Australia bowling skills test, in which they performed 30 trials of short (10), good (10), and full length (10) deliveries, bowled in five overs. Athletes were instructed to bowl at match intensity towards a rear-projected image of a right-handed batter on a screen (Figure 6.1), to simulate match conditions. The image of a batter was present in the current study to increase the representative design of the project, although the image was static. Unfortunately, the presence of an actual batsman in the trials was not viable due to the requirement for highly accurate performance outcome measures. The skills test measured the bowlers' ability to hit specific targets, with the resultant scores (0-100) averaged to give an accuracy score (See Chapter 6 for detail).

The location of all deliveries on the target screen was recorded with a video camera (Sony 3CCD HDR-FXIE, Sony Corporation, Tokyo). Testing was conducted in over spells where bowlers bowled in pairs to replicate match conditions (6 trials each). The tasks were performed in an unanticipated and random order. Instruction from the umpire prior to the run-up phase informed the participant which task to complete.

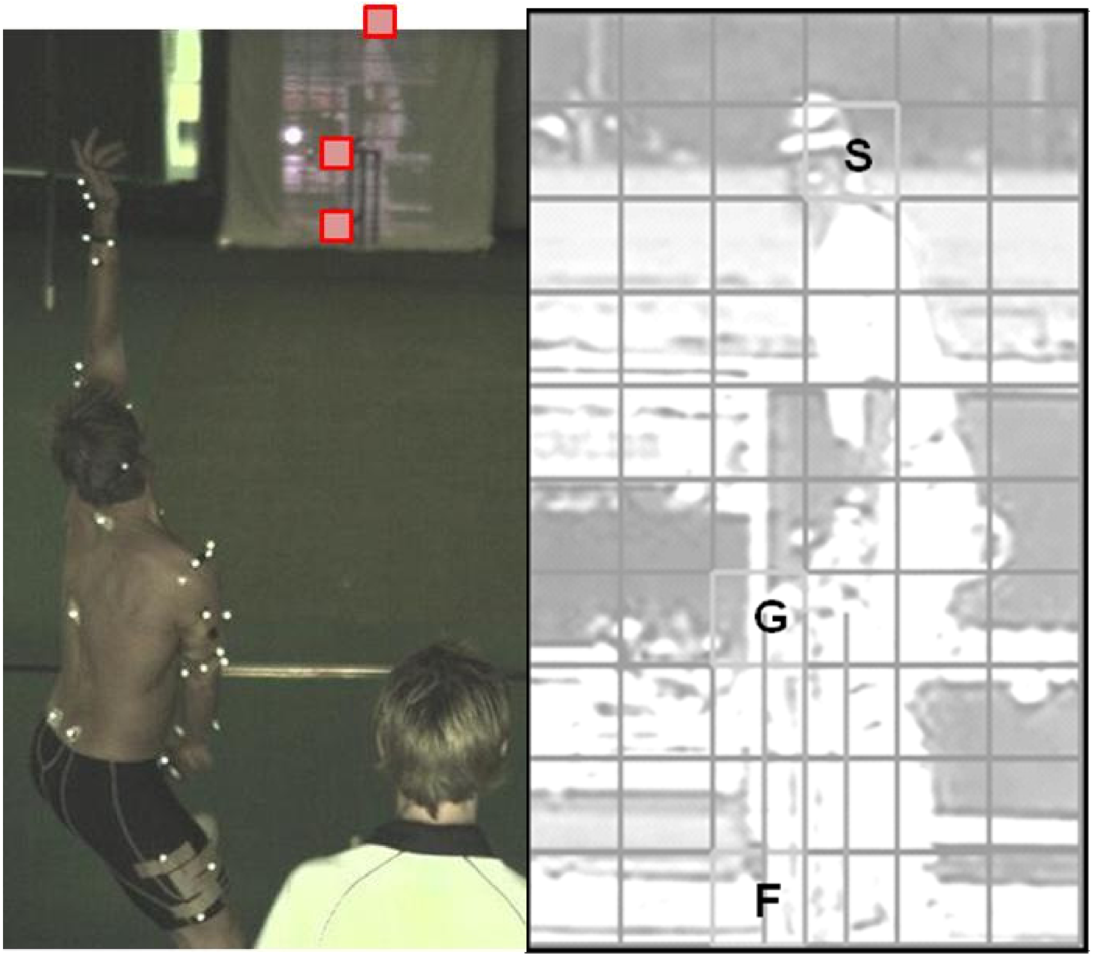

Figure 6.1: Skills test grid; showing the three target lengths: Short (S), Good Length (G) and Full (F) deliveries (detailed in Chapter 7).

6.3 DATA COLLECTION

A twenty two camera Vicon motion analysis system (Oxford Metrics Ltd., Oxford, United Kingdom) sampling at 250Hz was used to record three-dimensional co-ordinate data. Eighty retro-reflective 14mm markers were affixed to bony landmarks for biomechanical analysis. All markers were fixed to the participant with double-sided tape and then secured with additional medical strapping tape. These markers define the joint centres and local co-ordinate axes. Ground reaction force (GRF) data were recorded at 1000Hz using two 400x600mm force-plates (Kistler, Amherst, USA). A typical lab set up is shown below in Figure 6.2. A static and dynamic calibration procedure was conducted at the start of each test session, during which the ‘Image

Error' was calculated for each camera. This value is the RMS distance calculated in camera pixels and indicates the accuracy of the 3D reconstruction of the markers on the Vicon calibration wand used during the calibration process. In line with Australian Institute of Sport Biomechanics protocols, Image Error was less than 0.25 for each camera (Dowlan, 2003).

Figure 6.2 Lab set up and batsman image projection.

6.4 UWA MARKER SET

The UWA marker set and models have been developed by the Biomechanics Group at UWA and published abundantly in modelling (Besier, Sturnieks, Alderson, & Lloyd, 2003; Campbell, Lloyd, Alderson, & Elliot, 2008; Elliott et al., 2007) and applied research areas (Lloyd et al., 2000) (Chin, Elliott, Alderson, Lloyd, & Foster, 2009; Dempsey et al., 2007) (including a multitudes of PhD theses). The UWA model has been based on the calibrated anatomical systems technique (Cappozzo, 1984). This technique utilises embedded technical (TCS) and anatomical coordinate systems (ACS) for each rigid body segment. The University of Western Australia (UWA) full body marker set is shown below in Figure 6.3. It consisted of 80 markers placed on each participant at locations corresponding to various palpable bony landmarks or anatomical locations, or clusters (TCS) placed on arbitral location of minimal skin and soft tissue movement (Manal, Chang, Hamill, & Stanhope, 2005). A minimum of three markers per segment is required to define the location of a rigid body, and associated axis (orientation) and reconstruct bone-representative TCSs. Three markers affixed to semi-malleable pieces of plastic or aluminium (T-bar shaped) clusters were used. Table 6.1-2 labels and describes these numbered markers.

6.4.1 UWA STATIC MARKER SET

Data from a static trial were collected before dynamic testing. This static trial consisted of the participant in the centre of the capture space in order to calculate neutral joint positions and to align them to the global lab co-ordinate system. An initial static calibration trial allows determination of the location of joint centres and definition of segment ACSs based on anatomical markers. These markers were affixed to the medial and lateral malleoli of the ankles, anterior and posterior aspects of the shoulder, and styloid processes of the ulna and radius, medial and lateral epicondyles of the humerus and medial and lateral malleoli of the knee, and were removed following the static calibration trial. If left on during dynamics trials, these markers can interfere with movement or can come off during dynamic tasks (i.e. medial knee markers may rub during running).

Table 6.1: Static Marker number, name and description

Number	Label	Description
1	RASH	Right Anterior Shoulder
2	RPSH	Right Posterior Shoulder
3	LASH	Left Anterior Shoulder
4	LPSH	Left Posterior Shoulder
5	RLEL	Right Elbow Lateral Epicondyl
6	RMEL	Right Elbow Medial Epicondyl
7	LLEL	Left Elbow Lateral Epicondyl
8	LMEL	Left Elbow Medial Epicondy
9	RWRR	Right Wrist styloid porcess - radial
10	RWRU	Right Wrist styloid porcess-ulnar
11	LWRR	Left Wrist styloid porcess - radial
12	LWRU	Left Wrist styloid porcess-ulnar
13	RKLM	Right Knee Lateral Mallelous
14	RKMM	Right Knee Medial Mallelous
15	LKLM	Left Knee Lateral Mallelous
16	LKMM	Left Knee Medial Mallelous
17	RLMAL	Right Ankle Lateral Mallelous
18	RMMAL	Right Ankle Medial Mallelous
19	LLMAL	Left Ankle Lateral Mallelous
20	LMMAL	Left Ankle Medial Mallelous

6.4.2 UWA DYNAMIC MARKER SET

Dynamics markers are used to define each segment instantaneous orientation and position of orthogonal sets of axes (TCSs). These markers and cluster can be arbitrarily placed on the skin surface. The markers record relative positional information of the ACS for each segment (from the static trial) to allow accurate calculation of the movement kinematic data. Consequently, anatomical landmarks must be defined, with their position vectors determined relative to the relevant TCS. Where at least three anatomical landmarks exist per bony segment, ACSs can be constructed and associated position vectors and orientation axes calculated (Cappozzo, 1984; Della Croce, Cappozzo, & Kerrigan, 1999). With knowledge of the position vectors and orientation axes of the ACSs of two adjacent segments, joint kinematics can be estimated (Grood & Suntay, 1983; Woltring, 1994).

Table 6.2: Dynamic marker number, name and description

Number	Label	Description
21	LFHD	Left front head
22	LBHD	Left back head
23	RFHD	Right front head
24	RBHD	Right back head
25	C7	C7 vertebrae
26	T10	T10 vertebrae
27	CLAV	Sterno – clavicular notch
28	STRN	Xyphoid process
29,30,31	RACR1,2,3	Right acromion cluster:posterior, middle, anterior
32,33,34	LACR1,2,3	Left acromion cluster: posterior, middle, anterior
35,36,37	RUA1,2,3,	Right upper arm cluster: superior, middle, inferior
38,39,40	LUA1,2,3	Left upper arm cluster: superior, middle, inferior
41,42,43	BRUA1,2,3	Right low upper arm cluster: superior, middle, inferior
44,45,46	LRUA1,2,3	Left low upper arm cluster: superior, middle, inferior
47,48,49	RFA1,2,3	Right forearm cluster: ulnar, middle, radius side
50,51,52	LFA1,2,3	Left forearm cluster: ulnar, middle, radius side
53	RHNR	Right dorsal radial knuckle
54	RHNU	Right dorsal ulnar knuckle
55	RCAR	Right metacarpal
56	LHNR	Left dorsal radial side
57	LHNU	Left dorsal ulnar side
58	LCAR	Left metacarpal
59	RASI	Right anterior superior iliac spine
60	LASI	Left anterior superior iliac spine
61	RPSIS	Right posterior superior iliac spine
62	LPSIS	Left posterior superior iliac spine
63,64,65	LTH1,2,3	Left thigh cluster: superior, middle, inferior
66,67,68	RTH1,2,3	Right thigh cluster: superior, middle, inferior
69,70,71	LTB1,2,3	Left tibia cluster: superior, middle, inferior
72,73,74	RTB1,2,3	Right tibia cluster: superior, middle, inferior
75	LCAL	Left calcaneous
76	LMT1	Left metatarsal 1
77	LMT5	Left metatarsal 5
78	RCAL	Right calcaneous
79	RMT1	Right metatarsal 1
80	RMT5	Right metatarsal 5

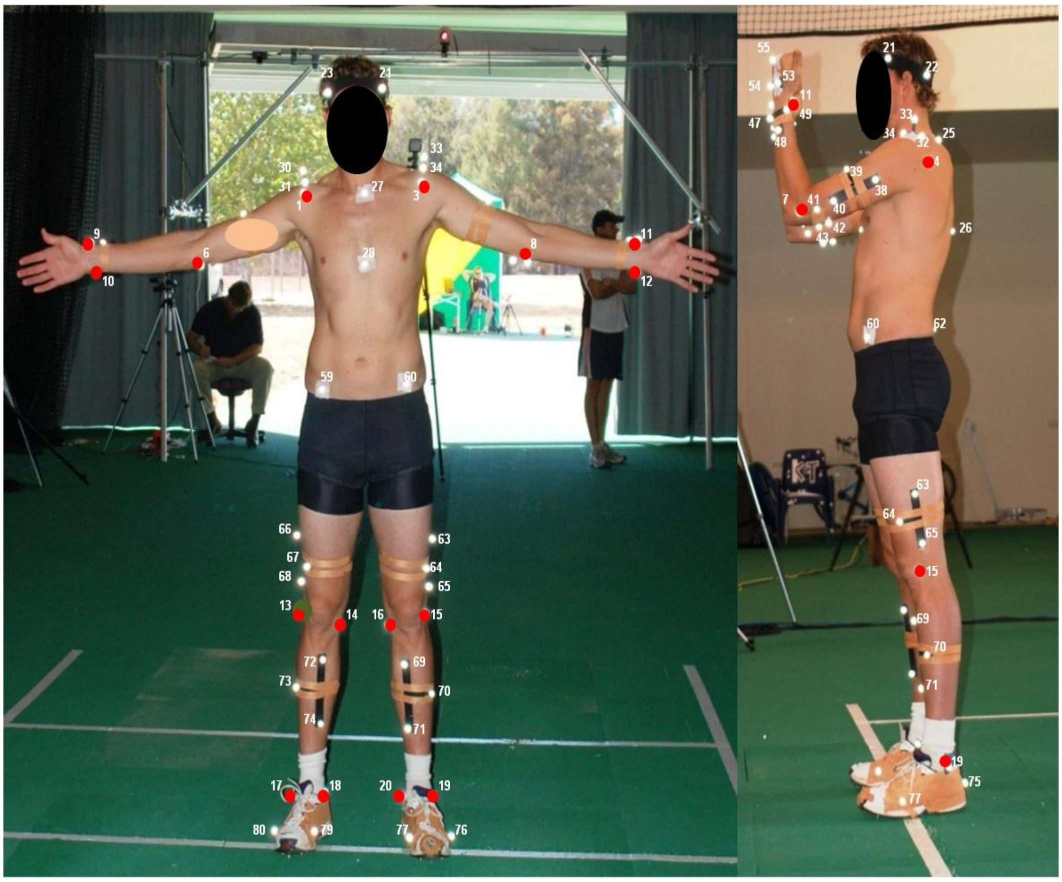
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Figure 6.3: Dynamic and static marker set: front and left side view.

6.5 CALCULATED VARIABLES

The UWA model was developed and written in BodyBuilder language, the algorithms used are described by the UWA modelling group (Besier et al., 2003; Campbell, Lloyd, Alderson, & Elliot, 2009; Lloyd et al., 2000). Model segment definitions are details below for the outputs discussed include:

Thorax: The origin of the thorax was located at the midpoint between the C7 and clavicle markers. The first axis (x) was a unit vector from C7 to mid point of the clavicle markers. The second (z) axis was the cross product of the x axis and a unit vector from the clavical to the sternum markers (with positive approximately right in a static posture). The third axis (y) was the cross product of the other two with positive approximately superior in static posture.

Upper arm: The origin of the upper arm was located at the midpoint between the epicondyle markers (EJC). The first axis (y) defined for this segment was the unit vector that pointed EJC to the SJC (with positive approximately superior in static posture). The x axis vector was the cross product of the y axis and a vector defined from the lateral to the medial epicondyle on the right arm and medial or lateral for the left arm (positive approximately anterior in static posture). The third axis (z) was then orthogonal to the other Y-Z plane two with positive approximately right in static posture.

Forearm: The origin of the forearm was located at the wrist JC. The first axis (y) defined for this segment was the unit vector that pointed from the WJC to the EJC (with positive approximately superior in static posture). The x axis vector was the cross product of the y axis and a vector defined radial to ulna styloid processes (opposite for right: positive approximately anterior for both). The third axis (z) was then orthogonal to the x-y plane with positive being to the right in static posture.

Pelvis: The origin of the pelvis was located at the midpoint between the ASIS markers. The first axis (z) defined for this segment pointed from the left ASIS to the right ASIS marker. The y axis vector defined from the midpoint between the two PSIS markers to the origin (with positive approximately anterior in static posture). The third axis (x) was then orthogonal to the other two with positive approximately superior in static posture.

Femur segments: The origin of the thigh segment was the knee joint centre (KJC) which was the midpoint between the lateral and medial knee epicondyles. The first axis (y) was defined as the unit vector from KJC to the HJC, with positive superior for static posture. A second axis (x) was the cross product of the first axis and a vector pointing from the LKE to the MEC (with positive being anterior). The third axis (z) was orthogonal to the y-x plane with the positive pointing from left to right.

Tibia segments: Similar to the thigh, the origins for the tibia segments were placed at the ankle joint centres (AJC), which were assumed be the midpoint between the lateral and medial malleoli. The first axis (y) was defined as the unit vector from AJC to the KJC with positive approximately superior for static posture. The second axis (z) was orthogonal to the first axis and to the vector pointing from the MMAL to LMAL with positive right side for static posture. The third axis (x) was orthogonal to the y-x axis (positive anterior).

6.6 JOINT ANGLE DEFINITIONS

All relative joint angles presented in the following chapters were expressed as child- parent segment Cardan angles following Grood and Suntay (1983). This process corresponded to the standard Euler Z-X-Y convention sequence of flexion/extension, adduction/abduction and internal/external rotation of the moving segment coordinate system with respect to the fixed segment coordinate system.

6.7 DATA ANALYSIS

Kinematic data process and analysis were performed using Vicon Nexus, Workstation and BodyBuilder software (5.2.4, Oxford Metrics Inc.). The aforementioned model was used to calculate lower and upper extremity kinematics. Raw data were smoothed using a Woltring Filtering routine with a predicted MSE value of 20. This value was determined based on a residual analysis according to Winter (p42) (Winter, 1990) using a custom Matlab routine (Matlab 2009b, The MathWorks, Nattick, CO).

After data clean up and smoothing and model calculation, a Matlab routine (Matlab 2009b, The MathWorks, Nattick, CO) was used to extract kinematic parameters.

Chapter 7: Anthropometric Measures and Kinematic Variations in the Generation of Ball Speed in Developing and Elite Cricket Fast Bowlers

7.1 ABSTRACT

This chapter identified movement pattern and anthropometric variables related to the generation of ball speed in elite and developing high performance fast bowlers. Eight national, 12 emerging and 12 junior Cricket Australia squad bowlers completed 30 match-intensity deliveries. Anthropometric measures, ball speed, three-dimensional full body kinematics and front and back foot kinetic data were recorded. Data were analysed utilising between-group and within-individual methods to measure movement pattern variations associated with the generation of ball speed. Junior and National bowling squads varied in mass and muscle mass anthropometric measures, but physical characteristics measures were not strongly related to ball speed generation compared to movement pattern factors. Correlations between group data suggested for junior bowlers a more side-on posture at back foot contact and greater lateral trunk flexion at ball release are related to increased ball speed, whereas the opposite held true for national bowlers. Increased front foot braking ground reaction force was associated with greater ball speed across groups. Group differences existed in key trunk kinematics between junior, emerging and national expert fast bowlers, leading to similar performance outcomes and high ball speed values.

Key words: biomechanics, cricket, expertise and performance

7.2 INTRODUCTION

In the previous chapters, coach and elite athletes identified the ability to generate fast ball speed as a key component of fast bowling expertise and one component that sets international and domestic players apart. In cricket at all levels, fast bowlers aim for accuracy and generation of maximum ball speed to take wickets (dismiss opposing batters) to win games. For these reasons, the study of technique and physical constraints on ball delivery speed in fast bowling has been a popular research topic in sports science (Bartlett et al., 1996). Disagreement exists with regard to mechanical factors believed to be associated with generating ball release speed (Bartlett, 2003; Portus et al., 2006; Salter et al., 2007). Other limitations of this fast bowling research include small participant sample sizes, low trial numbers, lack of clarity on skill level of participants and lack of within-individual investigations (Portus et al., 2004; Salter et al., 2007). Consequently, the relationship between movement patterns, anthropometry and ball speed needs to be more comprehensively investigated in elite and developing performers to advance understanding of fast bowling performance.

