Utilising Representative Learning Design to Underpin the Measurement and Development of Cricket Batting Expertise

by

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ABSTRACT

This thesis explored the skills underpinning expertise during an interceptive timing task through the lens of a representative learning design approach. This was achieved by: (1) examining what skilful behaviours cricket batting experts perceive to be critical to performance; (2) developing a representative skills assessment based on the batting experts perceptions and extant scientific literature; and (3) assessing the efficacy of two different practice approaches on developing the aforementioned skilful behaviours underpinning expertise.

In study 1, interviews with expert cricket coaches, whom were formally highly skilled batters, revealed the multi-dimensional nature of expert performance. This encompassed the need to possess extremely proficient coordinative, cognitive, perceptual and psychological skills. Additional emergent themes included the need to be attuned to the performance environment, and the continuously evolving landscape of affordances. A temporal model of batting was created from these themes, which encompassed: (1) A general search for information about their upcoming game; (2) followed by a more specific search and attunement to the performance environment, as the batter prepares to bat; (3) culminating in the moment of ball delivery, where the batter perceives and acts based on their intentions and the trajectory of the ball; (4) concluding with their between-ball routine whereby the batter reflects on the previous delivery, relaxes by engaging in task irrelevant thoughts, and then refocuses both their intentions and attention.

Given the significance of the performance environment to expert performance, study 2 examined the differences between advanced cricket batters (professional state-level) and their less-skilled counterparts, using a representative learning design framework. During this scenario, advanced batters were found to have scored more runs than both intermediate and basic skill level batters; underpinned by their ability to play more scoring shots, as well as

achieve superior bat-ball contact and footwork technique ratings. The more novel findings of this experiment were that advanced batters demonstrated greater flexibility in their shot selection (i.e. vertical and horizontal bat shots), while displaying greater stability in their foot movements (predominately played shots off the front foot). Also, contrary to previous findings, the timings of key movements (i.e. front foot movement and downswing of the bat) were found to be executed later by advanced batters relative to those less-skilled. When interviewed between overs, advanced batters reported their cognitions to be more externally focused, such as describing their strategies to score runs, rather than their less-skilled counterparts, who reported more internal factors such as achieving bat-ball contact or making technical changes. Finally, advanced batters had significantly lower reported levels of nervousness prior to their performance than both intermediate and basic skill level cricket batters. These findings highlight the skill level differences between interacting actions, cognitions and emotions of cricket batters, occurring within a real-world performance environment.

The final study compared the efficacy of two different practice approaches to developing those skills underpinning cricket batting expertise; specifically, the interacting actions, cognitions and emotions. Following 10-weeks of practice underpinned by a constraints-led approach (CLA) or traditional practice approach (TPA), participants in the CLA group shifted their cognitions to be more externally focused on factors such as scoring runs, while concurrently increasing the number of runs scored during the post-intervention skills-test scenario. This was a result of the CLA group executing a greater number of scoring shots, improved bat-ball contact and footwork technique ratings, compared to both their pre-intervention results and the TPA group post-intervention. The TPA group had little to no reported changes in their cognitions, while also demonstrating no significant differences in the number of runs scored, number of scoring shots, bat-ball contact or footwork technique rating from pre to post-intervention. Both groups also had a reduction in their reported nervousness levels from pre to post-intervention. Finally, the CLA group reported higher levels of enjoyment, challenge, and cognitive demand during their practice sessions compared to the TPA group. No difference was reported for the level of physical demands associated with practice, for either practice group. This experiment provides evidence for the efficacy of a CLA approach to coaching talented cricket batters. Creating practice environments that maintain appropriate perception-action couplings, and ensure intentions are in-line with performance demands, leads to the emergence of more functional movement solutions and cognitions commensurate with game play.

The combined findings of this investigation extends our understanding of the skills underpinning expertise, how these skills manifest during performance across various skill levels, and how different practice approaches can impact their development. A key feature of this analysis is the consideration given to the role of the performance environment in shaping an individual's behaviours. Representative learning design is an effective tool for researchers and practitioners investigating the manifestation of skilful behaviours, or seeking to expedite its development. Future research concerned with assessing or developing skills underpinning expertise, within environments that are characteristic of real-world settings, should consider adopting this approach.

STUDENT DECLARATION

I, Jonathan Connor, declare that the PhD titled ‘Utilising Representative Learning Design to Underpin the Measurement and Development of Cricket Batting Expertise’ is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, references, and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: [redacted]

Date: 3/07/2018

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LIST OF PUBLICATIONS AND PRESENTATIONS

Sections of this thesis have been published (or submitted for publication) and/or presented at relevant scientific conferences.

Publications

Chapter 4

Connor, J. D., Farrow, D., & Renshaw, I. (2018). Emergence of Skilled Behaviours in Professional, Amateur and Junior Cricket Batsmen during a Representative Training Scenario. Frontiers in Psychology, 9, 2012 - 2026.

Other publications during PhD

Woolley, T. L., Crowther, R. G., Doma, K., & Connor, J. D. (2015). The use of spatial manipulation to examine goalkeepers' anticipation. *Journal of sports sciences*, *33*(17), 1766-1774.

Connor, J.D, Crowther, R.G. & Sinclair, W. (2017). Effect of two different evasion manoeuvres on anticipation and visual behaviour in elite Rugby League players, *Motor Control, 1(1)*, 1 – 17.

Scientific Conference Presentations

Connor, J.D., Renshaw, I., Farrow, D & Abernethy, B. (2016). *Evaluating a 12 weeks games based program to improve cricket batting skill*, 6th International Teaching Games for Understanding Conference, Cologne, Germany, 25th – 27th July.

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Crowther, R.G., Woolley, T.L., Doma, K., Connor, J.D. & Pohlmann, J. (2015). *The role of video manipulation in skill acquisition*. 20th annual Congress, European College of Sport Science, Malmo, Sweden, 24th – 27th June.

Connor, J.D., Farrow, D., Renshaw, I., & Abernethy, B. (2015). *A Contemporary Look at the Ideologies of High Level Cricket Coaches: Creating Environments to Develop Batting Skill*, 5th World Congress of Science and Medicine in Cricket, Sydney, Australia, 23rd – 27th March.

Media Publications

Connor, J.D. (2017). Video explainer: Batting expertise and decision-making in cricket. Retrieved from https://theconversation.com/video-explainer-batting-expertise-and-decision-making-in-cricket-89366

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Invited Coaching Seminar Presentations

Connor, J.D. (2018). Level 2 Queensland Cricket Representative Coaching Course, Townsville, Australia (9th – 13th June)

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Connor, J.D. (2017). Level 2 Australian Cricket Representative Coaching Course, Bangalore, India (21st – 25th March)

Connor, J.D. (2017). Level 2 Australian Cricket Representative Coaching Course, Bangalore, India (27th – 31st March)

Connor, J.D. (2017). Level 2 Queensland Cricket Representative Coaching Course, Brisbane, Australia (9th – 13th June)

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CHAPTER 1: INTRODUCTION AND OVERVIEW OF THE THESIS

Introduction

The development of perceptual-motor skills has long been of great interest to academics and practitioners. In particular, interceptive timing tasks such as cricket batting, have provided a unique sporting task vehicle to explore the complex and interacting variables that differentiate experts from non-experts. Early experimental work focused on identifying expert's superior technical motor skills (Elliott, Baker, & Foster, 1993; Taliep, Galal, & Vaughan, 2007) and anticipatory abilities (Müller & Abernethy, 2006; Müller et al., 2009; Renshaw & Fairweather, 2000) often using laboratory-based tasks that enabled highly controlled and standardised experiments. However, this approach also removed key information such as individual, task and environmental constraints. As such, a failure to examine expert behaviours in situ (Müller, Brenton, & Rosalie, 2015) limited our understanding as to how the available landscape of affordances within performance environments shape emergent behaviour of experts, in the pursuit of specific task goals. Subsequent experimental work has highlighted the limitations of separating perception and action processes (Bruce, Farrow, Raynor, & Mann, 2012), including in some cases, the loss of the expertise advantage (Mann, Abernethy & Farrow, 2010).