Recent work has identified sufficient variation in within-bowler ball release speeds to allow relationships to be identified between movement patterns and ball release speed (Stodden, Fleisig, McLean, & Andrews, 2005; Stodden, Fleisig, McLean, Lyman, & Andrews, 2001). Salter and colleagues (2007) have suggested use of multiple regression analyses using a within-bowler methodology to provide detailed, specific information about individual movement patterning which is neglected in between-bowler methodologies. These ideas concurred with the advice of Mullineaux and colleagues (2001) who advocated single-participant methodologies to better understand how sport performance can be achieved by the adoption of distinct movement patterns in individual athletes. These methodological advances are important for developing understanding of performance enhancement and injury prevention in cricket fast bowling programmes.

Previous research on the generation of ball speed is limited to homogenous fast bowling samples and it is not understood whether developing, emerging and expert fast bowlers are characterised by similar movement patterns and anthropometric measures, relative to ball speed. Pyne and colleagues (2006) examined the relationship between junior and senior high performance athletes' anthropometric and strength characteristics and bowling speed. They observed differences in the variables and strength of correlation of predictors of peak ball speed between age groups, suggesting that growth and biological maturation largely accounted for greater peak ball speed in seniors. It was believed that early maturation may lead to performance enhancement in the junior (14 + 1.3 years) age group. However, results from the senior groups suggested that these factors were not uniquely important throughout development and that movement pattern and general strength should remain the primary focus of fast bowling development programmes (Pyne et al., 2006; Wormgoor et al., 2010).

Wormgoor and co-workers (2010) examined anthropometric, biomechanical, and isokinetic strength variables in 28 high performance fast bowlers. They found the front leg knee angle at ball release, front foot ankle height during the delivery stride, and relative peak torque strength for shoulder extension had a significant positive correlated to ball speed, and shoulder alignment in the transverse plane at front foot strike had a negative correlation (r values magnitude ranged from 0.39 to 0.52). However, a multivariate multiple stepwise regression analysis could not establish a multivariate predictive model for ball release speed (model was not more predictive than variables in isolation). One acknowledged weakness of Wormgoor and co-workers (2010) study was that only one delivery (the fastest ball) was analysed per bowler.

With these limitations of the existing literature in mind, the aim of the study in this chapter was to examine the relationship between movement patterns, anthropometric variables and ball speed as suggested in the previous chapter. This chapter will utilise methodology allowing within- and between-bowler analyses in a study of experts and developing experts. For this purpose a cross section of fast bowlers in the Cricket Australia high performance pace pathway were investigated, to determine firstly whether anthropometric differences exist between squads, secondly whether a relationship between anthropometrics and ball speed could be established, and thirdly which movement pattern factors were associated with increased ball speed within each squad.

7.3 METHODS

Participants were: 8 Cricket Australia nationally-contracted athletes (in the Australia or Australian ‘A’ squads) (NAT mean (s): age 29.1 (3.2) yrs; body mass 92.1 (5.3) kg; height 188.9 (7.7) cm); 12 emerging squad members (state bowlers selected in the Australia senior pace squad) (EMG mean (s): age 21.2 (3.3) yrs, body mass 89.9 (7.9) kg; height 190.3 (6.2) cm); and 12 junior pace squad (Australia Under-19 or state representative bowlers selected in the Australia junior pace squad) (JNR mean (s): age 17.3 (0.7) yrs; body mass 84.2 (4.9) kg; height 187.8 (3.4) cm). All individuals provided informed written consent and study procedures were approved by the human research ethics committees of the Australian Institute of Sport and the Queensland University of Technology.

Participants completed an adapted version of the Cricket Australia bowling skills test consisting of 30 trials bowling to a rear-projected image of a right-handed batsman on a skills test screen. Accurate good length deliveries (within a 30cm radius of the top of off stump, see chapter 8 for detail) were selected for analysis. As only accurate deliveries were selected for analysis, each bowler had a total of 6 to 10 good length trials that were used in the analysis (225 trials in total). Participants bowled over spells of six deliveries to replicate match performance conditions.

Anthropometric measures were taken following the protocols of Pyne et al. (2006). These measures (height, mass, 7 skin folds, 11 girths, 8 limb lengths and 8 limb breadths) were used to create and scale four compartment masses for a four-way fractionation of body composition, allowing total body mass to be partitioned into: fat mass, residual mass, muscle mass, and bone mass (Drinkwater & Ross, 1980; Pyne et al., 2006).

To assess ball release speed, a Stalker ATS radar gun (Applied Concepts, Texas, USA) was placed approximately 6m behind the stumps in line with the pitch and aimed at the point of ball release for each bowler. The typical error for ball release speed utilising the radar in the Australian Institute of Sport laboratory was 1.4 (95% confidence limits 1.1-2.1) km/h (Dowlan, 2003).

A Sports laser gun (Laveg LDM 300C, Jenoptik, Germany) tracked the bowler's lower back throughout the entire run-up. Displacement-time data were captured at 100Hz and treated with a 51-point moving average. Maximum and average speed over the entire run-up, and average speed over the last 5m (prior to the front crease) were calculated. Bowling action kinematics were measured from three-dimensional full body movement data captured using a 22-camera VICON motion analysis system (Oxford Metrics Ltd., Oxford, UK) sampling at 250Hz. A static and dynamic calibration procedure was conducted at the start of each test session, during which the 'Image Error' was calculated for each camera. This value is the RMS distance in camera pixels and indicates the accuracy of the 3D reconstruction of the markers on the Vicon calibration wand used during the calibration process. In line with Australian Institute of Sport Biomechanics protocols, Image Error was less than 0.25 for each camera (Dowlan, 2003). Trajectory data were treated with a Woltring quintic spline and a Mean Square Error of 20, based on residual analysis of key variables (Winter, 1990).

The University of Western Australia cluster-based VICON body builder model was used to calculate three-dimensional joint kinematics (Lloyd et al., 2000). Full body global and relative joint angles were measured using conventions outlined by Besier et al. (2003). Positional data at back foot contact (BFC), front foot contact (FFC) and ball release (BR), and range of motion, maxima and temporal data throughout these phases were calculated for 26 variables based on fast bowling and coaching literature. These variables included, back and front foot knee flexion angle, shoulder and pelvis alignment angle, pelvis to shoulder separation angle, pelvis to thorax separation (rotation) angle, pelvis to thorax separation (lateral flexion) and flexion (Table 7.2). Shoulder and pelvis alignment angle reports the alignment of the shoulders or pelvis in relation to the pitch. Zero degrees would represent the bowler being ‘front on’ to the pitch (shoulders square to the pitch in the direction of the ball to be delivered). Rotation to the right (as would be seen in a right handed bowler) would show a negative number and rotation to the left a positive number (See Figure 7. 1.). Knee flexion angles were measured around the back of the knee, with a straight leg being 0 degrees (See Figure 7.2).

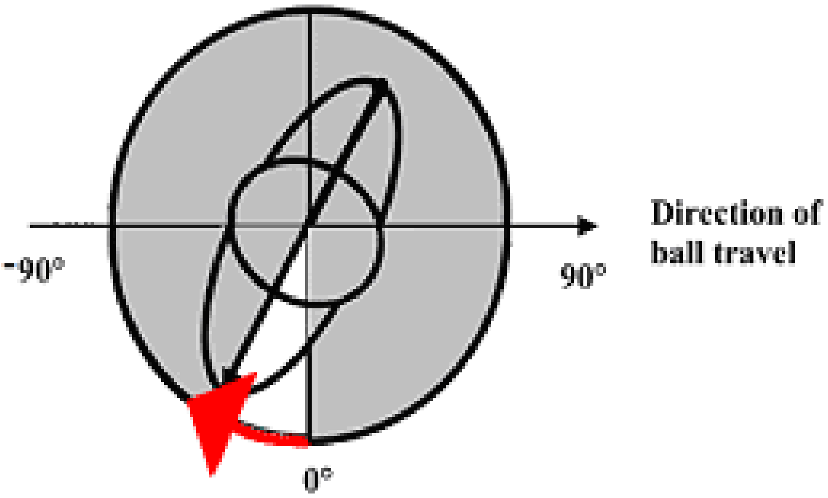

Figure 7.1: Graphical representation defining shoulder and pelvis alignment angles in the transverse plane (represented by non shaded area).

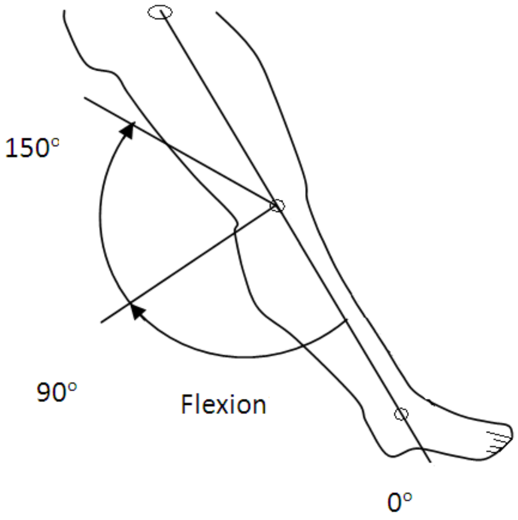

Figure 7.2: Graphical representation of the knee angles in the sagittal plane. .

Ground reaction force data (GRF) for BFC and FFC were collected at 1,000Hz (Kistler, Amherst, USA). Variables selected for analysis were based on the literature discussed in the introduction, where at least moderate correlations were found or suggested (in coaching literature) in smaller trial group analysis (Hanley et al., 2005; Portus, 2001; Salter et al., 2007; Wormgoor et al., 2010).

A one-way analysis of variance (ANOVA) with post hoc Scheffé testing was used to determine differences in anthropometric data between groups. Pearson's product moment correlation coefficients (r) and multiple mixed model regression analysis were used to assess the independent effects of anthropometric, kinematic, temporal and kinetic parameters on ball speed since the experimental design included analysis of multiple trials for each bowler. The most predictive (highest r^2), non-co-linear variables were entered into a multiple mixed-model regression analysis following the methods used by Stodden et al. (2001). An initial model was examined with all variables and then reduced using a stepwise modelling procedure (backward and forward), which eliminated non-significant variables without reducing model fit. Statistical significance levels were set at $p<0.05$ for all comparisons and data were expressed as means and standard deviations (s). Correlations were classified in accordance with advice from Hopkins et al. (2000a) as follows: r < 0.01 trivial, small 0.1 – 0.3, moderate 0.3 – 0.5, large 0.5 – 0.7, very large 0.7 – 0.9, nearly perfect > 0.9. JMP Statistics software version 8.0 (SAS Institute, Cary, USA) was used for all analyses.

7.4 RESULTS

The NAT group produced significantly higher ball speeds than the JNR group (35.0.0 $\pm$ 1.9 v 33.4 $\pm$ 1.2 $m.s^{-1}$, $p = 0.04$). NAT group ball speeds were similar to the EMG group (34.4 $\pm$ 0.9 $m.s^{-1}$). In the NAT group greater ball speed was associated with less fat mass. No statistically significant correlations between anthropometric measures and ball speed were observed in JNR and EMG groups (Table 7.1). The NAT squad had significantly greater values that the JNR in a range of anthropometrics variables, including body mass, muscle mass and residual mass; forearm, chest and gluteal girths, as well as biacromial, biliocristal, chest anterior–posterior and transverse breadths (Table 7.1).

Results from the reduced, mixed-model regression analysis indicated a very strong model fit in the NAT (r^2 = 0.91, Δr^2 = 0.89, RMSE =2.65, $p <$ 0.001), and JNR (r^2 = 0.78, Δr^2 = 0.76, RMSE = 2.50, $p < 0.001$) and a moderate fit in the EMG (r^2 = 0.47, Δr^2 = 0.44, RMSE = 3.18, $p < 0.001$) group. Mean values for selected kinematic, kinetic and temporal variables are shown in Table 7.2. The stepwise process from the initial model (variables entered shown in Table 7.2) is shown below in Tables 7.3 to 7.5.

Table 7.1: Selected anthropometrics correlated to ball speed (r) in Junior, Emerging and National fast bowlers.

	Junior					Emerging					National							
	Mean		S	R	p	Mean		s	r	p	Mean		s	r	P	F	p	
Height (cm)	187.8	±	3.4	-0.16	0.62	190.3	±	6.2	-0.48	0.12	188.9	±	7.7	-0.39	0.34	0.56	0.58	
Mass (kg)	84.2	±	4.9	0.27	0.39	89.9	±	7.9	-0.31	0.33	92.1	±	5.3	-0.40	0.33	4.41	0.02	*^{1}
<u>Skin folds</u> (mm)																		
Sum of 7	73.1	±	13.6	0.24	0.45	73.4	±	22.3	-0.19	0.55	71.0	±	13.5	-0.56	0.15	0.05	0.95	
<u>Composition (</u>kg)																		
Fat Mass	9.4	±	1.3	0.24	0.46	9.8	±	2.7	-0.29	0.36	9.4	±	1.8	-0.70	0.05$^\wedge$	0.15	0.86	
Residual Mass	21.4	±	1.9	0.28	0.38	24.0	±	2.2	-0.28	0.38	25.3	±	2.1	-0.35	0.39	9.65	0.00	*^{1}
Bone Mass	14.2	±	1.2	0.08	0.8	14.1	±	1.6	-0.38	0.23	13.9	±	0.6	0.09	0.83	0.14	0.87	
Muscle Mass	37.4	±	2.4	0.24	0.45	41.0	±	3.3	-0.27	0.39	42.4	±	3.2	-0.39	0.35	8.17	0.00	*^{1}
% Muscle	45.4	±	1.6	-0.06	0.86	46.2	±	1.7	0.32	0.32	46.6	±	1.4	0.16	0.7	1.53	0.23	
Ball Speed (m/s)	33.4	±	1.2	-	-	34.4	±	0.9	-	-	35.0	±	1.9	-	-	3.52	0.04	*^{1}

$^\wedge$Significant correlations with ball speed (p<0.05). *ANOVA significant group differences (p<0.05) and post hoc location: ^{1}JNR v NAT, ^{2}JNR v EMG, ^{3}EMG v NAT.

Table 7.2: Means and standard deviations of selected kinematic, temporal and kinetic data by group.

		Junior			Emerging			National		
		Mean		S	Mean		s	Mean		s
Kinematics (°)										
BFC	Trunk flexion *	-1.8	±	8.6	-5.6	±	10.1	-5.9	±	10.1
	Shoulder align	-37.1	±	15.0	-33.6	±	12.4	-34.1	±	10.6
	Pelvis *	-55.0	±	11.2	-55.3	±	10.0	-56.1	±	6.5
	Hip/shoulder	12.0	±	18.8	19.7	±	15.7	8.4	±	20.0
FFC	Trunk Lat flexion *	-18.0	±	7.8	-16.0	±	7.8	-15.1	±	9.2
BR	Trunk Lat flexion	-28.5	±	7.8	-26.1	±	6.9	-31.7	±	4.3
Shoulder counter rotation		40.8	±	12.2	38.5	±	11.3	39.4	±	12.2
RoM	Trunk Lat flexion	26.9	±	31.1	32.8	±	30.6	21.2	±	39.1
	Trunk flex	50.4	±	7.7	51.1	±	10.4	43.8	±	9.0
	Hip/shoulder	69.9	±	20.0	77.0	±	15.6	75.0	±	12.4
Back knee angle BFC *		42.9	±	12.5	40.4	±	11.7	41.3	±	15.0
Min. back angle		70.6	±	8.6	67.8	±	9.3	74.3	±	11.9
Front knee angle FFC *		9.8	±	9.4	5.9	±	6.9	10.7	±	6.9
Temporal: BFC-BR (sec)		0.29	±	0.04	0.31	±	0.03	0.31	±	0.05
Kinetics (body weight)										
FF max vertical *		5.9	±	1.7	6.3	±	1.3	7.4	±	1.4
FF max braking *		3.8	±	1.2	3.8	±	1.4	4.5	±	1.1
BF max vertical *		2.5	±	0.6	2.8	±	0.9	2.9	±	0.6
BF max braking *		1.1	±	0.6	1.7	±	0.7	1.4	±	0.4
Run-up Speed (m/s)										
Max speed *		6.6	±	0.4	6.5	±	0.4	6.5	±	0.5
Average Last 5m		5.7	±	0.4	5.8	±	0.4	5.7	±	0.4
Average		5.3	±	0.4	5.4	±	0.4	5.3	±	0.5

* Variable entered into initial regression model

In the NAT squad, as ball speed increased, bowlers showed greater max run up speed and back knee flexion and less lateral trunk flexion at FFC were associated with fast ball velocities. Additionally, front and back foot braking GRF increased as ball speed increased (Table 7.3).

Table 7.3: Steps of initial predictive model for ball speed in the national group.

Model	Predictor	R^2	Adjusted R^2	P
1	FF max braking	0.6662	0.6539	<0.0001
2	BF max braking	0.7835	0.7669	0.0009
3	Back knee angle BFC	0.9117	0.8969	0.0340
4	Max run-up speed	0.9380	0.9246	0.0047
5	Trunk Lateral flexion	0.948	0.9376	0.0182

For the EMG bowlers, as speed increased, bowlers showed a more side on shoulder angle at BFC. Additionally, increased front and back foot braking GRF and less lateral trunk flexion at FFC were associated with increased ball speed (Table 7.4).

Table 7.4: Steps of initial predictive model for ball speed in the emerging group.

Model	Predictor	R^2	Adjusted R^2	P
1	Shoulder align BFC	0.171	0.160	0.0002
2	BF max vertical	0.319	0.301	0.0001
3	Trunk later flexion FFC	0.387	0.362	0.0057
4	BF max braking	0.433	0.402	0.0183
5	FF max braking	0.481	0.444	0.0134

In the JNR bowlers, greater max run up speed was associated with increased ball speed. In addition, at BFC a more side on pelvis were and more trunk extension and greater back knee flexion were associated with increased ball speed. At FFC increased lateral trunk flexion and FFC max braking force with were associated with increase ball speed (Table 7.5).

Table 7.5: Steps of initial predictive model for ball speed in junior group.

Model	Predictor	R^2	Adjusted R^2	P
1	Trunk lateral flexion FFC	0.210	0.198	<0.0001
2	Max run-up speed	0.446	0.429	<0.0001
3	Trunk flexion BFC	0.588	0.569	<0.0001
4	Back knee angle BFC	0.752	0.736	<0.0001
5	FF max braking	0.796	0.779	0.0005
6	Pelvis angle BFC	0.805	0.786	0.0005

7.5 DISCUSSION

Ball release speed ranged between 29.4 to 37.5 m.s^{-1} (mean 33.4 m.s^{-1} (1.2), 31.6 to 36.9 m.s^{-1} (mean 34.4 m.s^{-1} (0.9)), and 31.7 to 38. 3 m.s^{-1} (mean 35.0 m.s^{-1} (1.9)), for JNR, EMG and NAT groups, respectively. These mean ball speeds were lower than values reported by Portus et al. (2006) (mean 37.6 m.s^{-1} (2.1) n= 21) in test, tour or one-day international matches. But they were similar to UK international and county speed data analysed by Stockill and Bartlett (1992) (mean 37.4 m.s^{-1} (1.8)), and other values recorded by Salter (2007) (mean 34.2 m.s^{-1} (1.6) n= 1, trials= 20) and Pyne et al. (2006) in senior first class bowlers (mean 35.2 m.s^{-1} (1.5) n= 24, trials= 18) and U16 junior representative bowlers (27.7 m.s^{-1} (2.5) n= 48, trials= 18).

Bowling squads varied in anthropometric measures including muscle mass, but these variables were not associated with ball speed. This observation supports the suggestions of Wormgor and colleagues (2010) that anthropometric measures may have a lower weighting of importance in determining ball release speed compared to technique factors. Alternatively, the weakness of correlations utilising small sample sizes, with a relatively close spread of values for anthropometric variables and ball speed may be a factor; therefore, further analysis including multiple skill levels and ball speeds may reveal a stronger correlation.