More recently, the concept of *representative learning design* has been used as a theoretical background to examine expertise. Egon Brunswik (1956) originally proposed 'representative design' as a means for researchers to maintain both functionality and action fidelity in their experimental design. Expanding on this concept, (Pinder, Davids, Renshaw, & Araújo, 2011b) more recently coined the term 'representative *learning* design', that stresses the importance of considering interacting constraints on movement behaviours, appropriate sampling of informational variables, and the coupling of perception and action processes during practice tasks and during tests (Renshaw & Gorman, 2015; Vilar, Araújo, Davids, & Renshaw, 2012). It is proposed that tasks which are more representative of the performance environment that they are sampling, are more likely to produce behaviours that can be transferred to provide real world application. This paradigm shift has renewed interest in exploring skilful behaviours more holistically, for example, by interviewing experts regarding their decision-making processes during performance (Macquet & Fleurance, 2007; Schläppi-Lienhard & Hossner, 2015), utilising game-scenario testing situations (Renshaw & Gorman, 2015), or investigating the efficacy of learning designs such as game-based and nonlinear pedagogies (Renshaw, Chow, Davids, & Hammond, 2010).

This thesis was directly motivated by representative learning design and aimed to further our understanding of expert interceptive timing skills. This is achieved by designing and utilising representative tasks when differentiating between skilled performers, and considering the utility of different practice approaches. Of interest then, is to firstly explore the interaction of intentions, perception and, actions reported by expert coaches, and then examine whether they can be reflected in more representative 'tests' of batting (Davids, Araújo, Vilar, Renshaw, & Pinder, 2013b). This representative skills test of batting would therefore allow for exploration of different practice approaches, and their efficacy in developing the underpinning skills of batting expertise.

In order to help guide researchers, Ericsson and Smith (1991) designed an inductive framework for the empirical analysis of experts, which involved; (1) observing performance in situ and capturing the quintessence of expertise, so as to design representative tasks; (2) identifying the underlying mechanisms within these representative settings; and finally (3) examine the development of expertise and the underpinning skills. However, adopting a representative learning design framework requires consideration of the performance environment, including what perceptual variables and contextual constraints shape emergent actions. Expert's knowledge about their performance environment, captured in the first experiment of this thesis, was utilised to design a representative task that would assess the coordinative, cognitive and affective skills underpinning expertise, as well as highlight differences between skilled cricket batters and their less skilled counter-parts.

An effective skills test to assess and measure learning must include precise and reproducible measurements; coupled with a controlled, standardised protocol that displays strong external validity (Faber, Nijhuis-Van Der Sanden, Elferink-Gemser, & Oosterveld, 2015). However, performance environments in which these skills are performed are inherently dynamic in nature. A common issue is the degree to which researchers are willing to "*loosen their grip on the former to achieve gains in the latter*" (Williams & Ericsson, 2005). Grounding a skills assessment protocol in representative learning design provides a principled approach to balancing the characteristically dynamic performance environment, with a standardised experimental protocol, in order to assess learning.

Over the last decade, there has been a shift in practice approaches from the drilling of skills in static (i.e. closed) environments towards small-sided, game-centred learning styles (Slade, 2015). Teaching Games for Understanding (Bunker & Thorpe, 1982) and its variants game sense (Den Duyn, 1997) or Play Practice (Launder, 2001) are exemplar approaches designed for physical education teachers as a learner-centred approach that emphasises tactical decision-making alongside technical development in practice activities. Skills are practiced by replicating real world performance situations, albeit on a smaller scale through the manipulation of playing surface size, equipment and the number of players involved. While there are some similarities between these approaches and principles of representative learning design, criticisms of these game-based learning styles has been targeted at their lack of theoretical foundations from a motor learning perspective (McMorris, 1998; Renshaw et al., 2016). Theoreticians have instead attempted to retrospectively apply a theoretical framework to underpin these approaches (Chow et al., 2007).

In contrast, a constraints-led approach (CLA) has been promoted as an effective method to underpin practice design, due largely to its theoretical underpinnings regarding the learner and the process of learning. As the practical application of nonlinear pedagogy, this approach applies key concepts such as individual-environment mutuality, self-organisation under constraints, perception-action coupling, and a dynamic system view of the individual's self-organised movement patterns forming under constraints. Newell (1986) described three key categories of constraints (i.e., task, environment, and performer) that interact to shape behaviour. Further work proposed that coaches and practitioners can manipulate these constraints to help learners generate specific and functional movement solutions to a task problem (Renshaw et al., 2010). While the manipulation of task constraints and its influence on decision-making behaviour has been demonstrated in team games such as rugby (Passos, Araújo, Davids, & Shuttleworth, 2008), volleyball (Davids, Bennett, Handford, & Jones, 1999) and running (Haudum, Birklbauer, Kröll, & Müller, 2012), the effect of a constraints-led approach on learning of interceptive skills such as cricket batting has not been undertaken (see Lee, Edwards, & Smith, 1984 for an exception in tennis). Additionally, little research has examined skill acquisition over a longer periods more akin to real world practice settings, such as a talent development programme, and addressing this issue is a primary aim of this thesis.

Currently, there is a genuine need for more practically applied research, underpinned by a sound theoretical approach, to further explore the nature of skilful behaviours and learning (Hoffman, 1990; Locke, 1990; Singer, 1990). This thesis is intended to fill part of this gap between theory and practice, through the use of representative task designs that appropriately samples the performance environment of the performer. Specifically, this thesis will:

a) capture expert's knowledge of their performance environment and the factors they believe shape their behaviours;

b) design a representative task, based on expert's knowledge, to assess skill level differences; and

c) contrast learning approaches used for the development of cricket batting skill using a representative testing protocol.

These aims were constructed in a logical and progressive fashion, as emphasised by previous work (Ericsson & Smith, 1991), in order to guide the focus and direction of each subsequent experiment. By providing empirically supported work for practitioners, it is hoped that future motor learning research may also incorporate greater practical applicability alongside scientific rigor. The experimental chapters have been written with the intent for publication. Hence, there is some repetition within the literature review and introduction sections of the experimental chapters. The lead author was also always the primary author of all chapters within this thesis. Additionally, the second and third listed authors provided assistance and both contributed equally to this thesis and experimental chapters.

Aims of the Dissertation

General Aims

This thesis aims to increase our understanding of interceptive timing expertise by leveraging concepts of representative learning design to create an assessment tool and investigate different skill learning approaches. As such, discovering the underpinning coordinative, cognitive and affective skills crucial to interceptive timing expertise are of particular importance. More broadly, this thesis aims to extend the growing literature addressing the task representativeness of experimental studies, and subsequent generalization to real-world tasks.

Specific Aims

1. To qualitatively explore the factors that encompass cricket batting expertise, from the perspective of expert coaches who were formerly highly skilled batters.
2. To explore the coordinative actions, cognitive and emotional differences between advanced, intermediate and basic skill-level performers during a representative experimental task.
3. To compare two different approaches to skill learning, one grounded upon nonlinear concepts while the other based on cricket coaching convention, and their efficacy to the development of skills underpinning interceptive timing task expertise.

Chapter Organisation

This chapter has introduced the primary topic of this dissertation, provided a rationale for the research undertaken, and discussed the general and specific aims of the thesis. Chapter 2 critiques the extant research addressing the study of domain-specific skill development, with specific reference to the ecological dynamics model and associated theories. In Chapter 3, a qualitative experiment is presented that explores what encompasses cricket batting expertise, from the perspective of expert coaches who were formerly highly skilled batters. Chapter 4 examines the differences between cricket batters of differing skill levels as manifested in their actions, cognitions and emotions during a representative task. Chapter 5 details an intervention study investigating the efficacy of two different practice approaches to skill learning on the development of cricket batting. The final chapter (Chapter 6) summarises the key findings of each chapter, as well as discussing the theoretical, methodological and practical implications. Potential directions for future research are also presented.

CHAPTER 2: REVIEW OF LITERATURE

Perceptual-motor skills

Study of the development of perceptual-motor skills in humans has generated numerous and diverse areas of investigation. From observing infants perceptual-motor skills as they transition into adulthood, to more novel areas of skill learning, such as an athlete's development of a specialised and domain-specific skill. Sports provide a particularly unique advantage, as researchers can observe expert performers who spend thousands of hours developing perceptual-motor skills that contribute to their sporting expertise. How these skills, which underpin expert performance, are developed has been the subject of much debate. For example, whether the process of learning is best described as an 'acquisition', rather than an 'adaptation' to properties within the performance environment (Araújo & Davids, 2011). Exploring how skills related to expertise change as a result of learning, and the process by which they can be learnt, continues to be an area of interest within motor learning.

In order to help guide researchers conducting empirical analysis of expertise, a framework has been proposed to address the various areas of expert performance (Ericsson & Smith, 1991). This three stage approach involves: (1) capturing expert performance; (2) identifying underlying mechanisms; and finally, (3) examining how expertise develops. The first stage of capturing expert performance, involves observing the performance so as to sample the quintessence of expertise. Methodological approaches have included examining performance in situ, analysis of live match play and simulated game play. The importance of representativeness can also been seen in the second phase of the approach, whereby researchers aim to identify the underlying mechanisms of expert performance. Previous research has often employed eye tracking devices to measure the eye movements of performers (Vickers, 2009), occluding vision at various time points (Müller, Abernethy, & Farrow, 2006) or collecting verbal reports (Ericsson, 2006). Finally, investigating the process of skill development has been undertaken by collecting retrospective reports of player training, verbal reports such as interviews, or training intervention studies. These examples provide a brief overview of the common aims and methods used to investigate expertise. An underlying issue within this area of research, which has received greater prominence over the last two decades, is what constitutes an experimental design that is representative of performance.

Recently, the concept of representative validity in motor learning experiments has been called into question (Oudejans, Headrick, & Pinder, 2015). Specifically, with regard to the legitimacy of analysing complex movement behaviours outside the performance environment in which they are normally performed (Pinder et al., 2011b). While concepts such as population sampling and external validity are commonplace in scientific designs, the idea of properly sampling perceptual information from the performance environment has not been viewed as being of great importance in experimental design in motor learning studies. Criticisms of these experimental designs include the potential to misidentify the skills that truly underpin expertise (Williams & Ericsson, 2005); not validly analysing movements that are representative of real-world behaviour (Dicks, Davids, & Button, 2009); or not capturing the role of the environment in the performance of complex coordinative, cognitive and psychological skills (Araújo, Davids, & Hristovski, 2006).

Sporting tasks, which involve an interceptive timing component, provide an ideal task vehicle to explore what impact the environment has on the reinforcement of skill expertise. Particularly within fast paced interceptive tasks, expert batters must overcome extreme temporal and spatial demands and produce effective, coordinated movement within a dynamic performance environment. As such, there have been recent calls to shift attention towards the role of the environment and its influence of an individual’s skilful behaviour (Araújo et al., 2006; Davids, Araújo, Correia, & Vilar, 2013a).

Ecological dynamics

Dynamical systems theory, in combination with ecological psychology theory, encompasses a scientific framework termed ecological dynamics (Araújo, Davids, Chow, Passos, & Raab, 2009). Viewing the individual as an adaptive and self-organising system means their emergent behaviour is a result of complex interactions between the individual, task and environmental constraints (Newell, 1986). This contrasts with more hierarchical theories that involve a 'central controller' making all executive decisions (Araújo & Davids, 2011). Deeply embedded within the ecological dynamics framework is the interconnected relationship between the individual and the environment, where understanding of one concurrently supports the understanding of the other (Araújo et al., 2006). Of interest to researchers adopting this framework is how performers couple their perception of informational variables to produce highly coordinated movement patterns.

Influence of ecological psychology

Based on Gibson (1979) and his influential work on perception, it has been proposed that individuals perceive environmental properties through an array of ambient energy in order to interact with the world. In this sense, direct perception does not require mediating or representational processes in between perceiving relevant visual information, and acting upon it. Indirect perception in contrast is assumed to rely on mediational and interpretative mechanisms that reside within the perceiver (Norman, 1980). The accuracy of the visual information being perceived is dependent on its ability to directly specify an object's properties, termed specifying information. A well founded example of specifying information is the optical variable tau, which specifies the time to contact of an approaching object (Lee, 1976). Conversely, non-specifying information is that which does not *directly* specify an object's properties, however may indeed provide meaningful, if not always reliable, information. It is important to note that this does not necessarily infer indirect perception, and consequently, representational mediating processes. Rather, direct perception can be considered along a continuum (Withagen, 2004).

In relation to expertise, skilful perceptual behaviour is thought to occur, in part, due to a more direct perception of visual information (Jacobs & Michaels, 2007; Runeson, Juslin, & Olsson, 2000). Perceiving information that directly specifies the properties of an object or event is important for performers to accurately regulate their actions in response to an evolving environment. The actions produced are a direct consequence of the optical flow from the displacement of the individual in the environment, which in turn means, the actions of the individual will also change the optical flow. Thus, the perceptions and actions of an individual are intertwined and share a reciprocal relationship (Gibson, 1979). Montagne, Cornus, Glize, Quaine, and Laurent (2000) investigated this concept within a sport-specific task by investigating the regulatory behaviour (i.e. movement variability) of performer's movements. Participants were required to perform a number of long jump trials, in which their inter-trial step distance was recorded. Rather than step-length regulation occurring during a specific step in their run-up, the results demonstrated a continuous, prospective control of perception whereby the performer's step-length changed as a direct result of perceiving the spatial distance from the target. The implications for perception-action coupling and understanding and investigating movement behaviours will be discussed in detail in a later section. Understanding perception and actions as a coupling provides an avenue to explore what opportunities for action are afforded by various performers (e.g. skilled and unskilled; young and old) and situations (Konczak, Meeuwsen, & Cress, 1992; Ranganathan & Carlton, 2007).