Results presented in this chapter corroborated the findings of Salter and colleagues (2007) who compared within (n = 1, trials = 20) and between-bowler methodologies (n = 20, trials = 20 or one per participant) to examine generation of ball speed in fast bowling. Use of multiple trials for individuals across groups afforded interpretation of individual movement solutions, which may not have been picked up when the data were grouped, or only one trial was representative per participant. Analyses of elite squads across the development pathway provide insight into the confirmation of several key components across groups, supporting previous research on the key role of maximum front foot braking GRF, side-on shoulder alignment (Portus et al., 2004; Wormgoor et al., 2010). Greater GRF allows a higher starting point for the transfer of kinetic energy through the joints. This transfer of energy has been postulated to be enhanced by a more rigid front knee at FFC (Portus et al., 2004), also resulting in an increased radial distance to the ball at release contributing to greater tangential force (and ball velocity) (Elliott, Foster, & Gray, 1986).

The role of braking forces in the generation of ball speed has been reinforced with results showing a common association with ball speed across groups. Recently, Ferdinands, Marshall and Kersting (2010) suggested the importance of centre of mass deceleration over the delivery stride for the transfer of kinetic energy available for transfer to the trunk and arm segments. Results presented in the JNR and NAT groups suggest back knee flexion is also associated with increased ball speed; further analysis is required to deduct it’s exact role but it may be postulated that increased flexion may aid in this braking and coordination of the bowling action during this deceleration phase.

Examination of trunk kinematics revealed increased trunk lateral flexion in JNR to create ball speed, which has been postulated to be linked to back injuries (Glazier, 2010). This relationship between trunk lateral flexion and ball release was not seen in the EMG and NAT groups where the opposite was true, where less trunk lateral flexion was related to increased ball release speed. The combination of lateral trunk flexion and rotation and axial rotational velocity of the lumbar spine has been termed the ‘Crunch Factor’ and postulated to be a key role in fast bowlers’ lumbar spine injury, which has been noted in other sports where the transfer of energy along the kinetic chain starts with rapid rotation of the pelvis (Glazier, 2010). Interestingly both lateral trunk flexion and more side-on postures were observed in the JNR. Differences in trunk kinematics presented between JNR and both senior groups may demonstrate a lack of core strength and postural control, which results in this group utilising movement patterns that place them under more stress as they try and “muscle it”. Although it has been postulated, there are no statistically significant links in male research. In fact Portus (2006) found young bowlers with more upright postures at BR gained stress fractures in the lower back compared to other movement patterns. Conversely, Stuelcken and colleagues (2010) linked increased lateral flexion range of motion to back pain history in elite women. Trunk extension at BFC was seen to be important across all groups, suggesting a more extended posture was associated with increased ball speed in all models. These insights highlight the need for an in-depth examination of trunk kinematics in elite developing fast bowlers, which has been examined historically from an injury perspective.

Recent work on multi-articular actions in sport suggests that movement patterning is shaped by the interactions of task constraints and the preferred coordination tendencies (Kelso, 1991) of the performer. Button and colleagues (2003) examined movement patterning in basketball shooting and found that participants differing in skill level exhibited a range of movement solutions linked to specific constraints on performance. These ideas concurred with the advice of Mullineaux, Bartlett, and Bennett (2001), who advocated single-participant methodologies to better understand how skilled performance can be achieved by the adoption of distinct movement patterns. Single-participant analysis will also allow individualised coaching analysis, allowing training programmes tailored for the bowler. A problem with the single-participant methodology is that generalisations cannot be externally reported, as the relationship may only occur for the individual. Stoden (2001) noted that in ball pitching kinematics, variations in mechanics and velocities produced by individuals exist and this variability within individual pitching mechanics is important to performance and should be addressed. Using their methodology, multiple trials from single participants are utilised. This analysis allows generalisations to be formed from relationships within bowlers, not from the magnitude of the parameters between bowlers (Stodden et al., 2001). While the findings presented in this chapter provide insight into differences with development age, they also highlight the need for more single-participant research analyses and an individualised approach to coaching fast bowling.

7.6 CONCLUSION

Examining fast bowling kinematic measures and utilising multiple trials from individual bowlers aided in determining specific variables associated with generation of ball speed. Differences in mechanics resulting in similar ball speeds suggest individuals use strengths and differences in movement patterns to find their own solutions. Development differences imply that some of these factors, particularly trunk kinematics, may be related to maturation and growth of individual performers. Recent data on the role of individualised optimal movement patterns (Glazier & Davids, 2009a) suggested that such analyses may be critical in research on high performance sport.

Chapter 8: Performance Accuracy and Functional Variability in Elite and Developing Fast Bowlers

8.1 ABSTRACT

The relationship between performance variability and accuracy in cricket fast bowlers of different skill levels under three different task conditions was investigated. Bowlers of different skill levels were examined to observe if they could adapt movement patterns to maintain performance accuracy on a bowling skills test. Eight national, 12 emerging and 12 junior Cricket Australia squad bowlers performed 30 trials of short (n=10), good (n=10), and full length (n=10) deliveries. Bowling accuracy was recorded by digitising ball position relative to the centre of a target. Performance measures were mean radial error (accuracy), variable error (consistency), centroid error (bias), bowling score and ball speed. Radial error changes across the duration of the skills test were used to record accuracy adjustment in subsequent deliveries. Elite fast bowlers performed better in speed, accuracy, and test scores than developing athletes. Bowlers who were less variable were also more accurate across all delivery lengths. National and emerging bowlers were able to adapt subsequent performance trials within the same bowling session for short length deliveries. Accuracy and adaptive variability were key components of elite performance in fast bowling which improved with skill level. In this study, only elite bowlers showed requisite levels of adaptive variability to bowl a range of lengths to different pitch locations.

Keywords: cricket, motor skills, elite athletes, performance analysis.

8.2 INTRODUCTION

An important characteristic of skilled behaviour concerns the functional relationship between adaptive variability and performance accuracy (Davids, Button, Araujo, Renshaw, & Hristovski, 2006b; Newell & Corcos, 1993). For example, in cricket fast bowling, accuracy of a delivery is predicated on functional levels of variability needed to adapt to changing performance conditions (Phillips et al., 2010b). Functional levels of movement pattern variability in fast bowling is important, but too much variability could adversely affect consistency of ball landing position/line and provide opportunities for a batter to score runs.

Previous research in fast bowling has focused on ball speed during performance (Bartlett et al., 1996; Portus et al., 2004; Salter et al., 2007) but the relationship between accuracy and performance consistency in elite and developing cricketers has received little attention. While the previous chapter focused on differences across skill levels in the generation of ball speed, coupled with this ability is accuracy and adaptability in fast bowling. Accuracy is a key component for taking wickets and reducing runs scored by opposition batters in cricket. Consistency is essential to build mental pressure by depriving batters of run scoring opportunities. From an ecological dynamics perspective, maintaining accuracy in an aiming task like bowling requires functional variability or movement flexibility to make appropriate adjustments to satisfy changing performance constraints (Davids et al., 2008; Newell & Corcos, 1993). In cricket, fast bowlers aim for consistency and accuracy while maintaining high ball speed and adjust movement patterns to generate different types of deliveries (e.g. bouncer, good length or yorker) when required (Woolmer et al., 2008). Performance flexibility is necessary for adapting to changing environmental and task constraints such as pitch conditions and to bowl against batters with different tactical styles.

In fast bowling, deliveries can be adapted by changing ball flight characteristics (trajectory), described as ‘line’, and landing position described as ‘length’. Delivery *line* refers to the horizontal location of the ball relative to the wicket, and *length* describes the proximity to target of the ball’s bounce point on the pitch. The ability to consistently bowl the ball onto a desired pitch location is crucial to successful performance (Woolmer et al., 2008). Delivery length can be grouped into three categories: short, good and full. Short length deliveries are aimed to bounce towards the batter's head and are often used as an intimidation tactic. Good length deliveries are aimed at the top of the wicket's off-stump and the ball is projected where the batter is unsure whether to move forwards or backwards to play it. Full length deliveries are aimed at the bottom of the bat and are difficult to play because the ball bounces so close to the batter (Woolmer et al., 2008).

Previous data on performance accuracy has been obtained as part of more general research programmes examining factors such as technique changes during repetitive bowling spells (Duffield, Carney, & Karppinen, 2008; Portus et al., 2000), effects of pitch length on performance and technique in junior bowlers (Elliott, Plunkett, & Alderson, 2005), and effects of dehydration in fast bowlers (Devlin, Fraser, Barras, & Hawley, 2001). Portus and colleagues(2000) found that, when bowling good length deliveries, bowlers with high counter rotation of the shoulders were less accurate during the latter stages of an 8-over spell. Typically in previous research only one type of delivery has been investigated and accuracy has not been considered. Some studies have only recorded data on the fastest ball speed, without reference to target accuracy at all (e.g. Pyne et al., 2006). However, a combination of short, good and full length deliveries, achieved through different bowling techniques is needed by fast bowlers to compete internationally. Additionally, due to restrictions preventing short pitched bowling in junior cricket (Cricket Australia, 2010), younger bowlers may be expected to demonstrate less control of short deliveries, than good or full length balls, due to lack experience with this specific skill.

In previous research highly skilled athletes have been shown to be more accurate and consistent than less skilled performers, in golf (Perkins-Ceccato, Passmore, & Lee, 2003), throwing tasks (Freeston, Ferdinands, & Rooney, 2007; Sachlikidis & Salter, 2007; van den Tillaar & Ettema, 2006) and baseball pitching (Escamilla, Speer, Fleisig, Barrentine, & Andrews, 2000). In cricket fast bowling Portus and colleagues (2000) used three rectangular scoring zones at the batters' stumps to measure bowling accuracy. Similar zoned performance outcome measuring systems have been used to examine bowling (Devlin et al., 2001; Duffield et al., 2008; Elliott et al., 2005) and throwing accuracy in cricket (Freeston et al., 2007; Sachlikidis & Salter, 2007). More rigorous methods for measuring accuracy and consistency have been presented in motor control to examine speed–accuracy trade-offs (Hancock, Butler, & Fishman, 1995). These measures provide more sensitive scales for examining accuracy and consistency across multiple delivery types than methodologies in previous fast bowling research.

A related question alluded to in previous work concerns whether high skilled performers are able to pick up and use performance outcome feedback to improve subsequent performance trials within the same practice session. Previous research demonstrated that, following post-performance outcome feedback, participants were able to correct movements in subsequent trials of a simple throwing task (Tottenham & Saucier, 2004). The repetitive nature of fast bowling highlights the pertinence of understanding the role of outcome feedback in this task. During bowling performance it is likely, given the repetitive nature of the task, augmented information from previous deliveries during performance can act as a significant informational constraint to assist performers to achieve desired performance outcomes (Newell, 1986). Therefore, the purposes of this chapter were to: (a) examine accuracy and consistency differences between skill levels in cricket fast bowling under three different task constraints; (b), examine the relationship between variability and accuracy in performance of this multi-articular action; (c), examine the relationship between speed and accuracy in fast bowling; and (d), identify whether bowlers differing in skill level could make adjustments to subsequent deliveries to enhance performance accuracy on a cricket bowling skills test.

8.3 METHODS

The same participants completed this study as in the previous chapter, they were: 8 Cricket Australia nationally-contracted athletes (in the Australia or Australian ‘A’ squads) (NAT mean (s): age 29.1 (3.2) yrs; body mass 92.1 (5.3) kg; height 188.9 (7.7) cm), 12 emerging squad members (state bowlers selected in the Australia senior pace squad) (EMG mean (s): age 21.2 (3.3) yrs, body mass 89.9 (7.9) kg; height 190.3 (6.2) cm), and 12 junior pace squad (Australia Under-19 or state representative bowlers selected in the Australia junior pace squad) (JNR mean (s): age 17.3 (0.7) yrs; body mass 84.2 (4.9) kg; height 187.8 (3.4) cm). Before participation, all individuals were informed of potential risks and requirements of the study and provided informed written consent. The study protocol was approved by the human research ethics committees of the Australian Institute of Sport and the Queensland University of Technology.

Participants completed an adapted version of the Cricket Australia bowling skills test, in which they performed 30 randomised trials of short (n=10), good (n=10), and full length (n=10) deliveries, bowled in five ‘overs’ of six deliveries each. Athletes were instructed to bowl at match intensity towards a rear-projected image of a right-handed batter on a screen, to simulate match conditions. The skills test measured the bowlers’ ability to hit specific targets, with the resultant scores (0-100) averaged to yield an accuracy score (Figure 8.1). Location of all deliveries on the target screen was recorded with a video camera (Sony 3CCD HDR-FXIE, Sony Corporation, Tokyo).

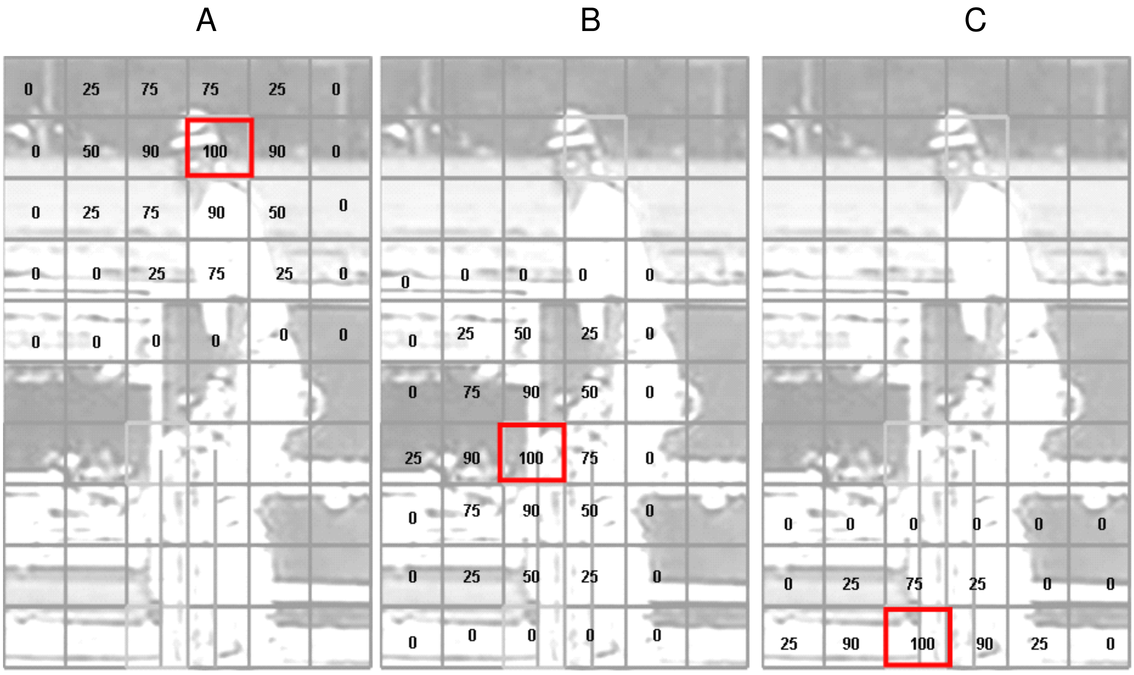

Figure 8.1: Accuracy Scoring System for Short (A), Good Length (B) and Full (C) deliveries.

The instant of ball contact on the target was digitised using customised software written in Visual Basic for Applications (Microsoft Corporation, Washington, USA). Known distances (20 x 20cm) on the target grid were used to calibrate the target area. Performance error was calculated by digitising ball position relative to the centre of the intended target. In line with previous work (Hancock et al., 1995), mean radial error, bivariate variable error, and centroid error were used as accuracy measures. Mean radial error (MRE) was calculated as the absolute distance to the centre of the target averaged across all trials for each participant. Each participant's midpoint test score was measured as the average hit location (mean x,y coordinate) over all trials for each task. The absolute distance of a participant's midpoint to the target midpoint is called the Centroid Error (CE) or Bias. The bivariate variable error (BVE), or consistency, was measured as the absolute distance to the participant's own midpoint averaged across all trials. To assess ball release speed a Stalker ATS radar gun (Applied Concepts, Texas, USA), was placed in line with the pitch and aimed at the point of ball release for each bowler approximately 6 m behind the stumps.

The effects of skill level and delivery type on accuracy were assessed using a multiple mixed design 3 x 3 (group x delivery type) analysis of variance (ANOVA) with repeated measures on the last variable. Post hoc multiple comparisons were performed using Bonferroni corrected t-tests to locate significant differences. Dependent measures were Score, MRE, CE, BVE, and Ball Speed. The relationship between consistency (BVE) and accuracy (MRE) was assessed using Pearson's product moment correlation coefficients (r). The relationship between accuracy and ball speed was assessed using Pearson's product moment correlation coefficients (r). First, each athlete's mean accuracy (MRE) and mean bowling speed were analysed. Second, for each trial, accuracy (RE) and ball speed normalised to each individual's maximum ball speed were analysed. All correlations were classified as follows: $r<0.01$ trivial, small 0.1 – 0.3, moderate 0.3 – 0.5, large 0.5 – 0.7, very large 0.7 – 0.9, nearly perfect > 0.9 (Hopkins, 2000b).

Repeated measures ANOVAs were used on participants' bowling accuracy data for each delivery type to assess effects of skill level on adaptability of performance outcomes. For each analysis, the within-participant measure was trial number, and the between-participants measure was skill level. The dependent measure was Radial Error (RE): the deviation (cm) between the ball impact point and the midpoint of the target for each trial.

8.4 RESULTS

Performance accuracy and consistency differences between participants of different skill levels in fast bowling under three different task constraints (bowling short, good and full length deliveries) are presented. Bowling performance outcomes significantly differed between groups in performance score and accuracy (MRE) ($p = 0.027$ and $p = 0.017$, respectively) across all task constraints. Post hoc comparisons revealed that the NAT group performance was significantly better than the JNR group in score (mean difference of 12.37%, $p = 0.030$) and accuracy (MRE: mean difference of 9.8 cm, $p = 0.024$). However, across all tasks, performance consistency (BVE) and bias (CE) were not significantly different between groups ($p = 0.059$ and $p = 0.063$ respectively), although they showed the same trends as other variables (Figure 8.2).

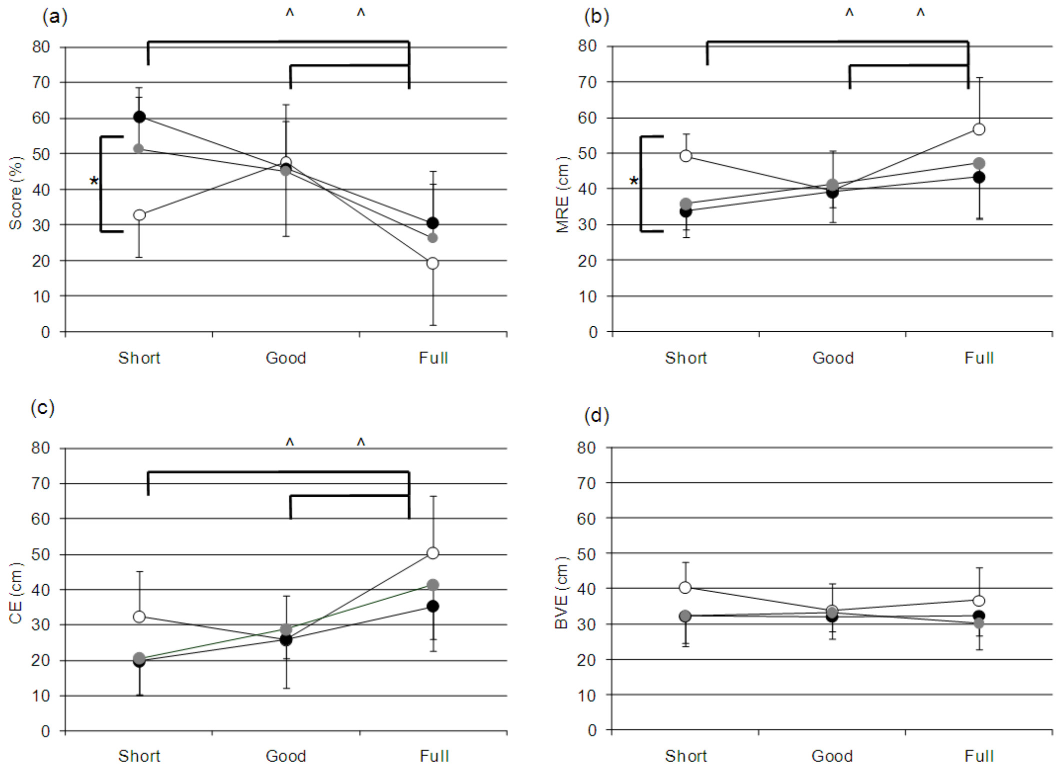

Figure 8.2: Accuracy expressed as (a) score, (b) mean radial error [MRE] (c) centroid error [CE], (d) bivariate error [BVE], National (black), Emerging (grey), and Junior (white) group means (+s). Post hoc comparison of significant main effects: *Significant difference between groups. ^Significant difference between tasks.