Affordances, having debated definitions (Michaels, 2003; Stoffregen, 2003), can be surmised as the resultant consequence of the interaction between environment and individual constraints in relation to a task-goal. Fajen, Riley, and Turvey (2009) in their review of affordances described key features of affordances; being mediated through direct perception; specific to the learner; linked closely with action, in relation to perception-action reciprocity; based on prospective control of behaviour; and dynamic in nature, such that opportunities for action emerge and dissipate on a moment by moment basis. An example to better elaborate this concept is to imagine an environment such as a cricket pitch; the surface affords upright standing and movement, the ball itself affords throwing or bowling. The opposition also can provide an abundance of affordances. For example, for a ball to be perceived as *interceptable*, the performer must possess the capability to run at the required speed, the necessary height to reach the ball, as well as possess the coordinative ability to capture the ball. Therefore, learning to attune to informational variables, that provide information on what actions are afforded to the performer, is a key outcome of interventions such as practice.

Jacobs and Michaels (2007) proposed a process by which performers learn to detect the specifying properties of informational variables. This process of change is referred to an education of intention, education of attention, and calibration. Given the many perceptions and actions that are possible in any given circumstance, a performer’s intention plays a significant role in both the visual information being attuned to and the subsequent motor response. In the example of interceptive timing tasks, different sports may encourage different intentions from performers, such as whether the oncoming object is hittable, catchable, avoidable, or its properties, such as speed and size (Jacobs & Michaels, 2007). In contrast, education of attention refers to the attendance towards more specifying variables, even if the intention of the performer does not change (Michaels & de Vries, 1998). Arzamarski, Isenhower, Kay, Turvey, and Michaels (2010) demonstrated that greater adaptation to more specifying variables within a novel task occurred as a result of educating a learner’s intentions, when compared with educating their attention through feedback. However, likely due to the difficulty in accounting for a learner’s intention, there has been limited empirical work with reference to more practical applicable sporting tasks. Lastly, as a result of changes in the intention or attention, the performer must also shift their perception of what actions are now available; a process referred to as (re-)calibration. Unlike the education of a performer's intentions and attentions, there has been far greater investigation into the changes in a performers action capabilities as a result of perceptual learning.

Perceiving new affordances can also occur through changes in the constraints of a performer (e.g. biological maturation, musculoskeletal injury) or changes in environmental and task constraints (Franchak & Somoano, 2018; Savelsbergh & van der Kamp, 1993). For example, due to the anatomical and physical changes occurring as a result of maturation, new movement solutions can spontaneously emerge. As a learner undergoes these changes, an emergence and decay of certain movement patterns will result (e.g. consider infant development from crawling to walking). Therefore, these new action capabilities can create emergent affordances for the individual to attune towards.

Influence of dynamic systems theory

Concurrent with the notion that perceptual processes draw inspiration from ecological psychology concepts, describing *how* complex motor skills are learnt draws upon ideas from dynamic systems theory (Davids, Button, & Bennett, 2008). Inspired by principles from thermodynamics and nonlinearity, scientists have attempted to address a primary problem in the motor learning field, coined Bernstein's problem. Bernstein (1967) described the development of coordination patterns as a process of mastering redundant degrees of freedom (DOF) within the moving organ, in order to convert it into a controllable system. Mastering redundant degrees of freedom was proposed to begin with a 'freezing' (i.e. constraining) of the movement parts, then, throughout the learning process, a progressive 'unfreezing' of necessary movement parts occurs. Additionally, this freezing and freeing of the degrees of freedom suggestibly transpires in a proximal to distal nature relative to the body centre. Subsequent experimental work in more complex skills has provided some support towards this concept (Hodges, Hayes, Horn, & Williams, 2005; Vereijken, Emmerik, Whiting, & Newell, 1992), albeit less so within more simple tasks (Konczak, Vander Velden, & Jaeger, 2009).

Applying the concepts of dynamic systems to motor learning, Newell (1985) proposed a nonlinear model describing the development of motor skills. Beginning with the coordination stage, the performer develops a basic, highly constrained coordination pattern aimed to overcome the primary task constraint (Newell, Van Emmerik, & McDonald, 1989). Following numerous practice attempts, learners eventually begin to release some previously constrained parts of their movement. This results in a demonstrable ability to control the amount of force produced as a result of the movement (Vereijken et al., 1992). For example, a batter in the control stage will manipulate the speed of the bat when coming into contact with the ball, by slowing down or limiting the distance travelled of the bat. While attempts have been made to empirically confirm this theory (Hodges et al., 2005; Wang, Ko, Challis, & Newell, 2014), further work is required. Finally, the skill phase reflects the ability of the learner to adapt their movement based on changes in the performance environment. Importantly, learning to produce skilful movement, according to Newell (1985), reflects a search for an optimal movement solution that solves the task problem; rather than repetitively repeating a movement solution to a problem (Lee, Swanson, & Hall, 1991).

Functional variability as a property of skill

A far less explored area of perceptual-motor skill is the changes in movement dynamics, as a result of changes in constraints or learning. Variability within movement patterns have been proposed to permit for stable, yet flexible motor-skill behaviour (Davids, Glazier, Araújo, & Bartlett, 2003b). Subtle adaptations of the motor system are seen as a way in which learners of all skill levels are able to overcome the inability to identically reproduce a movement; also referred to as repetition without repetition (Bernstein, 1967). Given the role of movement variability is parallel with the exploration of different movement solutions, it can also be appropriately referred to as a function of adaptability (Newell & James, 2008).

Spontaneous shifts in movement behaviours are proposed to represent a function of skill; that is, flexible and adaptive qualities of the learner (Seifert, Button, & Davids, 2013a). Consider the example described by Seifert and colleagues when explaining the functionality of movement variability. When different skill level performers are influenced by external constraints (e.g. changes in task goal), experts typically exhibit distinguishable changes in their coordination pattern that directly relate to the goal of the movement. For example, gliding coordination patterns are employed by skilled competitive swimmers to conserve energy. When the task-goal shifts to increasing speed, there are demonstrable changes to the movement couplings between different limbs. Novices, in contrast, display coordination patterns that behave more like an accordion in response to changing constraints; whereby, movement couplings remain the same, and instead, the frequency of movements (e.g. strokes) increases (Chollet, Seifert, & Carter, 2008; Seifert, Button, & Brazier, 2010; Seifert, Chollet, & Bardy, 2004)

Self-organisation and constraints on movement

Self-organisation and non-linear behaviour are both core components of dynamic systems approach to movement behaviour (Davids et al., 2008). In lieu of a central controller, self-organisation occurs as a result of the complex interactions between the individual and the environment. Non-linearity is therefore, a product of the constantly changing individual (e.g. changes in action capabilities, physical maturation, etc.) and the environment (e.g. changes in the affordances available, weather or terrain conditions; (Chow et al., 2006; Chow et al., 2007). In order to limit the number of possible states of configuration that can take place at any one time, constraints on the system act as boundaries to shape possible movements.