All groups revealed significant effects of delivery type (short, good, full) on score, accuracy and bias. Post hoc comparisons indicated that all groups differed when bowling full and short deliveries in score percentage ($p < 0.001$, mean difference of 22.86%), accuracy (MRE; $p = 0.004$, mean difference of 9.5 cm) bias (CE; $p < 0.001$, mean difference of 18.1 cm), and between good and full deliveries in score percentage ($p < 0.001$, mean difference of 20.86%), accuracy (MRE; $p = 0.002$, mean difference of 9.14 cm) Bias (CE; $p < 0.001$, mean difference of 15.56 cm) deliveries. These relationships were the same for all groups in bias (CE: no group*delivery type interaction: $p = 0.107$), but different between groups in score (group*delivery type interaction: $p = 0.035$) and accuracy (MRE: group*delivery type: $p = 0.032$) measures (Figure 8.2). No significant effect of task was found on consistency (BVE: $p = 0.402$) measures, in all groups (group*delivery type interaction: $p = 0.258$) (Figure 8.2).

Significant differences in ball speed were found between groups. JNR and NAT differed in ball speeds (p = 0.037), with a mean difference of 5.6 km.h^{-1}. However, EMG and JNR (p = 0.239), EMG and NAT (p = 0.908) groups did not differ in average ball speeds. There was no significant main effect of delivery type on ball speed (p = 0.204), in all groups (group*delivery type interaction: p = 0.871), indicating no trade-off between ball speed and delivery type in all groups.

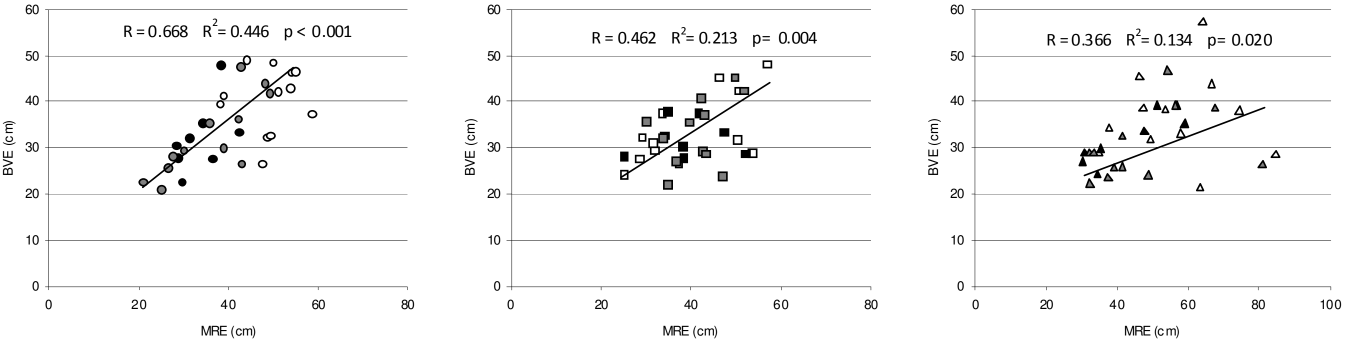

Figure 8.3: Relationship between consistency (BVE) and accuracy (MRE) for all NAT (black), EMG (grey) and JNR (white) short (a), good (b) and full (c) trials.

Examination of the relationship between variability and accuracy in fast bowling established that consistency (BVE) was positively correlated with accuracy (MRE) in short deliveries (large; r = 0.668, r^2 = 0.446, p < 0.001), with moderate correlations observed in good (moderate; r = 0.462, r^2 =0.213, p = 0.004) and full (moderate; r = 0.366, r^2 = 0.134, p = 0.020) length delivery types (Figure 8.3). We observed that, when data were collapsed across groups, participants who bowled faster were not more or less accurate across all deliveries. Ball speed was not linearly correlated with accuracy (MRE) in short (trivial; p = 0.282, r = -0.106), good (trivial; p = 0.369, r = 0.061) or full (trivial; p = 0.306, r = -0.093) length deliveries. When each delivery was normalised to each athlete’s maximum ball speed, accuracy (RE) was not linearly correlated with ball speed (%Max) in short (trivial; p = 0.416, r = 0.012), good (trivial; p = 0.089, r = -0.076) and full (trivial; p = 0.013, r = -0.128) length deliveries.

To identify whether bowlers could make adjustments to subsequent deliveries the Radial error of each delivery was analysed. In Short length deliveries repeated measures ANOVA revealed a main effect of RE across groups. Post hoc comparisons indicated that differences occurred between JNR and NAT ($p < 0.001$, mean difference of 15.5 cm) and JNR and EMG ($p = 0.001$, mean difference of 11.8 cm) groups' RE. However, EMG and NAT ($p = 0.805$) groups did not differ in RE. There was a significant main effect of trial on RE ($p = 0.005$) with a significant group*trial interaction: $p = 0.047$. Radial Error in the NAT group decreased over successive trials resulting in improved accuracy. The JNR group was not able to make the same adjustments and its RE fluctuated across trials (Figure 8.4).

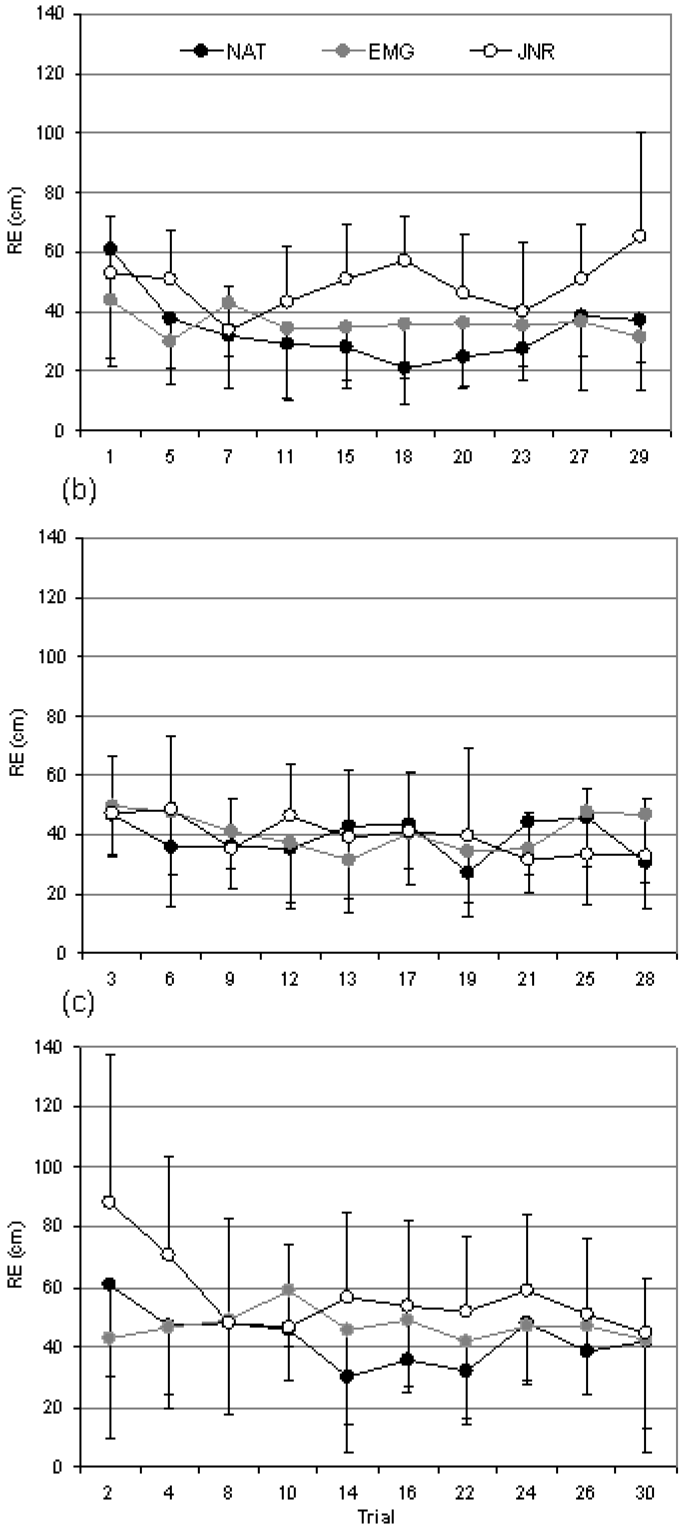

Figure 8.4: Radial Error (RE) for all short (a), good (b) and full (c) length deliveries for National (black), Emerging (grey), and Junior (white) group means (+s). In short length deliveries, NAT and EMG were able to decrease radial error with successive trials, all groups showed a trend of overall error reduction in full length deliveries, while no change was evident in good length deliveries.

For good length and full length deliveries no significant difference were found between NAT, EMG and JNR groups in RE. There was no significant main effect of trial on RE (p = 0.110, p = 0.054) and this relationship was the same in all groups (no group*trial interaction: p = 0.318, p = 0.380). For good length deliveries, NAT, EMG and JNR showed similar levels of error throughout and no trends or adjustments were observed with successive trials. Similar trends of adjustment with decreases in RE over successive trials were noted in all groups for full length deliveries (Figure 8.4).

8.5 DISCUSSION

Research on fast bowling expertise outlined in the previous chapters has established the importance of control in elite bowlers' ability to adapt delivery length to match a range of pitch conditions around the world (Phillips et al., 2010b). Here, differences in skill level in relation to accuracy outcomes in bowling short, good and full length deliveries were examined. Previous research on skilled performance in sport, from an ecological dynamics viewpoint, has highlighted the relationship between performance accuracy and functional variability (Davids et al., 2006b; Davids et al., 2008). However, there has been no work examining this relationship in cricket fast bowling, a multi-articular action in which too much variability might jeopardise accuracy. Functional flexibility in movement patterns may help individual athletes to adapt to changing sport environments and task demands (Davids & Glazier, 2010; Newell & Corcos, 1993). Research on coordination variability in sport has tended to examine expert performance only and it is not understood whether athletes of different skill levels or developmental ages show similar levels of variability in movement performance.

Existing work on fast bowling has established the importance of control in elite bowlers' ability to adapt delivery length to a range of pitch conditions around the world (Phillips et al., 2010b). Here, we examined differences in skill level relative to performance accuracy in consistently varying the production of short, good and full length deliveries. The performance outcome data suggested that more skilled groups (NAT and

EMG bowlers), were able to functionally adapt their actions to enhance accuracy on a range of bowling tasks. Short and good length deliveries were performed more successfully than full length balls, suggesting that the latter was more challenging task for all skill groups. Correlation analysis revealed that cricketers who bowled more accurately were also more consistent. In terms of skill level it appears that high skilled bowlers (NAT) are significantly more accurate (MRE) than JNR bowlers, but high skilled bowlers were not significantly more consistent (BVE) than less skilled bowlers. These findings can be explained in several ways. Although not significantly more consistent (p =0.06), the same trend of JNR performing more poorly is evident. Second, both MRE and BVE are absolute 'directionless' measures, (i.e. direction above or below the target 3cm is considered the same measure or error). This measurement issue has been highlighted on numerous occasions in the motor control literature (Hancock et al., 1995) and may result in the underreporting of BVE, in particular. Finally, one issue in examining performance of developmental groups is that there may be some 'noise' in a dataset, caused by the overlap in skill levels between participants in all groups.

It was observed that NAT bowers were also faster than JNR bowlers. There was no trade-off between speed and delivery type across groups, supporting previous suggestions of the importance of ball speed for accuracy in some tasks (Dupuy, Mottet, & Ripoll, 2000) where speed is an important factor in the successful performance of a skill. It should be noted, however, that athletes were not asked to bowl at different speeds and likely performed within their self-selected match intensity pace.

To examine whether bowlers were able to adjust subsequent deliveries during the test, we examined changes in radial error across all trials for short, good and full length deliveries. In short length deliveries, NAT and EMG were able to decrease radial error over successive trials, resulting in improved accuracy. The less experienced JNR group could not make the same adjustments and their radial error fluctuated across trials. In contrast, for good length deliveries the NAT, EMG and JNR groups showed similar error levels and no trends or adjustments were observed over successive trials. For full length deliveries the NAT, EMG and JNR groups performed similarly, with the same general improvement trends over successive trials. These results suggested that, in some delivery types, bowlers were able to make adjustments to subsequent deliveries during the skills test, achieved in the EMG and NAT group more often than the JNRs.

These results have a number of practical implications for talent development and training design in elite cricket programmes. As individuals progress in expertise and explore different performance solutions, it is important for them to explore different task requirements (delivery types, different batters) in the learning process. It is possible that NAT and EMG bowlers could complete the skills test more successfully because they had experienced more time in practice and competition, or because the increased demands of the game at this level required them to bowl with more functional variation and control (Woolmer et al., 2008). Regardless, exposure of JNR athletes to a range of different performance situations is advocated to support increased adaptability in fast bowling. As a bowler's career progresses he/she will encounter batters with different styles in a range of performance environments, therefore requiring a wider skill set.

Future research needs to provide a more comprehensive examination of influential constraints, including technical/coordination variants under a variety of task demands. For example, investigating kinematic adjustments with different delivery types would allow greater insight into the individual coordination dynamics and movement solutions of a skill group (e.g. varying ball speed or type and line and/or length in cricket fast bowling). Functional levels of variability in movement have been demonstrated as important in fast bowling to achieve flexible performance outcomes, although too much movement variability could adversely affect consistency of ball landing position/line and provide opportunities for a batter to score runs. Further research quantifying the complex relationship between technique variability (bowling action and coordination measures) and bowling accuracy (performance outcome), under different task constraints (delivery types), would provide further insights into expert performance in fast bowling.

8.6 CONCLUSION

Accuracy and consistency performance in elite, emerging and junior elite cricket fast bowlers from Australian pace squads were quantified. Increased accuracy and less target error in the NAT and EMG groups suggested these groups were more able to adapt to different task constraints than their JNR counterparts. Future research on how experts are able adjust movement patterns and the key biomechanics variables associated with successful adaptable movement solutions is suggested.

Chapter 9: Delivery stride ground reaction force and variability in junior and national elite fast bowlers

9.1 ABSTRACT

Ground reaction force data have been used extensively to examine movement in sports, such as fast bowling in cricket. Although peak ground reaction force has been identified as a key variable for performance, few attempts have been made to extensively examine its role in elite performance. The analysis of intra-individual movement variability can reveal important information about how individuals satisfy interacting constraints to achieve desired movement solutions. Here data on ground reaction force variables, including variability and asymmetry of the front and back foot ground reaction forces, is reported in the delivery stride of junior, emerging and national elite Cricket Australia fast bowling squad members. The purposes of this chapter are to: (1) quantify the variability present in selected back foot and front foot ground reaction force variables; (2) determine the level of asymmetry present during fast bowling; and (3) determine whether trends in variability observed in fast bowling performance are related to developmental age and asymmetries. Data revealed a greater magnitude of vertical and braking force in front foot contact across all groups, with greater variability (CV%) in the medio-lateral plane in both back and front foot contacts. In the elite group greater levels of asymmetry were observed in all three directions, although not all findings were statistically significantly different. In all groups, three main landing strategies were identified at front foot contact, with peak variability occurring around the vertical force maxima.

Keywords: variability, human movement patterns, ground reaction force, asymmetry, cricket

9.2 INTRODUCTION

Variability in human movement systems is omnipresent, and there is increasing interest in the role of variability in skilled performance where consistent performance outcomes are desired (Davids et al., 2003; Miller, Chang, Baird, van Emmerik, & Hamill, 2010). Traditionally movement system variability has been viewed as 'noise' that must be minimized for optimal performance, based on the assumption that skilled performers' movement patterns are invariant (Brisson & Alain, 1996). This traditional perspective has been challenged by dynamical systems theory, where variability is considered to be a central feature of expert performance, being viewed as functional and adaptive when it results in successful performance outcomes (Davids et al., 2003; van Emmerik & van Wegen, 2002). The variability observed in the emergence of functional coordination patterns reflects the cooperative behaviour of multiple biomechanical degrees of freedom during goal-directed movement (Glazier & Davids, 2009b).

Cricket fast bowling is a rich task for examining variability in human movement because it is a dynamic multi-articular action. It comprises a run-up, followed by a bound and a delivery stride where athletes transfer energy from the run-up and foot contacts through the body to produce high ball speed at release. In previous research examining cricket fast bowling performance, a number of applied studies have established a relationship between ground reaction force (GRF) variables and performance (Portus et al., 2004). The GRF is a force vector consisting of three components: a vertical component and two shear components, the antero-posterior (braking and propulsive forces) and medio-lateral (lateral balance or stability) components that act parallel to the performance surface. The vertical force component has received most attention in fast bowling research, primarily for the front foot in the delivery stride (e.g. Portus et al., 2004), displaying much larger forces than in running (Hurrion, Dyson, & Hale, 2000). Indeed, front foot GRFs were noticeably larger than back foot forces (4.8 - 5.85kN and 2.3 - 3.9kN respectively). Recently, Stuelcken and colleagues (2009) examined the magnitude of ground reaction forces in female fast bowlers, noting that the movement strategy the bowlers adopted (foot flat cf. heel-toe striking pattern) affected the vertical force-time curves and the magnitude of the peak, and loading rate. Although participant numbers in the study by Stuelcken and colleagues (2009) were too small to provide meaningful statistical comparisons, this study suggested that future fast bowling research needs to look beyond establishing the magnitude of the maximum force, to gain a more detailed understanding of the movement function captured by this key variable in performance. The incidence of several contact strategies (foot flat and heel-toe striking patterns) highlights the role of neurobiological degeneracy in skilled performance, where the same behavioural goal can be achieved through the coordination of structurally different components (Chow et al., 2008; Edelman & Gally, 2001). Given the insights provided by GRF variables on fast bowling performance, further investigation of variability and asymmetry is warranted to develop understanding of the role of functional variability in skilled and developing performance.

Previous research on movement variability in sport has tended to focus on expert performance only and it is not understood whether athletes of different developmental levels show similar levels of functional variability in movement performance (Bradshaw, Maulder, & Keogh, 2007; Mullineaux et al., 2001). Since there are no published data on the relationship between front and back foot ground reaction force variables, or the variability of these key performance parameters, the aims of this chapter were to: (1) provide an extensive examination of ground reaction force data in back and front foot contacts in fast bowling performance; (2) examine the intra-individual variability present in front and back foot ground reaction force variables in elite and developing fast bowlers; (3) determine the level of asymmetry between back and front foot ground reaction force measures in these bowlers; and (4) determine if there is an skill effect on observed variability and asymmetry of GRFs during fast bowling.

9.3 METHODS

9.3.1 PARTICIPANTS

Eighteen elite and developing male cricketers of the Cricket Australia high performance fast bowling squads participated in this study. They were divided into three groups based on their squad selection and age; these were: (i) in the Australia or Australian 'A' National squads (NAT); (ii) emerging bowlers, state representative bowlers selected in the Australia senior pace squad (EMG); and (iii) junior bowlers, Australia Under-19 or state Under-19 representative bowlers selected in the Australia junior pace squad (JNR) (see Table 9.1). Before participation, all individuals were informed of the potential risks and requirements of the study and provided informed written consent. The study protocol was approved by the human research ethics committees of the Australian Institute of Sport and the Queensland University of Technology.