Newell (1986) identified three categories of constraints which shape emergent behaviour for a movement system seeking a stable state of organisation constrain the system. These are the individual, task and the performance environment. Individual (synonymous with performer) constraints are referred to as the unique anthropometrical, physiological, cognitive and emotional traits that influence decision-making behaviour. These traits are further categorised as either structural physical constraints, such as the height, weight and genetic make-up, or functional constraints, which includes the psychological elements such as cognition, emotions or intrinsic motivation. The interaction between these constraints can often shape the way an athlete goes about solving a motor problem. For example, interviewing expert cricket fast bowlers using qualitative methodologies highlighted the substantial effect physical maturation had on their ability to bowl fast, and subsequently be selected in representative teams (Phillips, Davids, Renshaw, & Portus, 2010). Similarly, functional aspects of the bowler's constraints highlight the psychological characteristics, such as strong intrinsic motivation, required to reach elite levels of performance.

Environmental constraints refer to the surroundings of the learner. They can be further separated in to physical and social environmental constraints in relation to how they impact the learner's skill development. Physical aspects of the environment refer to the gravity, altitude and temperature that can impact on the production of skilled movement. Importantly, it also encompasses the playing area in which the skill is being performed or practiced, such as backyards, parks or empty spaces (Renshaw et al., 2010). The impact of physical environmental constraints on the development of motor-skills can be seen for example, in cricket batters, who describe how their playing space (such as backyard or driveway) as an adolescent helped shaped their coordinative strengths as an adult (Weissensteiner, Abernethy, & Farrow, 2009). Social aspects of environmental constraints refer more so to social and cultural expectations. Of particular importance is the availability of support structures, such as parental support, quality coaching and access to facilities or resources that act as constraints on motor-skill development.

Task constraints, as arguably the most significant constraint for practitioners, play a critical role in shaping the intentions of the performer. Examples of this include transitory task goals (during a game), size of the playing area, or equipment being utilised. For example, modifying equipment for children has been demonstrated as an effective approach to appropriately matching the demands of the task to the learner (Kachel, Buszard, & Reid, 2015; Limpens, Buszard, Shoemaker, Savelsbergh, & Reid, 2018). Manipulating these task constraints have been successful in promoting movement behaviours that more closely replicate the movement behaviours seen at adult level competition. Given that almost any constraint can be manipulated, it is critical for researchers and practitioners to follow a principled approach to constraint manipulation; that allows for relatively permanent and successful changes in skilful behaviours. Such a principled approach to practice would need to consider key tenets of ecological psychology, such as maintaining perception-action coupling, in order for behaviour to demonstrate fidelity towards behaviour produced during performance.

Representative learning design

Ensuring reliability and validity of experimental findings is of paramount importance in science. With reference to more applied disciplines, external validity also plays a crucial role as it considers the validity of generalized inferences in scientific research (Steckler & McLeroy, 2008). That is, it describes the generalization of experimental findings from a specific group to a larger population (population validity), or to different behavioural contexts than what was studied (Lucas, 2003). Ecological validity, which is frequently used in sports science research, refers to the degree in which (proximal) cues present in the experimental settings reflect the distal criterion state of the environment (Brunswik, 1956). These two types of validities are a mainstay within movement sciences. However, another Brunswikian term, commonly mistaken for ecological validity (Araújo, Davids, & Passos, 2007), is representative design. This approach refers to how the conditions of the experiment represent the behavioural setting in which it is intended to exemplify. Thus, the basis of representative design is using inductive logic, like it is applied to statistical sampling of a population, and apply it to experimental design (Araújo et al., 2006). The use of representative design has arguably had the most impact in the study of adaptive movement behaviours (Araújo & Davids, 2009; Davids, 1988; Dicks, Davids, & Araújo, 2008).

Brunswik was a strong advocate against the classical one-variable systematic design inherited from the field of physics (Brunswik, 1956). Similar to Fisher and Birren (1947), who developed multivariate analysis of variance and other related methods, both perceived practically applied findings as unjustified given the rigidity of certain experimental designs (Hammond, 1954). Brunswik therefore argued that the logic of sampling theory – used to confirm population validity – be applied to the stimulus used within experimental designs. This would ensure greater ecological generality of results, however, this also represents a challenge to researchers. For example, instead of using stimulus variables because of their potentially similar physical or geographic nature, the consideration for their usage should be based on whether or not they are ecologically valid.

Furthering this concept, (Pinder et al., 2011b) proposed a new term, coined representative learning design, to aid practitioners in utilising concepts of Brunswik's representative design. This approach stresses the importance of: sampling informational variables from performance environments; creating dynamic settings that include the interacting constraints on decision-making behaviours; and maintenance of perception and action couplings. Its application extends to coaches creating practice environments for their learners, as well as to researchers examining the behaviours of experienced or expert performers. Importantly, however, researchers that do not incorporate features of representative learning design into their experimental approach risk not allowing critical aspects of expert performance to be explored (Araújo et al., 2007). Rather, following these principles, coaches, practitioners and researchers can ensure functionality and action fidelity in learning designs (Pinder et al., 2011b).

When evaluating a representative learning design, there are two crucial features that practitioners and researchers must be acutely aware. Firstly, functionality, which describes the extent in which perceptual information present during practice tasks, are comparable to a competition environment. Secondly, action fidelity, which addresses the similarity of an individual's movement behaviour during practice to competition. For example, poorer functionality has been demonstrated when cricket batter's movements were examined batting against ball projection machines compared with bowlers (Pinder, Renshaw, & Davids, 2009). Due to the changes in informational constraints, such as the lack of pre-ball flight information in the ball projection machine condition, subsequent changes in the batter's movement timings occurred. Compromised action fidelity was highlighted by Barris, Davids, and Farrow (2013) investigation on springboard divers practicing on dry-land compared to the normal performance environment (aquatic). While the topographical characteristics of the movements appeared similar, there were significantly greater step lengths, jump heights and board depression angles, during the approach and hurdle phases, when performed in the aquatic environment. A key element of representative learning design is the importance of coupling individual's perception and action during experimental and practice designs.

The practical applications of representative learning design can be seen prominently in more recent studies. Krause, Farrow, Reid, Buszard, and Pinder (2018), for example, designed and validated a representative learning design checklist to assist coaches and practitioners implementing this approach. Specifically addressing the sport of tennis, the representative practice assessment tool (RPAT) operationalizes the examination of functionality and action fidelity. Their findings suggested that the RPAT was sensitive enough to distinguish between tasks that can be considered higher or lower in representative learning design, and, distinguish between different task designs. This can, therefore, be of particular benefit to coaches seeking to design practice tasks for learners at different skill levels.

Similar approaches have been observed in cricket batting, whereby research practitioners make recommendations regarding representative learning design to coaches charged with creating learning environments (Pinder, Renshaw, Davids, & Kerhervé, 2011c). Ball projection machines are regularly utilised in training environments to simulate a bowler delivering a ball. The advantages of ball machines are the large amounts of volume and repetition that can be achieved, without the need for a bowler. However, as result of the lack of functionality, batter's movement couplings become altered in an effort to still achieve the task-goal of making contact with the ball (Pinder et al., 2011b). Weighing up the advantages and disadvantages, Pinder and colleagues suggested ball projection machines be considered a supplement rather than replacement to facing a bowler during practice. Additionally, future research could be directed towards improving the functionality of ball projection machines, in an effort to improve the overall representativeness.