Table 9.1: Participant specifications by group means ± s.

	n	Age (years)	Height (cm)	Weight (kg)
Junior	6	17.4 ± 0.6	189.2 ± 4.0	85.4 ± 4.9
Emerging	6	19.5 ± 3.2	188.1 ± 6.8	87.5 ± 8.5
National	6	28.0 ± 4.2	190.9 ± 9.6	89.5 ± 6.1
Mean		21.7 ± 5.5	189.4 ± 6.9	87.6 ± 6.5

9.3.2 DATA COLLECTION

Participants performed 30 repeated fast bowling trials at match intensity, including good, short and full length deliveries. The trials were performed in a purpose-built sports biomechanics laboratory, which permitted a 25m run-up. Two force platforms (Kistler, Amherst, USA) were used to collect back and front foot ground reaction force (GRF) data. Force data were sampled at 1,000Hz, and only data with complete back and front foot force plate contacts were included for analysis. For these analyses, a vertical force threshold of 20N was used to identify the beginning and end of the ground contact. For each foot contact, data on several variables were collected and calculated using established methods (Korhonen et al., 2010). The average rate of impact loading, LRave, was defined as the peak vertical force divided by the time of occurrence relative to initial touchdown (Hurrion et al., 2000;

Korhonen et al., 2010). Other GRF variables included the maximal and average values of the vertical (Fz), anterior-posterior (Fy), and medial-lateral (Fx) forces. Additionally, temporal variables, contact time (tcontact) and time to maximal values (Fz, Fy and Fx) were obtained from the force-time traces. GRF data were normalised to individual participants' body weight to allow for comparisons to published data and across groups.

9.3.3 VARIABILITY AND ASYMMETRY MEASURES

The coefficient of variation (CV) statistic was used to determine the intra-individual variability of measures for back and front foot contacts. The asymmetry between dominant (back leg = right leg for a right-handed bowler) and non dominant (front leg = left leg for a right-handed bowler) leg variables was quantified with a symmetry index (SI) of the vertical GRF parameters, as proposed by Robins, Herzog and Nigg (1987) (Eq. 1):

$$SI = \frac{2 \times (X_D - X_{ND})}{(X_D + X_{ND})} \times 100 \qquad (1)$$

In equation 1, x_D is the variable for the dominant leg and x_{ND} the same variable on the non dominant leg. When SI is zero there is perfect symmetry between each side. A positive number indicates dominant limb prominence, and a negative value implies non-dominant limb prominence. SI was also adapted to the absolute symmetry index (ASI) (Giakas & Baltzopoulos, 1997), which is advantageous when averaging the symmetry indices over multiple trials or across individuals, as positive and negative values do not eschew or mask results. It is important to note that typically the back and front foot contacts are not expected to be symmetrical, and this measure will allow quantification of the *amount* of difference between limbs.

9.3.4 ANALYSIS

For each foot contact group, comparisons for the mean values of all the dependent variables and symmetry indices (SI and ASI) were made using a one-way analysis of variance (ANOVA), with post hoc Scheffé testing used to determine differences between groups. Because of the number of multiple comparisons a partial Bonferroni adjustment was made and statistical significance levels were set at $p<0.02$ for all comparisons. Data were expressed as means and standard deviations (s).

9.4 RESULTS

9.4.1 PATTERNS OF VERTICAL GRF CURVES

The vertical GRF curves showed considerable variations between individuals and between foot contacts (Figs. 1 and 2). Across individuals some GRF curves showed a double waveform ((b)–(c)) with an initial impact peak, generally with the second maxima more dominant than the first. In others, a singular maximum often with a larger peak was observed (a). Generally, the variability in measures increased around the maxima(s). In Figure 9.1, it can be observed that variations of the force curves indicated possible differences in individual movement strategies within the sample of bowlers.

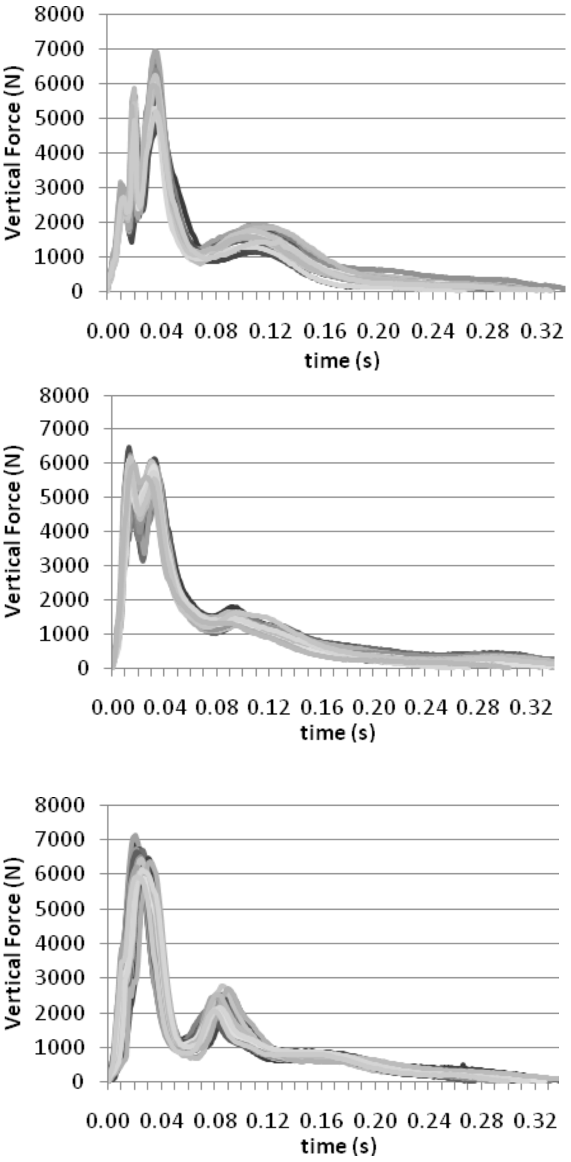

Figure 9.1: Examples of three different types (most typical) vertical GRF curves for three participants (30 trials each) impact peak (a), twin peak (b) and one maxima (c) strategies at front foot contact.

9.4.2 EFFECTS OF DEVELOPMENT

During the fast bowling trials the NAT group showed mostly greater FFC in Fz values compared to the EMG and JNR groups, with several of these comparisons being statistically significant (Table 9.2). In BFC surprisingly strong similarities were observed for most variables in the groups, considering the different nature of the curves presented across individuals.

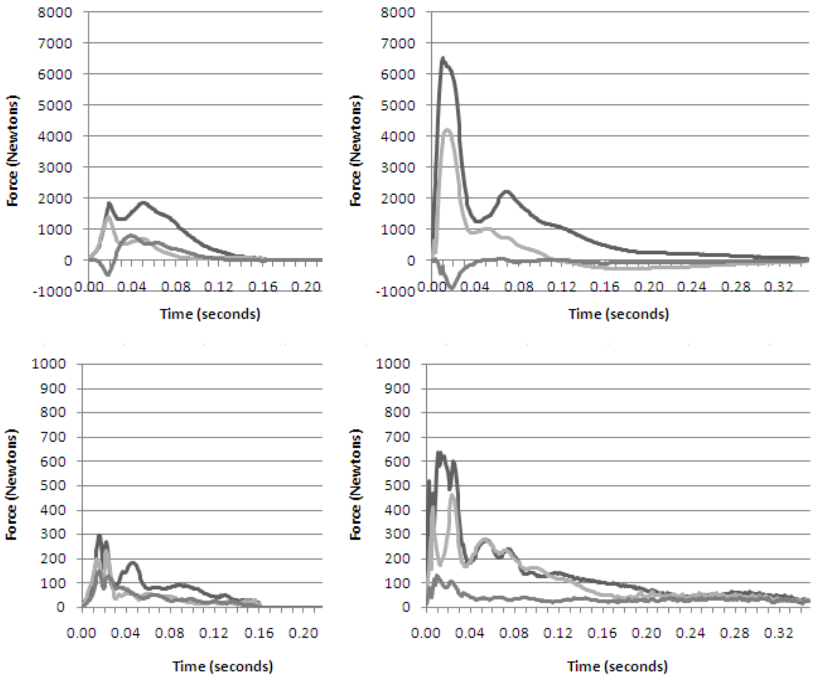

Figure 9.2: Back and Front foot mean force (top) and standard deviation (top) for an individual NAT bowler: Vertical (Fz: black), Anterior–posterior (Fy: light grey) and medial-lateral (Fx: grey).

9.4.3 INTRA–INDIVIDUAL VARIABILITY

When presented graphically, trial-to-trial variability of the force parameters appears largest in Fz for both front and back foot contacts. However, when considered relative to its mean in the CV statistic, medial and lateral forces were of higher magnitude and increased from BFC to FFC (see Figure 9.2 and Table 9.2). Each component of force showed similar trends, but with considerably higher values at FFC, particularly in the medial – lateral directions.

9.4.4 VARIABILITY AND AGE

Generally, there was no systematic increase in variability across variables (CV%) from the JNR, to the EMG and the NAT group; but the test-to-test variability between the three age groups varied only in a few parameters and not systematically with age.

Table 9.2: Back and front foot components of GRFs in fast bowling in JNR, EMG and NAT Mean ± SD.

	Back Foot				Front Foot			
	JNR	EMG	NAT		JNR	EMG	NAT	
Vertical								
Fz Impact	2.23 ± 0.77	2.27 ± 0.67	2.18 ± 0.86		5.00 ± 1.63	6.34 ± 0.74	7.42 ± 1.18	*JvN
LR Impt ave	108.9 ± 55.3	135.5 ± 36.5	109.5 ± 52.6		600.9 ± 524.0	424.6 ± 189.5	541.8 ± 206.7	
t Fz Impt	0.02 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	*JvE, N	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	*JvN
Fz max	2.31 ± 0.37	2.72 ± 0.80	2.53 ± 0.32		7.18 ± 1.88	6.25 ± 0.79	7.79 ± 1.07	
LRave	41.8 ± 8.9	70.6 ± 66.3	67.4 ± 38.8		386.2 ± 300.1	230.5 ± 88.26	501.5 ± 170.4	
t Fz max	0.06 ± 0.01	0.05 ± 0.02	0.05 ± 0.03		0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	*EvN
Fz ave	1.19 ± 0.22	1.11 ± 0.09	1.12 ± 0.11		1.31 ± 0.24	1.14 ± 0.07	1.30 ± 0.13	
Fz Impulse	46.1 ± 12.2	51.8 ± 22.1	34.2 ± 22.3		116.6 ± 18.9	155.3 ± 43.93	98.1 ± 69.8	
T contact	0.20 ± 0.04	0.21 ± 0.05	0.20 ± 0.04		0.30 ± 0.05	0.37 ± 0.05	0.31 ± 0.07	
A/P								
Fy max	1.67 ± 0.47	1.78 ± 0.61	1.61 ± 0.74		4.67 ± 0.90	4.37 ± 0.77	4.60 ± 0.61	
LRave	75.9 ± 29.6	92.6 ± 48.2	75.9 ± 58.63		207.1 ± 120.0	153.7 ± 28.14	228.1 ± 75.64	
t Fy max	0.02 ± 0.01	0.03 ± 0.02	0.03 ± 0.02		0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	
Fy ave	0.28 ± 0.02	0.30 ± 0.09	0.34 ± 0.11		0.39 ± 0.20	0.29 ± 0.06	0.37 ± 0.10	
Fy Impulse	11.04 ± 5.32	13.88 ± 6.38	9.30 ± 5.17		31.87 ± 7.81	40.66 ± 15.63	25.34 ± 15.65	
M/L								
Pos peak	0.56 ± 0.31	0.60 ± 0.16	0.66 ± 0.20		0.46 ± 0.33	0.27 ± 0.18	0.29 ± 0.23	
Tmax	0.03 ± 0.01	0.04 ± 0.01	0.04 ± 0.01		0.05 ± 0.04	0.06 ± 0.05	0.06 ± 0.06	
Neg peak	-0.49 ± 0.14	-0.66 ± 0.32	-0.45 ± 0.25		-0.85 ± 0.60	-0.54 ± 0.23	-0.80 ± 0.34	
Tmin	0.03 ± 0.02	0.02 ± 0.00	0.02 ± 0.00		0.03 ± 0.01	0.05 ± 0.05	0.03 ± 0.01	

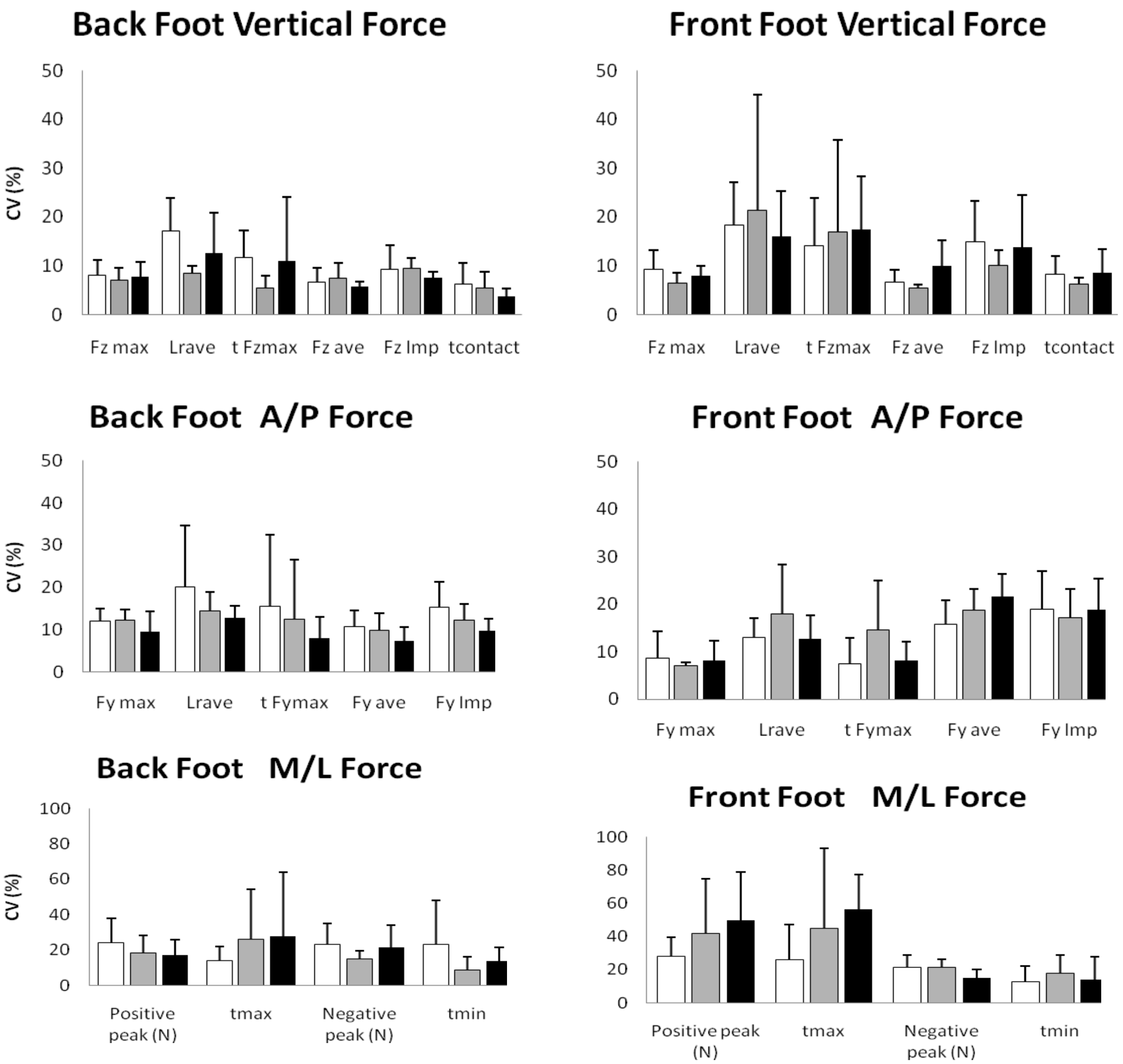

Figure 9.3: Intra-individual coefficient of variations of back and front foot contact vertical (a), horizontal (b) and medio-lateral (c) variables for JNR (white), EMG (grey) and NAT (black) Means and SD by group.

9.4.5 ASYMMETRY

Generally, the NAT group showed larger asymmetries compared to the JNR group, for example with respect to ML force (positive peak: 3.51 ± 1.13% versus 5.70 ± 1.38%) and several Fz variables (i.e. tFzMax: 3.58 ± 0.65% versus 5.34 ± 0.65%). Significant differences were found between Nat and EMG in ML force, time to negative peak SI (20.5 ± 44.7% versus -66.4 ± 50.7%) and between JNR and NAT in time to positive peak ASI measures (70.1 ± 27.7% versus 122.7 ± 34.1%). In summary, age-related symmetry effects were found only in two comparisons and were not systematic effects. However, high standard deviation values (implying individual differences and different movement strategies) indicate the variability present in all participants.

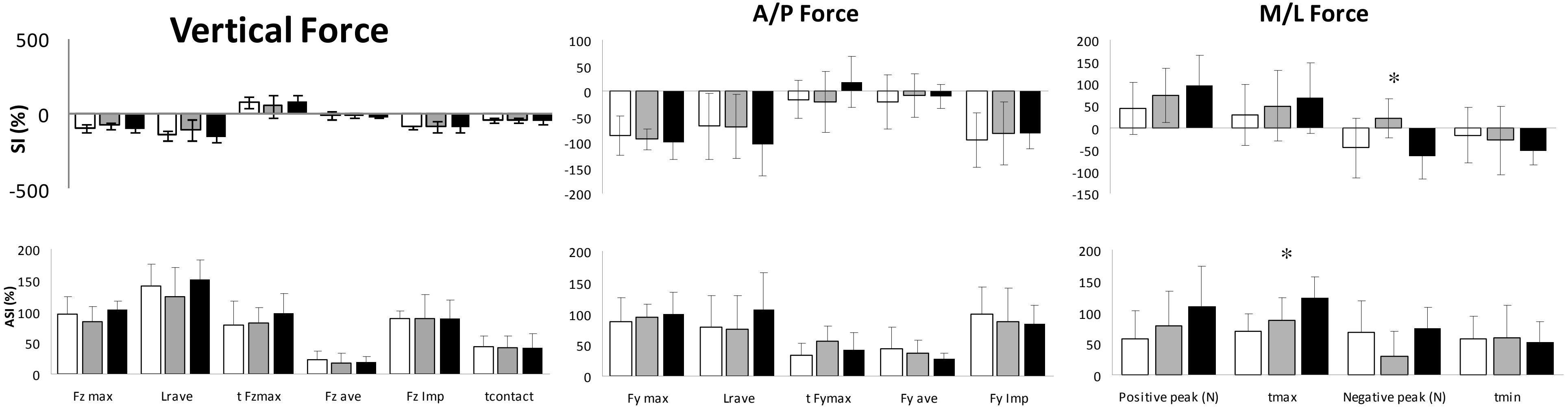

Figure 9.4: Asymmetry (ASI and SI) of selected back and front foot contact vertical (a), horizontal (b) and medio-lateral (c) variables for JNR (white), EMG (grey) and NAT (black) Means and SD by group.

9.5 DISCUSSION

The purpose of this chapter was to identify typical patterns of vertical GRF curves produced during the delivery stride in fast bowling in a sample of elite and developing fast bowlers, and to observe whether changes occurred in the variability and asymmetry of these variables with expertise development.

9.5.1 LANDING STRATEGIES

Three contact strategies were identified at point of front foot contact (frequency shown in Table. 9.3, below). Stuelcken and Sinclair (2009) reported similar trends in a study of elite female fast bowlers, noting that some bowlers exhibited a heel-toe striking pattern (impact; characteristic initial impact peak followed by a larger peak), and others displayed a flat-foot striking pattern (one predominant peak).

Table 9.3: Participant landing strategy by group.