While these empirical examples address the design of practice environments, there are further avenues for future representative learning design research to be of benefit. For example, it is unknown whether experimental designs that are representative of the performance environment may be better at discriminating between skill level performers, or potentially better discriminate skills that are performed under dynamic conditions (e.g. changes in coordination patterns as a result of different ball trajectories). Furthermore, this 'snapshot' of a learner's skill could be further applied as a measurement of their current skill level, and used to explore the efficacy of various practice approaches on a learner's development.

Limitations to field-based testing

Capturing skills that underpin expertise using a field-based method, is subject to its own set of unique challenges. Time constraints (i.e., to test a whole squad of players), resource restrictions (e.g. available facility, required number of sport scientists), and limitations to operating equipment outside of a laboratory (i.e., ability of high-speed cameras to capture data outside) are common issues limiting field-based testing. While Ericsson and Smith (1991) framework encouraged underlying mechanisms of performance to be captured in the laboratory under representative settings, there may be instances where scientists must adopt more pragmatic methods.

Portus, Timms, Spratford, Morrison, and Crowther (2010) designed a field-based assessment protocol for cricket batting that required batters to face 42 deliveries from a ball projection machine at two different bowling speeds, with three different ball trajectories, while being tasked with striking the ball into seven predetermined gaps within the field. While the test as a whole discriminated between elite, emerging, and junior batters, there were no-subcomponents (e.g. ball speed, ball length, batting shot type or shot accuracy) that could be used as a smaller version of the test to discriminate between skill levels. Reiterating the conclusions of Portus of colleagues, there is a genuine need for a more multidisciplinary approach to exploring the different aspects of cricket batting, and how they can discriminate between skilled and lesser skilled performers.

An important aspect of field-based testing is the aspiration to attain representative conditions without sacrificing the systematic approach to investigating key variables. For example, it is proposed that the aforementioned field-based cricket batting skills test may be improved by better incorporating elements of representative learning design. Firstly, the disadvantages of using ball projection machines have been well and truly covered within this review (Pinder, Davids, Renshaw, & Araújo, 2011a; Pinder et al., 2009; Pinder et al., 2011c).

In summary, while they offer a simple solution to standardising the ball delivery's trajectory, they also significantly alter the movement timings of batters. Instead, methods could be introduced in an attempt to standardise both the opposition bowler and their bowling deliveries. Utilising only right or left handed bowlers, recording bowling speed every delivery to ensure minimal variation, and recording ball trajectory so that all participants face similar length deliveries are all proposed methods to improve representativeness while maintaining standardisation.

Another strategy to improve the representativeness could be achieved by improving the fidelity of the task demands. Rather than informing the batter what ball trajectory they would be facing, and instructing them exactly where to hit the ball, a more dynamic game-based task would be commensurate with actual game demands. For example, randomising the ball length conditions would allow batters to freely score in any zone they choose. Subsequent findings may also highlight a predisposition for certain skill level batters to strike the ball into particular scoring zones, or more broadly, demonstrate certain intentions and attentional focus that are a traits of a certain skill level performers. Fundamentally, dynamic tasks allow learners to interact with an evolving environment and make use of higher order cognitive processes. Therefore, researchers may use this to explore how these higher order cognitive processes manifest alongside motor skill in dynamic tasks. The clear advantage of this methodological approach would also reflect the task-goals within game for batters.

Finally, both laboratory and field-based skills tests should strive to replicate the skill demands placed on the performers. An assumption of Portus and colleague's batting skills test is the aim to measure the accuracy of batters striking the ball between two cones. However, batters performing under normal match conditions are not required to strike the ball between two fields with such degrees of accuracy used in their experiment. Instead, cones set 4 m apart more accurately represent opposition fielders, and the potential distance they could cover when attempting to intercept a ball struck by the batter. It is unsurprising then that the accuracy of striking a target was not a discriminatory function of skill level. In line with the final stage of Ericsson and Smith (1991) framework, designing a valid skills assessment would provide a means to explore how different practice approaches impact skill learning.

Cricket Batting

Cricket batting is a quintessential example of how the human perceptual-motor system, with practice, can adapt towards incredible feats. Cricket batters are required to intercept a cricket ball delivered (i.e. bowled) by an opposition player, and propel it towards gaps in the field or over the boundary rope in order to score runs. At the professional level, the temporal demands placed on the batter means there is approximately 450ms to coordinate an optimal movement and intercept the oncoming delivery (Stretch, Bartlett, & Davids, 2000). Further exacerbating the temporal demands of cricket batting is the inherent delay present within any system that responds to a stimulus (Lee et al., 1983; Bootsma & van Wieringen, 1990). Applying this concept towards a sporting task, McLeod (1987) examined the visual-motor delay in skilled cricket batters attempting to contact a ball that deviated laterally off the playing surface. The delay present was approximated as 200 ms, however, did not take into account the lag time required to alter the direction of the bat in response to the changing direction of the ball. Regardless of the exact duration of the visual-motor delay, it is clear that expert batters are required to attune to key perceptual information in order to successfully intercept an oncoming delivery (Abernethy & Zawi, 2007; Seifert, Orth, Button, Brymer, & Davids, 2017). The ability of an individual's perceptual-motor skills to overcome these severe demands has been the primary topic of interest within this area.

Anticipation is arguably the most explored attribute of expertise in sporting tasks (Aglioti, Cesari, Romani, & Urgesi, 2008; Morris-Binelli & Müller, 2017; Rosalie & Müller, 2013). The ability to perceive kinematic information, as well as other relevant contextual information from the performance environment, in order to guide coordinative behaviour, has been well established trait of expertise (Williams, Ward, Knowles, & Smeeton, 2002). In reference to cricket batting, skilled batters demonstrate a greater attunement towards the trajectory of the opposition bowler's delivery, and can perceive the likely trajectory at earlier time points, when compared to their lesser skilled counter-parts (Brenton, Müller, & Mansingh, 2016; Müller et al., 2006; Renshaw & Fairweather, 2000). The exact mechanism, and further explanation, will be provided in the following section. Findings from studies exploring anticipation in cricket batting are in line with findings from other interceptive timing tasks (Savelsbergh, Van der Kamp, Williams, & Ward, 2005; Abernethy, 1990).

Early experimental work investigating the perceptual abilities of skilled performers demonstrated a greater ability to detect relevant visual information available within their performance environment, than less-skilful performers (Abernethy, 1990; Wright, Pleasants, & Gomez-Meza, 1990). The resultant effect of this greater attunement allowed for superior accuracy when anticipating the actions of an opposition performer. As such, more skilled performers can anticipate earlier, are more attuned to the location of more specifying information within the performance environment (Mann, Williams, Ward, & Janelle, 2007). (Müller et al., 2006) compared high and low skilled cricket batter's capability to attune to visual information at various time points of the balls flight path. By occluding the batter's vision prior to ball release, and just prior to the ball bouncing after contacting the pitch, with a non-occlusion condition, it was concluded that pre-bounce ball flight information to be most critical for both high and low skilled batters. Perhaps most interesting was the author's suggestion that there was no strong evidence of advanced pick-up of ball trajectory, indirectly measured via a batter's movement responses, apparent in the experiment. Instead, batter's adapted to the demands of the occlusion task by adopting a default movement strategy that presumed every ball was a full length delivery.