	Impact Peak	Twin Peak	One Maxima
Junior	4	1	1
Emerging	1	5	-
National	-	2	4
Total	5	8	5

In agreement with these findings, data presented in this chapter demonstrate that bowlers with a flat-foot striking pattern had a shorter time to peak vertical force, generally displaying an increased loading rate, as seen in Figure 9.1. The twin peak strategy also observed lies between the other two strategies. Visual inspection of video footage suggests it is likely the result of a lateral followed by a medial front-foot contact rather than a even flat-foot contact, with the time between medial and lateral front contact very close before a full flat-foot contact is achieved (similar to the one maxima peak strategy). A greater peak of GRF allows greater transfer of energy through the limbs to ball release. Numerous researchers have formulated versions of spring-mass models that reproduce the impact and active force peaks during running (Alexander, 1995; Nigg & Anton, 1995). These models consist of masses (representing body mass and foot, for example) connected by springs (leg, shoe or similar reflection potential cushioning properties). They have been able to replicate typical gait GRF curves, where body mass and the leg spring produce the smooth active force curve, while the foot mass and shoe spring produce the abrupt impact peak. Similarly in fast bowling it has been suggested that bowlers who have an extended knee or who extend the knee at front-foot contact had higher peak forces and greater rates of force development (Portus et al., 2004; Stuelcken & Sinclair, 2009). These impacts and force peaks in fast bowling are determined by multiple components, including the mass of the bowlers, run-up and landing velocity, shoe properties and lower extremity kinematics, and height of front leg in delivery stride before FFC.

9.5.2 VARIABILITY

While there were no systematic increases in GRF production from the JNR to the EMG and the NAT groups in levels of variability, intra-individual variability was evident particularly in medial and lateral forces. These results provide evidence that individuals utilize movement pattern variability and intentionality to seek and explore new performance solutions and cope with performance instabilities (meta-stability) (Davids, Bennett, & Newell, 2006a). Meta-stability occurs in regions of a perceptual-motor performance landscape where the system is poised in a state of dynamic stability. Here, movement systems can rapidly undergo phase transitions to new, more functional states of organization as constraints change, allowing creative and adaptive behaviours to emerge. In practice this approach requires exposure to meta-stable regions of the performance landscape during learning and development, allowing experts and developing experts to discover new modes of behaviour to satisfy interacting perceptual, affective and task constraints. These new modes of performance are likely to emerge as novel solutions to performance problems as developing athletes co-adapt their responses to challenging constraints imposed by opponents and environments as discussed in Phase one of this thesis (Phillips et al., 2010b). Fast bowling is an extremely dynamic skill, where the run-up shapes the delivery stride position and dynamics, and the flexible nature of the skill and the open performance environment requires co-adaptation by the performer to constantly seek functional performance solutions to meet the dynamic demands. Learning designs promoting variable practice conditions in dynamic game-like environments are advocated, as such conditions allow development athletes to harness inherent variability in order to match the needs of competition environments.

9.5.3 ASYMMETRY

Generally, the NAT group showed larger asymmetries compared to the JNR group, although skill related significant effects were not systematic. While this is an unconventional use of the symmetry measure, the magnitude of asymmetry recorded (normal gait ~10%) does highlight the level of independence between the limbs required to perform this skill. Perhaps with larger sample sizes more statically significant differences can be established between skill levels.

9.6 CONCLUSION

The findings confirmed the view that standard movement templates for coordinating multi-articular actions do not exist in skilled performers (Hristovski, Davids, & Araujo, 2006). Degenerate movement systems can be exploited to achieve movement goals with functional, varying movement patterns. This idea suggests that learning design should encourage learners in team games like cricket to experience variable practice conditions so that they learn to harness inherent variability in order to adapt their actions in dynamic performance environments.

Chapter 10: Epilogue

10.1 INTRODUCTION

The purpose of this chapter is to overview the key findings from the current programme of work. A discussion of the implications of these research findings for the construction of talent development programmes in cricket will be presented.

10.2 KEY FINDINGS AND IMPLICATIONS

10.2.1 STUDY 1: EXPERTISE DEVELOPMENT AS A COMPLEX SYSTEM

Developing experts resemble complex evolving systems. They harness nonlinear transitions in performance, seek out new challenges, and are exposed to optimal learning designs, self discovery and rich support networks in the acquisition of expertise. The developmental trajectories data revealed that the unique constraints impinging on numerous levels of the system can be investigated at many levels (including differences in familiar support, birthplace locality, specialisation late in sport, formal development programme support, and different rates of maturation), resulting in varying non linear pathways to fast bowling excellence. Data identified a central role for: (a) unstructured practice activities in optimal learning, (b) strong support networks advantageous to cognitive, physical and emotional development, and (c) cultural constraints.

The difference between 'place of birth' effects and 'place of development' effects was discussed, suggesting the need for a more complex analysis of developmental histories. Additionally, birth date effects may have been mediated by opportunities for younger players to play with older, more experienced players (in a supportive environment). This experience creates a controlled, supportive, mentored learning programme, dissimilar to traditional identification programmes which may facilitate talent de-selection rather than development (Abbott et al., 2005).

10.2.2STUDY 2: DEGENERACY AND ADAPTABILITY IN EXPERT PERFORMANCE

Analysis of experiential knowledge of elite athletes and coaches highlighted the importance of appropriately designed talent development programmes that attribute greater significance to the role of adaptability in expert performance. Other important insights of expert cricketers concerned the reality of different rates of athlete development and variations in expressions of components of expertise which shaped individual development trajectories. The data suggested that more attention in talent development programmes needs to be paid to emphasising the multidisciplinary nature of talent. The data also suggested that the object of such programmes should be talent development, rather than talent selection. Experiential knowledge of experts in sport was revealed as a source of information that could complement empirical knowledge of expertise acquisition.

The data are harmonious with the view that expert athletes exemplify a dynamic complex system, in the systemic degenerate nature of the components and their interactions. This systemic conceptualization is harmonious with other research (Johnson et al., 2010; Simonton, 1999); the athletic, dynamic and complexity of requisite movement patterns in cricket results in a large weighting on key physical and skill components. These factors were always concurrent with the relevant psychosocial skills to perform at an international level, since athletes without some level of talent in physical, skill and psychological components were felt likely to not progress to the international level.

10.2.3STUDY 3: DEGENERACY IN THE GENERATION OF BALL SPEED IN DEVELOPING AND ELITE FAST BOWLERS

Study 3 identified movement pattern and anthropometric variables related to the generation of ball speed in elite and developing high performance fast bowlers. Junior and national bowling squads varied in mass and muscle mass anthropometric measures, but physical characteristics measures were not strongly related to ball speed generation compared to movement patterns. Although the examination of trunk kinematics revealed increased trunk lateral flexion in the junior bowlers to create ball speed, this relationship was not seen in the emerging group, and in the national group the opposite was true. Interestingly both lateral flexion and more side-on postures were observed in the junior group. This observation may demonstrate a lack of core strength and postural control, resulting in this group utilising movement patterns that place them under more stress as they try and "muscle" it. Trunk extension at BFC was seen to be important across all groups, suggesting a more extended posture was associated with increased ball speed in all models. These insights highlight the need for an in-depth examination of trunk kinematics in elite developing fast bowlers.

Differences in mechanics resulting in similar ball speeds suggest that fast bowlers utilise different strategies because of weaknesses and individual differences to find their own movement solutions. Development differences imply some of these factors, particularly trunk kinematics, may be related to developmental level. Examining fast bowling kinematic measures and utilising multiple trials from individual bowlers aided in determining specific variables associated with the generation of ball speed. Recent data on the role of individualised optimal movement patterns (Glazier & Davids, 2009a) suggested that such analyses may be critical in research on high performance sport.

10.2.4 STUDY 4: ADAPTABILITY OF EXPERTS AND DEVELOPING EXPERTS: PERFORMANCE OUTCOMES

The relationship between consistency and accuracy in cricket fast bowlers of different skill levels under three different task conditions was examined. This study sought to determine whether bowlers of different skill levels could adjust accuracy in subsequent deliveries during performance of a cricket bowling skills test. Elite fast bowlers performed better in speed, accuracy, score and bias measures than the developing bowlers. Bowlers who were more consistent were also more accurate across all delivery lengths. National and emerging bowlers were able to improve subsequent performance trials within the same practice session for short length deliveries. Performance of the bowling skills test demonstrated that accuracy and consistency are key components of elite performance in fast bowling, which develop with skill level. In this study, only elite bowlers showed the ability to bowl a range of lengths to different target locations. This observation suggests the presence of functional flexibility in movement patterns, which may help athletes adapt to changing sport environments and demands (Davids & Glazier, 2010). Further research quantifying movement pattern variability (bowling action and coordination measures) and bowling accuracy (performance outcome), under different task constraints (delivery types), would allow further insights into expert performance in fast bowling.

10.2.5 STUDY 5: VARIABILITY OF EXPERTS AND DEVELOPING EXPERTS: GROUND REACTION FORCE

Analysis of intra-individual movement variability can reveal important information about how individuals satisfy interacting contracts to achieve desired movement solutions. Ground reaction force data have been used extensively to examine movement in sports, such as cricket fast bowling. Three contact strategies were identified at point of front foot contact. The findings confirmed the view that standard movement templates for coordinating multi-articular actions do not exist in skilled performers (Hristovski et al., 2006). The findings confirmed that degenerate movement systems can be exploited to achieve movement goals with functional, varying movement patterns.

While there were no systematic increases in GRF production from the junior, to the emerging and the national groups in levels of variability, intra-individual variability was evident, particularly in medial and lateral forces. These results provide evidence that individuals utilize movement pattern variability and intentionality to seek and find new performance solutions and cope with performance instabilities (Davids et al., 2006a). These new modes of performance are likely to emerge as novel solutions to performance problems, as developing athletes co-adapt their responses to challenging constraints imposed by opponents and performance environments (Phillips et al., 2010b). Fast bowling is an extremely dynamic skill, where the run-up shapes the delivery stride position and dynamics. The flexible nature of the skill and the open performance environment requires co-adaptation by the performer to constantly seek functional performance adaptations as task solutions. Learning design should encourage learners in team games like cricket to experience variable practice conditions so that they learn to harness inherent variability in order to adapt their actions in dynamic performance environments.

10.3 IMPLICATIONS FOR FUTURE RESEARCH AND LIMITATIONS

The examination of fast bowling presented in this thesis outlines the truly multi-factorial nature of fast bowling expertise. Initially in the qualitative phase of this programme of research (Chapters 3, 4, and 5) all components of expertise were explored. But in the subsequent Chapters the focus moved to the technical and anthropometric (Chapter 6), performance outcome accuracy and adaptability (Chapter 7) and specific movement patterning and variability (Chapter 8) of elite fast bowlers. While this is narrowing was necessary to conduct in depth analyses on each component, examining the additional components identified i.e. psychological skill and characters were outside the scope of this dissertation. The exclusion of the analysis of psychological skill and characteristics from in depth quantitative analysis was a limitation of this programme of work and should be considered for future research.

One possible limitation of the quantification phase of this research was the laboratory-based nature of the studies. Previous research was criticised in Chapter 2, particularly the task demands of the technical tests, for not providing a valid representation of the competitive performance setting (cf. the importance of representative experimental design in studies of human behaviour) (Araujo et al., 2007). Although the image of a batter was present in the current study, it was still a static image. Unfortunately the presence of an actual batsman was not viable due to the requirement for highly accurate performance outcome measures which would have been compromised with the inclusion of a batter in the test design. Incidentally, a pilot test with a batsman who moved away after release so that outcome measures were recorded was criticised by the participant bowlers as ‘unrealistic’. Still the laboratory based studies displayed some correlation with the environmental demands on an individual during a dynamic competitive performance situation. Recent advances in three dimensional motion analysis technologies allowing three dimensional analyses to occur outdoors and during daylight might afford exciting future opportunities for examining expert performance in game-like situations.

The limited sample group could be criticised, the true nature of the expertise in the samples studied in the qualitative and quantitative phases meant that these participants were few in number. It is important to note that the sample was clearly comprehensive and representative of all fast bowling experts (past and present) in Australian cricket. To conduct a comprehensive multidisciplinary analysis, longitudinal team-based research would be required, with the addition of a cohort of fast bowlers who did not make it to the international level but who may have been identified as talented at some stage during development. Insights from the previous chapters would suggest the following areas of interest in a future multidisciplinary examination of such cohorts: (a) movement patterning differences and variability associated with different deliveries types, (b) trunk coordination differences across developmental groups, and (c) personality characteristics across developmental groups in the fast bowling high performance pathway.

10.4 IMPLICATIONS FOR TALENT DEVELOPMENT PROGRAMMES

The examination of fast bowling expertise utilising a multidisciplinary approach highlighted the nonlinear nature of the acquisition of expertise and confirmed the degenerate nature of complex movement systems such as fast bowling. Talent development programmes should encourage learning designs that promote metastability, fostering phase transitions to new, more functional states of organisation as constraints change. The multidisciplinary nature of talent development should remain at the forefront of talent development programmes. For the talented individual to utilise technical adaptability, find new performance solutions and cope with instabilities (meta-stability) requires complementary cognitive attributes (e.g., confidence, sacrifice, dedication, and perseverance). Aligned with this strategy, learning design should also promote variable practice conditions so that fast bowlers learn to harness inherent variability in order to adapt their actions in dynamic performance environments including varying delivery tasks and pitch types.

10.5 CONCLUSION

Fast bowling in cricket can be understood through employing the dynamical systems theoretical framework. However, the complexity of the fast bowling system means that future talent development and research need to adopt multidisciplinary sports science and coaching strategies. Utilising qualitative and quantitative methodologies to examine the acquisition of fast bowling expertise, the importance of degeneracy and adaptability in fast bowling has been highlighted alongside learning designs that promotes dynamic learning environments.

Chapter 11: Bibliography

Abbott, A., Button, C., Pepping, G.-J., & Collins, D. (2005). Unnatural selection: talent identification and development in sport. *Nonlinear Dynamics, Psychology, & Life Sciences, 9*(1), 61-88.

Abbott, A., & Collins, D. (2002). A theoretical and empirical analysis of a 'state of the art' talent identification model. *High Ability Studies, 13*(2), 157-178.

Abernethy, B. (2005). *Sport expertise: From theory to practice.* Paper presented at the Applied Sport Expertise and Learning Workshop, Canberra, Australia.

Abernethy, B., & Wood, J. (2001). Do generalized visual training programmes for sport really work? An experimental investigation. *Journal of Sports Sciences, 19*, 203-222.

Alexander, R. M. (1995). Simple models of human movement. *Applied Mechanical Reviews, 48*, 461–469.

Anderson, D. I. (2002). Do critical periods determine when to initiate sport skill learning? . In F. L. Smoll & R. E. Smith (Eds.), *Children and Youth in Sports: A Biopsychosocial Perspective* (2 ed., pp. pp105-148.). Indianapolis: Brown & Benchmark.

Araújo, D. (2007). Promoting ecologies where performers exhibit expert interactions. *International Journal of Sport Psychology, 38*, 73-77.

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise, 7*(6), 653-676.

Araujo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: Comment on Rogers, Kadar, and Costall (2005). *Ecological Psychology, 19*(1), 69-78.

Araújo, D., Davids, K., & Serpa, S. (2005). An ecological approach to expertise effects in decision-making in a simulated sailing regatta. *Psychology of Sport and Exercise, 6*(6), 671-692.

Bak, P., & Chialvo, D. R. (2001). Adaptive learning by extrenal dynamics and negative feedback. *Physical Review E, 63*(3), 031912.

Baker, J. (2007). Commentary on Ericsson et al. Nature and nurture interact to create expert performers. *High Ability Studies, 18*(1), 57-58.

Baker, J., Côté, J., & Abernethy, B. (2003). Sport-specific practice and the development of expert decision-making in team ball sports. *Journal of Applied Sport Psychology, 15*(1), 12 - 25.

Baker, J., Côté, J., & Deakin, J. (2005). Expertise in ultra-endurance triathletes early sport involvement, training structure, and the theory of deliberate practice. *Journal of Applied Sport Psychology, 17*(1), 64 - 78.

Baker, J., & Davids, K. (2007). Sound and fury, signifying nothing? Future directions in the nature-nurture debate. *International Journal of Sport Psychology, 38*(1), 135-143.

Baker, J., & Horton, S. (2004). A review of primary and secondary influences on sport expertise. *High Ability Studies, 15*(2), 211 - 228.

Bartlett, R. (2006). *Artificial intelligence in sports biomechanics: New dawn or flase hope*. Paper presented at the The 8th Australasian Conference on Mathematics and Computers in Sport, Queensland, Australia.

Bartlett, R., & Robins, M. (2008). Biomechanics of throwing. In Y. Hong & R. Bartlett (Eds.), *Handbook of Biomechanics and Human Movement Science* (pp. 285-295). New York: Routledge.

Bartlett, R. M. (2000). Principles of throwing. In V. M. Zatsiorsky (Ed.), *Biomechanics in Sport: Performance Enhancement & Injury Prevention* (pp. 365-380). Oxford: Blackwell Sciences Ltd.

Bartlett, R. M. (2003). The science and medicine of cricket: an overview and update. *Journal of Sports Sciences, 21*(9), 733-752.

Bartlett, R. M., Stockill, N. P., Elliott, B. C., & Burnett, A. F. (1996). The biomechanics of fast bowling in men's cricket: A review. *Journal of Sports Sciences, 14*(5), 403-424.

Beek, P. J., Jacobs, D. M., Daffertshofer, A., & Huys, R. (2003). Expert performance in sport: Views from the joint perspectives of ecological psychology and dynamical systems theory. In J. L. Starkes & K. A. Ericsson (Eds.), *Expert Performance in Sport* (pp. 321-344). Champaign, IL: Human Kinetics.

Besier, T. F., Sturnieks, D. L., Alderson, J. A., & Lloyd, D. G. (2003). Repeatability of gait data using a functional hip joint centre and a mean helical knee axis. *Journal of Biomechanics, 36*, 1159-1168.

Bloom, B. S. (1985). *Developing Talent in Young People*. New York: Ballantine.

Bradshaw, E. J., Maulder, P. S., & Keogh, J. W. L. (2007). Biological movement variability during the sprint start: Performance enhancement or hindrance? *Sports Biomechanics, 6*(3), 246-260.

Brisson, T. A., & Alain, C. (1996). Should common optimal movement patterns be identified as the criterion to be achieved? *Journal of Motor Behavior, 28*, 211-223.

Burden, A. M., & Bartlett, R. M. (1990). *A kinematic investigation of elite fast and fast-medium cricket bowlers.* Paper presented at the VIIIth International Symposium of the Society of Biomechanics in Sports, Prague.

Burnett, A., Khangure, M., Elliott, B., Foster, D., Marshall, R., & Hardcastle, P. (1996). Thoracolumbar disc degeneration in young fast bowlers in cricket: a follow up study. *Clinical Biomechanics, 6*, 305-310.

Burnett, A. F., Barrett, C., Marshall, R., Elliott, B. C., & Day, R. (1998). Three-dimensional measuremnet of lumbar spine kinematics for fast bowlers in cricket. *Clinical Biomechanics, 13*, 574-583.

Burnett, A. F., Elliott, B. C., & Marshall, R. N. (1995). The effect of a 12-over spell on fast bowling technique in cricket. *Journal of Sports Sciences, 13*, 329-341.

Button, C., MacLeod, M., Sanders, R., & Simon, C. (2003). Examining movement variability in the basketball free-throw action at different skill levels. *Research Quarterly for Exercise and Sport, 74*(3), 257-269.

Campbell, A., Lloyd, D., Alderson, J., & Elliot, B. C. (2008). MRI validation of a new regression model for glenohumeral centre of rotation estimation. *Journal of Biomechanics, 41*(S1), 165.

Campbell, A., Lloyd, D., Alderson, J., & Elliot, B. C. (2009). MRI development and validation of two new predictive methodsof glenohumeral joint centre location identification and comparison with established techniques. *Journal of Biomechanics, 42*, 1527–1532.

Cannane, S. (2009). *First Tests - Great Australian Cricketers and the Backyards that Made Them.* Sydney, NSW: Harper Collins Publishers.

Cappozzo, A. (1984). Gait analysis methodology. *Human Movement Science, 3*, 27–54.

Carter, J. E. L., & Heath, B. (1990). *Somatotyping: Development and Applications*. Cambridge: Cambridge University Press.

Chin, A., Elliott, B., Alderson, J., Lloyd, D., & Foster, D. (2009). The off-break and "doosra": Kinematic variations of elite and sub-elite bowlers in creating ball spin in cricket bowling. *Sports Biomechanics, 8*(3), 187 - 198.

Chow, J. Y., Davids, K., Button, C., & Koh, M. (2008). Coordination changes in a discrete multi-articular action as a function of practice. *Acta Psychologica, 127*(1), 163-176.

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araujo, D. (2006). Nonlinear pedagogy: A constraints-led framework for understanding emergence of game play and movement skills. *Nonlinear Dynamics, Psychology, & Life Sciences, 10*(1), 71-103.

Cobley, S., Baker, J., Wattie, N., & McKenna, J. (2009). Annual age-grouping and athlete development: A meta-analytical review of relative age effects in sport. *Sports Medicine, 39*(3), 235-256.

Coghlan, A. (2003). Elite athletes born to run. *New Scientist, 30*, 4-5.

Coleman, L. J. (2007). Commentary on Ericsson et al. Parts do not make a whole. lumping expertise into one whole. *High Ability Studies, 18*(1), 63-64.

Corbetta, D., & Veriejken, B. (1999). Understanding development and learning of motor coordination in sport: The contribution of dynamical systems theory. *International Journal of Sport Psychology, 30*(44), 507-530.

Côté, J. (1999). The influence of the family in the development of talent in sports. *The Sport Psychologist, 13*, 395-417.

Côté, J., Baker, J., & Abernethy, B. (2007). Practice and play and the development of sport expertise. In G. Tenenbaum & R. Eklund (Eds.), *Handbook of Sport Psychology* (3 ed., pp. 184-202). New Jersey: Wiley.

Côté, J., Ericsson, K. A., & Law, M. P. (2005). Tracing the development of athletes using retrospective interview methods: A proposed interview and validation procedure for reported information. *Journal of Applied Sport Psychology, 17*(1), 1 - 19.

Côté, J., & Hay, J. (2002). Children's involvement in sport: A developmental perspective. In J. M. Silva & D. Stevens (Eds.), *Psychological foundations of sport* (pp. 2nd ed, 484–502). Boston: Merrill.

Côté, J., Macdonald, D. J., Baker, J., & Abernethy, B. (2006). When ‘‘where’’ is more important than ‘‘when’’: Birthplace and birthdate effects on the achievement of sporting expertise. *Journal of Sports Sciences, 24*(10), 1065-1073.

Côté, J., Salmela, J. H., Baria, A., & Russell, S. J. (1993). Organizing and interpreting unstructured qualitative data. *The Sport Psychologist, 7*(2), 127-137.

Cowdrey, M. C. (1974). *Tackle Cricket*. London: Stanley Paul.

Cricket Australia. Laws and Policies Retrieved September 2, 2010, from http://cricket.com.au/laws-policies

Davids, K., & Araújo, D. (2010). The concept of 'organismic asymmetry' in sport science. *Journal of Science & Medicine in Sport, 13*(6), 633-640.

Davids, K., Araújo, D., Button, C., & Renshaw, I. (2007). Degenerate brains, indeterminate behavior and representative tasks: Implications for experimental design in sport psychology research. In G. Tenenbaum & R. Eklund (Eds.), *Handbook of sport psychology (3rd ed.)*. New York: Wiley.

Davids, K., & Baker, J. (2007). Genes, environment and sport performance: Why the nature-nurture dualism is no longer relevant. *Sports Medicine, 37*(11), 961-980.

Davids, K., Bennett, S. J., & Newell, K. (2006a). *Movement system variability*. Champaign: Human Kinetics.

Davids, K., & Button, C. (2004). Variability and constraints in dynamical movement systems. In R.H. Morton (ed.), *Massey University, Proceedings of the Seventh Australasian Conference on Mathematics and Computers in Sport, Palmerston North, N.Z., Massey University, 2004, p.1-12.* Australia.

Davids, K., Button, C., Araujo, D., Renshaw, I., & Hristovski, R. (2006b). Movement models from sports provide representative task constraints for studying adaptive behavior in human movement systems. *Adaptive Behaviour, 14*(1), 73-94. doi: 10.1177/105971230601400103

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of Skill Acquisition: A Constraints-Led Approach*. Champaign, Il: Human Kinetics.

Davids, K., Glazier, P., Araujo, D., & Bartlett, R. (2003). Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. *Sports Medicine, 33*(4), 245-260.

Davids, K., Renshaw, I., & Glazier, P. (2005). Movement models from sports reveal fundamental insights into coordination processes. *Exercise and Sport Sciences Review, 33*(1), 36-42.

Davids, K. W., & Glazier, P. S. (2010). Deconstructing neurobiological coordination. *Exercise and Sport Sciences Reviews, 38*(2), 86-90.

Della Croce, U., Cappozzo, A., & Kerrigan, D. (1999). Pelvis and lower limb anatomical landmark calibration precision and its propagation to bone geometry and joint angles. *Medical and Biological Engineering and Computing, 37*(1), 155-161.

Dempsey, A. R., Lloyd, D., Elliot, B. C., Steele, J., Munro, B., & Russo, K. A. (2007). The effect of technique change on knee loads during sidestep cutting. *Medicine & Science in Sports & Exercise, 39*(10), 1765–1773.

Dennis, R., Farhart, R., Goumas, C., & Orchard, J. (2003). Bowling workload and the risk of injury in elite cricket fast bowlers. *Journal of Science and Medicine in Sport, 6*(3), 359-367.

Dennis, R., Finch, C., Elliott, B., & McIntosh, A. (2006). Using field-based screening measures to determine the risk of injury to adolescent and adult cricket fast bowlers. *Journal of Science & Medicine in Sport, 9*(6 Suppl), 25-25.

Dennis, R., Finch, C., & Farhart, P. (2005). Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *British Journal of Sports Medicine, 39*, 843-846.

Devlin, L. H., Fraser, S. F., Barras, N. S., & Hawley, J. A. (2001). Moderate levels of hypohydration impairs bowling accuracy but not bowling velocity in skilled cricket players. *Journal of Science and Medicine in Sport, 4*(2), 179-187.

Drinkwater, D., & Ross, W. D. (1980). Anthropometric fractionation of body mass. In W. Ostyn, G. Buenen & J. Simons (Eds.), *Kinanthropometry* (pp. 177-188). Baltimore: University Park Press.

Duchon, A. P., Kaelbling, L. P., & Warren, W. H. (1998). Ecological robotics. *Adaptive Behavior, 6*(3-4), 473-507.

Duffield, R., Carney, M., & Karppinen, S. (2008). Physiological responses and bowling performance during repeated spells of medium-fast bowling. *Journal of Sports Sciences, 27*(1), 27–35.

Dunwoody, P. T. (2006). The neglect of the environment by cognitive psychology. *Journal of Theoretical and Philosophical Psychology, 26*, 139-153.

Dupuy, M. A., Mottet, D., & Ripoll, H. (2000). The regulation of release parameters in underarm precision throwing. *Journal of Sports Sciences, 18*(6), 375 — 382.

Durand-Bush, N., & Salmela, J. (2001). The development of talent in sport. In R. N. Singer, H. A. Hausenblas & C. M. Janelle (Eds.), *Handbook of Sport Psychology* (Second ed., pp. 269-289). New York, USA: John Wiley & Sons, Inc.

Durand-Bush, N., & Salmela, J. (2002). The development and maintenance of expert athletic performance: Perceptions of world and olympic champions. *Journal of Applied Sport Psychology, 14*(3), 154-171.

Edelman, G. M., & Gally, J. A. (2001). *Degeneracy and complexity in biological systems.* Paper presented at the National Academy of Sciences, USA.

Elferink-Gemser, M. T., Visscher, C., Lemmink, K. A. P. M., & Mulder, T. (2007). Multidimensional performance characteristics and standard of performance in talented youth field hockey players: A longitudinal study. *Journal of Sports Sciences, 25*(4), 481 - 489.

Elliott, B., & Alderson, J. (2007). Laboratory versus field testing in cricket bowling: A review of current and past practice in modelling techniques. *Sports Biomechanics, 6*(1), 99 - 108.

Elliott, B., Foster, D., & Gray, S. (1986). Biomechanical and physical factors influencing fast bowling. *Australian Journal of Science & Medicine in Sport, 18*(1), 16-21.

Elliott, B., Foster, D., John, D., Ackland, T., & Fitch, K. (1989). Biomechanical correlates of fast bowling and back injuries in cricket: A prospective study. *Journal of Biomechanics, 22*(10), 1007-1234.

Elliott, B., & Khangure, M. (2002). Disc degeneration and fast bowling in cricket: an intervention study. *Medicine & Science in Sports & Exercise, 34*(11), 1714-1718.

Elliott, B., Plunkett, D., & Alderson, J. (2005). The effect of altered pitch length on performance and technique in junior fast bowlers. *Journal of Sports Sciences, 23*(7), 661-667.

Elliott, B., Wallis, R., Sakurai, S., Lloyd, D., & Besier, T. (2002). The measurement of shoulder alignment in cricket fast bowling. *Journal of Sports Sciences, 20*, 507-510.

Elliott, B. C. (2000). Back injuries and the fast bowler in cricket. *Journal of Sports Sciences, 18*, 983-991.

Elliott, B. C., Alderson, J. A., & Denver, E. R. (2007). System and modelling errors in motion analysis: Implications for the measurement of the elbow angle in cricket bowling. *Journal of Biomechanics, 40*(12), 2679-2685.

Elliott, B. C., Davis, J. W., Khangure, M. S., Hardcastle, P., & Foster, D. (1993). Disc degeneration and the young fast bowler in cricket. *Clinical Biomechanics, 8*(5), 227-234.

Elliott, B. C., Hardcastle, P. H., Burnett, A. F., & Foster, D. H. (1992). The influence of fast bowling and physical factors on radiologic features in high performance young fast bowlers. *Sports Medicine, Training & Rehabilitation, 3*(2), 113-130.

Ericsson, K. A. (1996). *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games*. Mahwah, NJ: Lawrence Erlbaum Associates.

Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363-406.

Ericsson, K. A., & Smith, J. (1991). *Toward a general theory of expertise: Prospects and limits*. New York: Cambridge University Press.

Escamilla, R. F., Speer, K. P., Fleisig, G. S., Barrentine, S. W., & Andrews, J. R. (2000). Effects of throwing overweight and underweight baseballs on throwing velocity and accuracy. *Sports Medicine, 29*(4), 259-272.

Falk, B., Lidor, R., Lander, Y., & Lang, B. (2004). Talent identification and early development of elite water-polo players: a 2-year follow-up study. *Journal of Sports Sciences, 22*(4), 347 - 355.

Ferdinand, R., Marshall, R., & Kersting, U. (2010). Centre of mass kinematics of fast bowling in cricket. *Sports Biomechanics, 9*(3), 139-152.

Fleisig, G. S., Barrentine, S. W., & Escamilla, R. F. (1996). Biomechanics of overhand throwing with implications for injuries. *Sports Medicine, 21*, 421–437.

Foster, D., John, D., Elliott, B., Ackland, T., & Fitch, K. (1989). Back injuries to fast bowlers in cricket: a prospective study. *British Journal of Sports Medicine, 23*(3), 150-154.

Foster, D. H., & John, D. (1987). The inter-relationships between fast bowling techniques, physical characteristics and physiological capacities of junior fast bowlers, to injuries in cricket *National Sports Research Program. Applied Sports Research Program.* Nedlands, W.A.; Australia: Department of Human Movement and Recreation Studies, University of Western Australia.

Freeston, J., Ferdinands, R., & Rooney, K. (2007). Throwing velocity and accuracy in elite and sub-elite cricket players: A descriptive study. *European Journal of Sport Science, 7*(4), 231 - 237.

Gabbett, T., Georgieff, B., & Domrow, N. (2007). The use of physiological, anthropometric, and skill data to predict selection in a talent-identified junior volleyball squad. *Journal of Sports Sciences, 25*(12), 1337-1344.

Gagné, F. (2004). Transforming gifts into talents: the DMGT as a developmental theory. *High Ability Studies, 15*(2), 119-147.

Giakas, G., & Baltzopoulos, V. (1997). Time and frequency domain analysis of ground reaction forces during walking: an investigation of variability and symmetry. *Gait Posture, 5*, 189-197.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research.* New York Aldine.

Glazier, P., Paradisis, G., & Cooper, S. (2000). Anthropometric and kinematic influences on release speed in men's fast-medium bowling. *Journal of Sports Sciences, 18*(12), 1013-1021.

Glazier, P. S. (2010). Is the 'crunch factor' an important consideration in the aetiology of lumbar spine pathology in cricket fast bowlers? *Sports Medicine, 40*(10), 809-815.

Glazier, P. S., & Davids, K. (2009a). Constraints on the complete optimization of human motion. *Sports Medicine, 39*(1), 15-28.

Glazier, P. S., & Davids, K. (2009b). The problem of measurement indeterminacy in complex neurobiological movement systems. *Journal of Biomechanics, 42*(16), 2694-2696.

Glazier, P. S., Davids, K., & Bartlett, R. M. (2003). Dynamical systems theory: a relevant framework for performance-orientated sports biomechanics research. *Sportscience, 7*.

Gould, D., Dieffenbach, K., & Moffett, A. (2002). Psychological characteristics and their development in olympics champions. *Journal of Applied Sport Psychology, 14*(3), 172-204.

Gould, D., Eklund, R. C., & Jackson, S. (1993). Coping strategies used by U.S. olympic wrestlers. *Research Quarterly for Exercise and Sport, 64*, 83-93.

Greenspan, R. J. (2001). The flexible genome. *Nature Genetics, 2*, 383-387.

Gregory, P. L., Batt, M. E., & Wallace, W. A. (2004). Is risk of fast bowling injury in cricketers greatest in those who bowl most? A cohort of young English fast bowlers. *British Journal of Sports Medicine, 38*(2), 125-128.

Grood, E. S., & Suntay, W. J. (1983). A joint coordinate system for the clinical description of three-dimensional motions: Application to the knee. *Journal of Biomechanical Engineering, 105*, 136–144.

Hamill, J., van Emmerik, R. E. A., Heiderscheit, B. C., & Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics, 14*(5), 297-308.

Hammond, K. R., & Bateman, R. A. (2009). Sport psychology as an instance of ecological psychology. *International Journal of Sport Psychology, 40*(1), 38-49.

Hancock, G. R., Butler, M. S., & Fishman, M. G. (1995). On the problem of two-dimensional error scores: measures and analyses of accuracy, bias, and consistency. *Journal of Motor Behavior, 27*(3), 241-250.

Handford, C., Davids, K., Bennett, S., & Button, C. (1997). Skill acquisition in sport: Some applications of an evolving practice ecology. *Journal of Sports Sciences, 15*(6), 621-640.

Hanley, B., Lloyd, R., & Bissas, A. (2005). Relationships between ball release velocity and kinematic variables in fast bowling in cricket. *Journal of Sports Sciences, 23*(2), 112-113.

Helsen, W. F., Hodges, N. J., van Winckel, J., & Starkes, J. L. (2000). The roles of talent, physical precocity and practice in the development of soccer expertise. *Journal of Sports Sciences, 18*, 727-736.

Helsen, W. F., Starkes, J. L., & Hodges, N. J. (1998). Team sports and the theory of deliberate practice. *Journal of Sport & Exercise Psychology, 20*, 12-34.

Hoare, D. G., & Warr, C. R. (2000). Talent identification and women's soccer: An Australian experience. *Journal of Sports Sciences, 18*, 751-758.

Hodges, N. J., & Starkes, J. L. (1996). Wrestling with the nature of expertise: A sport specific test of Ericsson, Krampe, and Tesch-Römers (1993) theory of deliberate practice. *International Journal of Sport Psychology, 27*, 400-424.

Holt, N. L., & Dunn, J. G. H. (2004). Toward a Grounded Theory of the psychosocial competencies and environmental conditions associated with soccer success. *Journal of Applied Sport Psychology, 16*(3), 199 - 219.

Holyoak, K. J. (1994). Symbolic connectionism: Toward third-generation theories of expertise. In K. A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp. 301–336). New York: Cambridge University Press.

Hopkins, W. G. (2000a). Measures of reliability in sports medicine and science. *Sports Medicine, 30*(1), 1-12.

Hopkins, W. G. (2000b). A new view of statistics, from http://www.sportsci.org/resource/stats/

Howe, M. J. A., Davidson, J. W., & Sloboda, J. A. (1998). Innate talents: Reality or myth? *Behavioral and Brain Sciences, 21*(3), 399-407.

Hristovski, R., Davids, K. W., & Araujo, D. (2006). Affordance-controlled bifurcations of action patterns in martial arts. *Nonlinear Dynamics, Psychology and the Life Sciences, 10*(4), 409-444.

Hurrion, P. D., Dyson, R., & Hale, T. (2000). Simultaneous measurement of back and front foot ground reaction forces during the same delivery stride of the fast-medium bowler. *Journal of Sports Sciences, 18*, 993-997.

Hyllegard, R., Radlo, S. J., & Early, D. (2001). Attribution of athletic expertise by college coaches. *Perceptual and Motor Skills, 92*(1), 193-207.

Jaitner, T., Mendoza, L., & Schollhorn, W. I. (2001). Analysis of the long jump technique in the transition from approach to takeoff based on time-continuous kinematic data. *European Journal of Sport Science, 1*(5), 1-12.

Johnson, M. B., Edmonds, W. A., Jain, S., & Cavazos, J. (2010). Conceptualizing the systemic interplay of athlete development. *International Journal of Sport Psychology, 41*(1), 1-23.

Kærns, M., Elston, T. C., Blake, W., & Collins, J. J. (2005). Stochasticity in gene expression: From theories to phenotypes. *Nature Reviews Genetics, 6*, 451-464.

Kauffman, S. (1995). *At home in the universe: The search for laws of complexity.* London: Viking.

Kauffman, S. A. (1993). *The Origins of Order: Self-organization and Selection in Evolution*. New York: Oxford University Press.

Kelso, J. A. (1991). Anticipatory dynamical systems, intrinsic pattern dynamics and skill learning. *Human Movement Science, 10*, 93-111.

Korhonen, M. T., Suominen, H., Viitasalo, J. T., Liikavainio, T., Alen, M., & Mero, a. A. (2010). Variability and symmetry of force platform variables in maximum-speed running in young and older athletes. *Journal of Applied Biomechanics, 26*, 357-366.

Liu, Y.-T., Mayer-Kress, G., & Newell, K. M. (2006). Qualitative and quantitative change in the dynamics of motor learning. *Journal of Experimental Psychology: Human Perception and Performance, 32*(2), 380-393.

Lloyd, D. G., Alderson, J., & Elliott, B. (2000). An upper limb kinematic model for the examination of cricket bowling: A case study of Mutiah Muralitharan. *Journal of Sports Sciences, 18*, 975-982.

Manal, K., Chang, C.-C., Hamill, J., & Stanhope, S. J. (2005). A three-dimensional data visualization technique for reporting movement pattern deviations. *Journal of Biomechanics, 38*(11), 2151-2156.

Martindale, R. J. J., Collins, D., & Daubney, J. (2005). Talent development: A guide for practice and research within sport. *Quest, 57*, 353-375.

McGarry, T., Anderson, D. I., Wallace, S. A., Hughes, M. D., & Franks, I. M. (2002). Sport competition as a dynamical self-organizing system. *Journal of Sports Sciences, 20*, 771-781.

Mehta, R. D. (2000). Cricket ball aerodynamics: myth versus science. In A. J. Subic & S. J. Hakke (Eds.), *The Engineering of Sport Research, Development and Innovation* (pp. 153-167). Oxford: Blackwell Science.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis (2nd ed.).* Thousand Oaks, CA: Sage.

Miller, R. H., Chang, R., Baird, J. L., van Emmerik, R. E., & Hamill, J. (2010). Variability in kinematic coupling assessed by vector coding and continuous relative phase. *Journal of Biomechanics, 43*(13), 2554-2560.

Morgan, T. K., & Giacobbi, P. R. (2006). Toward two grounded theories of the talent development and social support process of highly successful collegiate athletes. *The Sport Psychologist, 20*(3), 295-313.

Morris, T. (2000). Psychological characteristics and talent identification in soccer. *Journal of Sports Sciences, 18*(9), 715-726.

Morriss, C., & Bartlett, R. (1996). Biomechanical factors critical for performance in the men's javelin throw. *Sports Medicine, 21*(6), 438-446.