More recently, different types of gaze strategies employed by expert and novice performers have been identified; potentially explaining, in part, one mechanism behind the pickup of different perceptual information (Sarpeshkar, Abernethy & Mann, 2017). Interestingly, the methodological approach utilised by Sarpeshkar and colleagues differs considerably from earlier studies. As opposed to utilising video simulations to examine perceptual abilities, the eye movements of batters were recorded in situ. That is, batters were required to intercept an oncoming ball while eye movements were being recorded. The ramifications of this methodology will be discussed further in a later section (Farrow, Abernethy & Jackson, 2005). Experiments that incorporate elements of representative learning design, such as maintaining the coupling of the perception of an opposition bowler and subsequent batting action, have been somewhat scarce within previous cricket batting research.

Earlier empirical work on cricket batting has been primarily focused on the biomechanics of coordinated movement patterns. The methodological approach adopted to examining batting movements has varied from: batters 'shadowing' the movement while watching video footage of a bowler (Taliep et al., 2007); intercepting a cricket ball delivered by an opposition bowler on an artificial surface (Elliott et al., 1993; Stretch, Buys, Toit, & Viljoen, 1998); to intercepting a cricket ball delivered by an opposition bowler on a turf playing surface (Stretch, Buys, & Viljoen, 1995). In fact, Stretch et al. (2000) reported on kinematic data of a batting shot during an international game. However, a current limitation is the lack of diversity in the different types of cricket shots that have been explored. For example, all of the aforementioned studies have investigated one specific type of batting movement; specifically, a front foot vertical bat shot. As such, there is limited to no empirical evidence on the execution of back foot or horizontal cricket bat shots. Furthermore, the perceptual-action process of batting, whereby batters must choose which shot to execute one of these different coordination patterns as the ball is approaching them, has yet to be explored.

Cricket affords batters the opportunity to strike the ball anywhere within a 360^{o} field of play. The resulting effect is any number of possible different coordination patterns being employed. Biomechanical analysis of cricket batting has focused solely on one specific coordination pattern (front foot movement coupled with vertical bat shot) under conditions that lack high levels of representativeness. Yet, it is argued that under more dynamic and representative conditions can adaptive movements appear. That is, as a response to evolving task goals or changes in perceptual information within the performance environment. Methodologies allowing for greater idiosyncrasy within movements would provide a means to analyse adaptability among different skill level performers.

Pinder, Davids, and Renshaw (2012) investigated the meta-stability of junior cricket batters when exposed to cricket deliveries of varying trajectory. Their findings highlighted stable performance zones within 4 m of the batter (i.e. that elicited front foot shots) and further than 8 m away from the batter (i.e. elicited back foot shots). However, perhaps most interesting was the meta-stable performance region that existed between those two areas. Batters were reported to execute a variety of front foot and back foot shots in response to deliveries pitching between 4 m and 8 m from the batter. It is currently unclear whether the ‘size of the meta-stable performance region is a function of skill level. That is, whether more skilful performers display meta-stability of their movements within a smaller area. In addtition to Pinder and colleagues findings, it is also unclear whether the varying level of stability demonstrated in foot movements would also apply to vertical and horizontal bat shots. Clearly, more research is required to understand the functional variability and stability of coordinative movements in response to the trajectory of an oncoming object

While receiving the majority of focus within the literature, the technical features of expert's motor coordination patterns forms only one narrow perspective of expertise. This has meant less consideration being given to *how* skilled batters adapt within a dynamic performance environment (Seifert et al., 2013a). A key aspect that has been underrepresented is the 'why' and 'when' skilled performers execute a particular coordination pattern or attend to certain perceptual variables (Araújo & Davids, 2011). For example, what processes an expert batter employs in order to overcome; an opposition bowler trying to dismiss them; the pitch surface undergoing changes as a result of weather; and the eventual deterioration of the ball, which alter the ball characteristics such as bounce and lateral movement (Carré, Baker, Newell, & Haake, 1999), are suggested to be critical factors in expert batting performance. This was in fact highlighted by former international cricket batter Greg Chappell;

> *The video replays [of the dismissal] only tell you part of the story. They tell you it's a snapshot of that instant… the wicket may have come from something that happened two balls, three balls, six balls, eighteen balls before. [from example] a fast bowler [might have] bowled a bouncer that all of a sudden shakes [the batters] confidence and all of a sudden therefore the footwork fails/breaks down and the decision making breaks down because they might be expecting a short ball when they get a full ball and they're in trouble. So again, I'm very conscious of the fact that what players thinks about, what they expect, what their intent is, has a very big bearing on what their physical activity, physical actions are* (Renshaw, 2010).

Clearly, game-specific contextual information (encompassing all the changing features of the performance environment) play a key role in shaping expert intentions, perception and actions. Understanding expertise from this perspective requires greater consideration of factors that influence an individual's decision-making, such as their tactical or situational knowledge

(Abernethy, Gill, Parks, & Packer, 2001), cognitions (Araújo & Davids, 2009) and emotions (Headrick, Renshaw, Davids, Pinder, & Araújo, 2015).

Exploring factors underpinning expertise

Ericsson and Smith (1991) proposed the capturing of expertise, so as to further identify the underlying mechanisms and explore how skill development occurs. Proposed methods included capturing match analysis and in situ investigation of performance. Such analysis in cricket batting has revealed the severe motor skill demands at an international level, as well as the cognitive and physical demands explored during simulated games. (Stuelcken, Portus, & Mason, 2005) reported movement analysis data of cricket batters during an international level game. Their findings highlighted the severe spatio-temporal demands, such that foot movements are on average initiated 380 ms prior to, and conclude within less than 100 ms before, bat-ball contact. In comparison to almost all other interceptive timing tasks, cricket entails a significantly greater performance duration that can occur over multiple days. As such, psychological strategies such as self-talk have been identified in elite level batters (Miles & Neil, 2013). While these findings highlight the various demands of expert performance, how these factors interact and influence each other remains unclear.

A limitation to the study of expert performance has been the ability of researchers to simultaneously explore all elements that contribute to expert performance and highlights the need to adopt an inter-disciplinary approach (Renshaw & Gorman, 2015). Indeed, contemporary models of expertise are multi-dimensional (Araújo et al., 2010; Phillips et al., 2010); encompassing a range of skilful behaviours including coordinative (Wilson, Simpson, Van Emmerik, & Hamill, 2008), perceptual (Helsen & Starkes, 1999), cognitive (Voss, Kramer, Basak, Prakash, & Roberts, 2010) and emotive behaviours (Headrick et al., 2015). A subsequent challenge for researchers is therefore to adopt methods that enable more holistic analysis of expert performance.

One such method that has gained prominence when exploring factors related to expert performance, is extracting information from expert coaches. Specifically, coach's experiential knowledge can be a source of valuable information to help guide empirical analysis (Greenwood, Davids, & Renshaw, 2012). Relating to expertise, coaches – specifically those who themselves were former expert players – can report on the demands of their sport specific skills as lived events, providing granular details that may be further explored through empirical analysis (Renshaw, 2010). Greenwood, Davids, and Renshaw (2014) described how expert coaches' experiential knowledge was invaluable in identifying novel informational sources that constrain performance adaptions within their sporting domain. Conclusions from Greenwood and colleague's study advocated for greater integration of experiential knowledge possessed by expert coaches, alongside theoretically underpinned empirical knowledge, to advance future applied research and pedagogical practice.