Morriss, C. J., Bartlett, R. M., & Fowler, N. (1997). Biomechanical analysis of the men’s javelin throw at the 1995 world championships in athletics. *New Studies in Athletics, 12*, 32-41.

Müller, S., & Abernethy, B. (2006). Batting with occluded vision: An in situ examination of the information pick-up and interceptive skills of high- and low-skilled cricket batsmen. . *Journal of Science and Medicine in Sport, 9*, 446-458.

Mullineaux, D. R., Bartlett, R. M., & Bennett, S. (2001). Research design and statistics in biomechanics and motor control. *Journal of Sports Sciences, 19*, 739-760.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor skill acquisition in children: Aspects of coordination and control* (pp. 341-360). Boston, MA: Martinies NIJHOS.

Newell, K. M., & Corcos, D. M. (1993). *Variability and Motor Control*. Champaign, IL: Human Kinetics.

Newell, K. M., Liu, Y.-T., & Mayer-Kress, G. (2001). Time scales in motor learning and development. *Psychological Review, 108*(1), 57-82.

Newell, K. M., & Slifkin, A. B. (1998). The nature of movement variability. In J. J. Piek (Ed.), *Motor Behavior and Human Skill*. Champaign, IL: Human Kinetics.

Nigg, B. M., & Anton, M. (1995). Energy aspects for elastic and viscous shoe soles and playing surfaces. *Medicine and Science in Sports and Exercise, 27*, 92–97.

Obler, L. K., & Fein, D. (1988). *The Exceptional Brain: Neuropsychology of Talent and Special Abilities*. New York: Guilford Press.

Perkins-Ceccato, N., Passmore, S. R., & Lee, T. D. (2003). Effects of focus of attention depend on golfers' skill. *Journal of Sports Sciences 21*(8), 593–600.

Phillips, E., Davids, K., Renshaw, I., & Portus, M. (2010a). The development of fast bowling experts in Australian cricket. *Talent Development & Excellence, 2*(2), 137–148.

Phillips, E., Davids, K., Renshaw, I., & Portus, M. (2010b). Expert performance in sport and the dynamics of talent development. *Sports Medicine, 40*(4), 271-283.

Portus, M. (2001). *Relationships between cricket fast bowling technique, trunk injuries and ball release speed.* Paper presented at the XIXth International Symposium on Biomechanics in Sports, San Francisco, CA.

Portus, M. (2006). *Technique mechanisms involved in lumbar spine injuries and ball release speed in cricket fast bowlers.* Ph.D., University of Western Australia, Perth.

Portus, M., Farrow, D., Elliott, B., & Mason, B. (2003). Development of evidence based coaching guidelines to reduce the risk of lower back injury in cricket fast bowlers. *Journal of Science & Medicine in Sport, 6*(Supplement), 82-82.

Portus, M., Mason, B., Elliott, B., Pfitzner, M., & Done, R. (2004). Technique factors related to ball release speed and trunk injuries in high performance Cricket fast bowlers. *Sports Biomechanics, 3*(2), 263-284.

Portus, M. R., Galloway, H., Elliott, B. C., & Lloyd, D. (2007). Pathomechanics of lower back injuries in junior and senior fast bowlers: a prospective study. *Sport Health, 25*(2), 8-9.

Portus, M. R., Rosemond, C. D., & Rath, D. A. (2006). Fast bowling arm actions and the illegal delivery law in men's high performance cricket matches. *Sports Biomechanics, 5*(2), 215 - 230.

Portus, M. R., Sinclair, P. J., Burke, S. T., Moore, D. J. A., & Farhart, P. J. (2000). Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sports Sciences, 18*(12), 999-1011.

Pyne, D. B., Duthie, G., Saunders, P. U., Petersen, C. A., & Portus, M. R. (2006). Anthropometric and strength correlates of fast bowling speed in junior and senior cricketers. *Journal of Strength & Conditioning Research, 20*(3), 620-626.

Rankinen, T., Bray, M. S., Hagberg, J. M., Perusse, L., Roth, S. M., Wolfarth, B., et al. (2006). The human gene map for performance and health-related fitness phenotypes: the 2005 update. *Medicine and Science in Sports and Exercise, 38*(11), 1863-1888.

Ranson, C. A., Burnett, A. F., King, M., Patel, N., & Sullivan, P. B. (2008). The relationship between bowling action classification and three-dimensional lower trunk motion in fast bowlers in cricket. *Journal of Sports Sciences, 26*(3), 267 - 276.

Reilly, T., Williams, A. M., Nevill, A., & Franks, A. (2000). A multidisciplinary approach to talent identification in soccer. *Journal of Sports Sciences, 18*, 695-702.

Renshaw, I., Davids, K., Shuttleworth, R., & Chow, J. Y. (2009). Insights from ecological psychology and dynamical systems theory can underpin a philosophy of coaching. *International Journal of Sport Psychology, 40*(4), 540-602.

Robinson, R. O., Herzog, W., & Nigg, B. M. (1987). Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *Journal of Manipulative and Physiological Therapeutics, 10*, 172-176.

Sachlikidis, A., & Salter, C. W. (2007). A biomechanical comparison of dominant and non-dominant arm throws for speed and accuracy. *Sports Biomechanics, 6*(3), 334 - 344

Salter, C. W., Sinclair, P. J., & Portus, M. R. (2007). The associations between fast bowling technique and ball release speed: A pilot study of the within-bowler and between-bowler approaches. *Journal of Sports Sciences, 25*(11), 1279 - 1285.

Schöllhorn, W. I. (2003). Coordination dynamics and its consequences on sport. *International Journal of Computer Science in Sport, 2*, 40-46.

Simonton, D. K. (1999). Talent and its development: An emergenic and epigenetic model. *Psychological Review, 106*(3), 435-457.

Simonton, D. K. (2007). Commentary on Ericsson et al. Talent and expertise: the empirical evidence for genetic endowment. *High Ability Studies, 18*(1), 83-84.

Singer, R., & Janelle, C. (1999). Determining sport expertise: From genes to supremes. *International Journal of Sport Psychology, 30*, 117-150.

Soberlak, P., & Côté, J. (2003). The developmental activities of elite ice hockey players. *Journal of Applied Sport Psychology, 15*(1), 41-49.

Starkes, J. (2000). The road to expertise: is practice the only determinant? *International Journal of Sport Psychology, 31*(4), 431-451.

Stockill, N. P., & Bartlett, R. M. (1992). A three dimensional cinematographical analysis of the techniques of international and English country cricket fast bowlers. *The 10th Symposium of the International Society of Biomechanics in Sports* 52-55. .

Stockill, N. P., & Bartlett, R. M. (1994). An investigation into the important determinants of ball release speed in junior and senior international cricket bowlers. *Journal of Sports Sciences, 12*, 177-178.

Stodden, D. F., Fleisig, G. S., McLean, S. P., & Andrews, J. R. (2005). Relationship of biomechanical factors to baseball pitching velocity: Within pitcher variation. *Journal of Applied Biomechanics, 21*(1), 44-56.

Stodden, D. F., Fleisig, G. S., McLean, S. P., Lyman, S. L., & Andrews, J. R. (2001). Relationship of pelvis and upper torso kinematics to pitched baseball velocity. *Journal of Applied Biomechanics, 17*(2), 164-172.

Strauss, A., & Corbin, J. (1998). *Basics in Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (2nd ed.). London: Sage Publications.

Stretch, R. (1991). Anthropometric profile and body composition changes in first-class cricketers. *South African Journal for Research in Sport, Physical Education and Recreation, 14*(2), 57-64.

Stretch, R. (2001). Epidemiology of cricket injuries. *International SportMed Journal, 2*(2), 1-7.

Stubbe, J. H., Boomsma, D. L., & De Geus, E. J. C. (2005). Sport participation during adolescence: A shift from environmental to genetic factors. *Medicine and Science in Sports and Exercise, 37*, 563-570.

Stuelcken, M., Ferdinand, R. E. D., & Sinclair, P. (2010). Three-dimensional trunk kinematics and low back pain in elite female fast bowlers. *Journal of Applied Biomechanics, 26*(1), 52-61.

Stuelcken, M., Pyne, D., & Sinclair, P. (2007). Anthropometric characteristics of elite cricket fast bowlers. *Journal of Sports Sciences, 25*(14), 1587-1597.

Stuelcken, M. C., & Sinclair, P. J. (2009). A pilot study of the front foot ground reaction forces in elite female fast bowlers. *Journal of Science and Medicine in Sport, 12*(2), 258-261.

Sumpter, D. J. T. (2006). The principles of collective animal behaviour. *Philosophical Transactions of the Royal Society B: Biological Sciences, 361*, 5-22.

Tesch, R. (1990). *Qualitative Research: Analysis Types and Software Tools.* New York: Falmer.

Thelen, E. (1995). Motor development: A new synthesis. *American Psychologist, 50*(2), 79-95.

Thelen, E., & Smith, L. B. (1994). *A Dynamics Systems Approach to The Development of Cognition and Action*. Cambridge, MA: MIT Press.

Tottenham, L. S., & Saucier, D. M. (2004). Throwing accuracy during prism adaptation: male advantage for throwing accuracy is independent of prism adaptation rate. *Perceptual and Motor Skills, 98*(3), 1449-1455.

Vaeyens, R., Güllich, A., Warr, C. R., & Philippaerts, R. (2009). Talent identification and promotion programmes of Olympic athletes. *Journal of Sport Sciences, 27*(13), 1367–1380.

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent identification and development programmes in sport: Current models and future directions. *Sports Medicine, 38*(9), 703-714.

van den Tillaar, R., & Ettema, G. (2006). A comparison between novice and experts of the velocity-accuracy trade off in overarm throwing. *Perceptual and Motor Skills, 103*(2), 503-514.

van der Kamp, J., Rivas, F., van Doorn, H., & Savelsbergh, G. J. P. (2008). Ventral and dorsal system contribution to visual anticipation in fast ball sports. *International Journal of Sport Psychology, 39*, 100-130.

van Emmerik, R. E. A., Hamill, J., & McDermott, W. J. (2005). Variability and coordinative function in human gait. *Quest, 57*, 102-123.

van Emmerik, R. E. A., & van Wegen, E. E. H. (2002). On the functional aspects of variability in postural control. *Exercise & Sport Sciences Reviews, 30*(4), 177-183.

Weissensteiner, J., Abernethy, B., & Farrow, D. (2009). Towards the development of a conceptual model of expertise in cricket batting: A grounded theory approach. *Journal of Applied Sport Psychology, 21*, 276–292.

Weissensteiner, J., Abernethy, B., Farrow, D., & Müller, S. (2008). The development of anticipation: A cross-sectional examination of the practice experiences contributing to skill in cricket batting. *Journal of Sport & Exercise Psychology, 30*, 1-23.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual Perception and Action in Sport*. London: Routledge, Taylor, Francis.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science, 24*, 283-307.

Williams, A. M., & Ward, P. (2007). Perceptual-cognitive expertise in sport: exploring new horizons. In G. Tenenabum & R. Eklund (Eds.), *Handbook of sport psychology* (3 ed., pp. 203-223). New York: John Wiley & Sons.

Winter, D. (1990). *Biomechanics and Motor Control of Human Movement. 2nd Edition*. New York: John Wiley & Sons, Inc.

Wolstencroft, E. (2002). Talent identification and development: An academic review. Edinburgh: sportscotland.

Woltring, H. J. (1994). 3-D attitude representation of human joints: A standardization proposal. *Journal of Biomechanics, 27*(12), 1399-1414.

Woolmer, B., Noakes, T., & Moffett, H. (2008). *Bob Woolmer's Art and Science of Cricket*. Cape Town, South Africa: Random House Struik.

Wormgoor, S., Harden, L., & McKinon, W. (2010). Anthropometric, biomechanical, and isokinetic strength predictors of ball release speed in high-performance cricket fast bowlers. *Journal of Sports Sciences, 28*(9), 957 - 965.

Yang, N., MacArthur, D. G., Gulbin, J. P., Hahn, A. G., Beggs, A. H., Easteal, S., et al. (2003). ACTN3 Genotype is associated with human elite athletic performance. *The American Journal of Human Genetics, 73*(3), 627-631.

Young, B. W., & Salmella, J. H. (2001). *Diary analyses of practice and recovery activities for elite and intermediate middle distance runners.* Paper presented at the International Society of Sport Psychology 10th World Congress of Sport Psychology, Skiathos Island: Greece.

Zanone, P. G., & Kelso, J. A. S. (1992). Learning and transfer as dynamical paradigms for behavioral change. *Advances in psychology, 87*(3), 563-582.

Appendices

APPENDIX A: STUDY ONE AND TWO: PARTICIPANT INFORMATION SHEET AND CONSENT FORM

PARTICIPANT INFORMATION for QUT RESEARCH PROJECT

A Qualitative Examination of The Development of Fast Bowling Expertise

Research Team Contacts	
Elissa Phillips PhD Candidate	Ian Renshaw Senior Lecturer
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Description

This project is being undertaken as part of a PhD project for Elissa Phillips. The project is funded by Cricket Australia, Australian Institute of Sport and QUT. The funding bodies will have access to the data obtained during the project.

The purpose of this project is to identify key contributing factors to the development of fast bowling expertise. This will be achieved by a qualitative examination of former and present expert fast bowlers and international coaches. The interviews will aim to establish current knowledge and opinions on best practice in fast bowling development.

The research team requests your assistance because you have been identified as a former or present expert fast bowler, international coach or parent of an expert bower. Due to the small number of people internationally who reach such status your assistance is valued in our search for experiential knowledge relating to fundamental factors and skill components that contribute to fast bowling expertise.

Participation

Your participation in this project is voluntary. If you do agree to participate, you can withdraw from participation at any time during the project without comment or penalty. Your decision to participate will in no way impact upon your current or future relationship with QUT (for example your grades), Australian Institute of Sport or with Cricket Australia (for example team selection).

The project involves the submission of anonymous (non-identifiable) material, it should be noted that it will not be possible to withdraw, once they have been submitted.

Your participation will involve an interview and three questionnaires. It is expected the interviews will last between 1-3 hours.

If you choose to participate in this research you will be asked to supply the name of one coach and/or parent whom may be contacted to verify interview details. You will be contacted by telephone and informed of the research aims and study background and asked if you have any questions. Interviews dates will then be finalised and take place in person where possible. You will be asked of your preferred interview venue, if you would like to meet at your own home or in a pre-booked state cricket meeting room. Where the researcher is unable to fly to your location, the interview will be held via telephone.

All interviews will be conducted by the main research and tape recorded.

Expected benefits

It is expected that this project will not benefit you directly. However, it may benefit Australian

Cricket and fast bowlers of the future. The results from this project will be used by Cricket Australia to improve the current fast bowling development pathway, talent development and coaching guidelines.

Risks

There are no risks beyond normal day-to-day living associated with your participation in this project.

QUT provides for limited free counselling for research participants of QUT projects, who may experience some distress as a result of their participation in the research. Should you wish to access this service please contact the Clinic Receptionist of the QUT Psychology Clinic on 3138 4578. Please indicate to the receptionist that you are a research participant.

Confidentiality

All comments and responses are anonymous and will be treated confidentially. The names of individual persons are not required in any of the responses.

Interviews comments will be verified by the participants prior to final inclusion. Audio recordings will be kept in locked storage for five years after the contents have been transcribed and will not be used for any other purpose (e.g. as an instructional aide). They will not be accessible to anyone outside the research team. It should be noted it is not possible to participate in the project without the interview being recorded.

Consent to Participate

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

Questions / further information about the project

Please contact the research team members named above to have any questions answered or if you require further information about the project.

Concerns / complaints regarding the conduct of the project

QUT is committed to researcher integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Officer on 3138 2340 or ethicscontact@qut.edu.au. The Research Ethics Officer is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

QUT CONSENT FORM for QUT RESEARCH PROJECT

A Qualitative Examination of The Development of Fast Bowling Expertise

Statement of consent

By signing below, you are indicating that you:

- have read and understood the information document regarding this project
- have had any questions answered to your satisfaction
- understand that if you have any additional questions you can contact the research team
- understand that you are free to withdraw at any time, without comment or penalty
- understand that you can contact the Research Ethics Officer on 3138 2340 or ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project
- agree to participate in the project
- understand that the project will include audio and/or video recording

Name ....

Signature ....

Date .... / .... / ....

APPENDIX B: STUDY THREE, FOUR AND FIVE: PARTICIPANT INFORMATION SHEET AND CONSENT FORM

PARTICIPANT INFORMATION for QUT RESEARCH PROJECT

Coordination and Adaptability of Expert Fast Bowlers

Research Team Contacts

Elissa Phillips PhD Candidate 02 6214 7329 elissa.phillips@ausport.gov.au	Keith Davids Head of School 07 3138 8744 k.davids@qut.edu.au

Description

This project is being undertaken as part of a PhD project for Elissa Phillips. The project is funded by Cricket Australia, Australian Institute of Sport and QUT. The funding bodies will have access to the data obtained during the project.

The purpose of this project is to profile the coordination of expert fast bowlers across the developmental spectrum, and gain an insight into the adaptability of coordination patterns across several delivery lengths. This will be achieved by a quantitative examination of biomechanics and anthropometry of fast bowlers in the Cricket Australia High Performance Pathway.

The research team requests your assistance because you have been identified as a fast bowler in the Cricket Australia Pace Program. Due to the small number of people in these squads your assistance is valued in our search for greater understanding of expertise skill acquisition and coordination patterns in fast bowling.

Participation

Your participation in this project is voluntary. If you do agree to participate, you can withdraw from participation at any time during the project without comment or penalty. Your decision to participate will in no way impact upon your current or future relationship with QUT (for example your grades), Australian Institute of Sport or with Cricket Australia (for example team selection).

Your participation will involve performance of fast bowling skills test, consisting of three different delivery conditions. Video recordings from multiple cameras will be made to analyse movement dynamics. The system used involves a set of reflective markers which are fixed to body landmarks using a mild adhesive tape. Only the motion of the markers is picked up by the camera system. Anthropometrical measures (including; height, body mass, skinfolds, diameters and girth measurements) will be undertaken, it is expected this will last between 2-3 hours. The research will be conducted in Canberra.

If you choose to participate in this research, you will be contacted by telephone and informed of the research aims and study background and asked if you have any questions. Testing dates will then be finalised and your transportation to Canberra organised by members of the research team.

Expected benefits

It is not expected that this project be of benefit you directly. You will receive general feedback on your results from sports science and coaching staff. The project may be of benefit to the Cricket Australia community. The results from this project will be used by Cricket Australia to improve the current fast bowling development pathway, talent development and coaching guidelines.

Risks

There are no risks beyond normal day-to-day living and cricket training associated with your participation in this project. However, staff trained in first aid will be at close hand in case of physical injury or an emergency.

Confidentiality

All data recorder are non identifiable Video and three dimensional data will be kept in locked storage for five years and will not be used for any other purpose (e.g. as an instructional aide). They will not be accessible to anyone outside the research team. It should be noted it is not possible to participate in the project without three dimensional data being recorded.

Consent to Participate

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

Questions / further information about the project

Please contact the research team members named above to have any questions answered or if you require further information about the project.

Concerns / complaints regarding the conduct of the project

QUT is committed to researcher integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Officer on 3138 2340 or ethicscontact@qut.edu.au. The Research Ethics Officer is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

CONSENT FORM for QUT RESEARCH PROJECT

Coordination and Adaptability of Expert Fast Bowlers

Statement of consent

By signing below, you are indicating that you:

- have read and understood the information document regarding this project
- have had any questions answered to your satisfaction
- understand that if you have any additional questions you can contact the research team
- understand that you are free to withdraw at any time, without comment or penalty
- understand that you can contact the Research Ethics Officer on 3138 2340 or ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project
- agree to participate in the project
- for projects involving minors: have discussed the project with your child and their requirements if participating
- understand that the project will include audio and/or video recording

Name

Signature

Date / /

Statement of Child consent

Your parent or guardian has given their permission for you to be involved in this research project. This form is to seek your agreement to be involved.

By signing below, you are indicating that the project has been discussed with you and you agree to participate in the project.

Name

Signature

Date / /