Reporting on expert's perceptions and experiences of their own performances, using qualitative methodologies, has brought about significant findings in motor learning research (Binet, 1893/1966; Ericsson, 2006; Groot, 1966). Grounded theory has been a more common qualitative method to explore factors relating to both expert characterization (Fletcher & Sarkar, 2012; Phillips, Davids, Renshaw, & Portus, 2014) and development (Morgan & Giacobbi Jr, 2006; Weissensteiner et al., 2009). The advantage of this approach lies in the freedom to explore interconnecting factors within complex and dynamic situations, concurrently with the flexibility to redirect the focus of investigation to other emergent factors (Hussein, Hirst, Salyers, & Osuji, 2014). Additionally, identifying key variables from the perspective of experts provides a principled method to select and deselect experimental variables (Renshaw & Gorman, 2015) in any follow-up quantitative studies. Subsequent approaches, which aim to quantify aspects of expertise, would then be better utilised once the contextual constraints within real-world performances were more clearly understood.

Measuring and distinguishing skill level differences between experts and non-experts

Measuring skills that underpin expertise within sporting tasks has been a common endeavour, particularly within sporting development programmes (Faber et al., 2015; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). One such approach used in talent identification programs involves developing a skills testing battery to measure key attributes required during performance. The National Football League (NFL) and American Basketball Association (NBL) hosts some of the most well-known drafting combine processes that measure the 'predicted potential' of college athletes (Teramoto, Cross, Rieger, Maak, & Willick, 2018; Weaver, Hindenach, & Vos, 2015). The battery of tests involves multiple days of physical, psychological and medical testing to profile athletes. An underlying assumption to this draft process, and indeed all skills tests conducted, is that the skills (e.g. physical, mental) being examined during tests, accurately reflect the skills being performed under game demands. However, the validity of this assumption is often questioned for a number of reasons. Most critically, the types of performance attributes measured by generalized assessments are not able to capture the domain-specific attributes required during performance (Gibbon, 2015; Tricot & Sweller, 2014). Having been highlighted previously by Renshaw and Gorman (2015), this notion is no more evident than the well-known limitations of mental intelligence tests used to assess the decision-making capabilities of quarterbacks (Lyons, Hoffman, & Michel, 2009). Terry Bradshaw and Dan Marino, being among the seven worst performers to have completed the test, are also considered two of the best quarterbacks in history (Ankersen, 2012). Given the inability of generalized tests to distinguish between skilled performances, greater attention has been paid to more domain-specific tests of skill (Broadbent, Causer, Williams, & Ford, 2015). The following section describes the findings of previous experiments distinguishing the skilful behaviours of skilled and less skilled performers, as well as the methodologies used to measure these skill level differences.

Skilful actions

Distinguishing between expert's and their less-skilled counterpart's coordination patterns routinely focuses on the outcome (e.g. successfully intercepting an object) and the underpinning technical features; that suggestibly explain the successful or unsuccessful execution (Lees, 2002). This has been demonstrated in a wide range of interceptive timing tasks, including catching tasks like soccer goalkeeping (Suzuki, Togari, Isokawa, Ohashi, & Ohgushi, 2011) or striking sports such as cricket batting (Stretch et al., 2000) baseball (Szymanski et al., 2007), tennis (Elliott, Fleisig, Nicholls, & Escamilia, 2003) or squash (Marshall & Elliott, 2000). A key element of all successful coordination within these tasks is the superior temporal and spatial ability of skilled performers to intercept the approaching object.

Skilled performer's superior temporal and spatial ability occurs as a result of their perception of informative visual cues that guide their coordinated action. In parallel to this, is the differences in that occur in movement coordination. These technical differences include topographical features (e.g. bat located in different position; (Noorbhai & Noakes, 2016), coupling of sub-movements (Weissensteiner, Abernethy, & Farrow, 2011), movement durations (Escamilla et al., 2009) and the initiation of movement (Stretch et al., 1998) have all been reported as important contributing factors of skill. Weissensteiner and colleagues (2011) examined the characteristics associated with intercepting a cricket ball in high and low skilled cricket batters. Utilising a bowling machine, batters were tasked with performing a singular coordination pattern (i.e. an on-drive) to hit the ball towards a target area. Their experiment highlighted specific technical features of a batter's movement that distinguished between different skill level performers. In particular, the earlier timing of the front foot movement and initiation of the downswing of the bat in more skilled batters. Differences were also observed in the order event of movements, with higher skilled batters completing their forward stride prior to commencing the downswing of the bat, while lesser skilled initiated the downswing prior to completing their forward stride. Additionally, the higher skilled batters demonstrated greater temporal and spatial accuracy in their coordination action when tasked with executing the specific coordination pattern. While this work provides crucial information of interceptive expertise, one area in need of greater attention is the movement repertoire of skilled performers; that is, their ability to execute different coordination patterns while satisfying the task goal.

A common approach in biomechanical and technique analysis is to examine a singular coordination pattern when comparing between different skill level performers. However, an issue within interceptive timing sports such as cricket or tennis, is the demands of the sport require performers to execute multiple different coordination patterns, depending on contextual factors such as the trajectory of the delivery or the intentions of the individual (Macquet & Fleurance, 2007). While isolating a singular coordination pattern creates for a more standardised and controlled experimental procedure, it also presents limitations in the generalisation of findings. Functional variability, that is the ability of the performer to switch between attractor states of movement and still achieve the task goal, of the performer is accounted for (i.e. non-existent) in order to more closely examine the movement variability of different skill level performers. This approach limits the understanding of the functional variability possessed by skilled performers, such as their ability to switch between coordination states to achieve a task goal.

Perceptual skills

In order for performers to execute a coordinative response to an oncoming object, they must first perceive the informational variables that dictate both the spatial and temporal features of the objects trajectory. The most overt salient information for contacting (or in some instances, avoiding) a moving object is its flight path, which can entail its trajectory, velocity and acceleration (Todd, 1981). However, within sporting situations, there are a multitude of advanced (i.e. present before the object begins moving) visual information that can allow the performer to circumvent severe temporal demands. Information sourced from situational probabilities, such game tactics (Farrow & Reid, 2012), or perceiving opposition's patterns of movement, prior to releasing the object, can shape the intentions and prime the performer's motor system prior to contact with the object occurring.

While it seems theoretically advantageous to move earlier if one can perceive visual information that affords earlier movement, there may be contextual factors at play. For example, (Müller & Abernethy, 2012) proposed an inverse relationship between the onset of visual information that can afford a movement response, and the accuracy of that visual information. That is, attuning to earlier visual information may be a source of non-specifying information to the batter, while later visual information (e.g. ball flight) is more specifying of the properties batters attune to. This would suggest that more skilled batters may not necessarily execute the timing of their movement earlier per se, but instead, move at the critical time point in which they can execute their footwork and batting stroke with greater certainty of the trajectory of the ball.

Weissensteiner et al. (2011) explored the technical components of cricket batting most linked to expert batting performance. Utilising a ball projection machine, skilled and less-skilled batters were tasked to strike each ball between two cones. Skilled batters demonstrated significantly earlier movement timings compared to their less-skilled counterparts. However, batters in this condition were aware of the trajectory of the upcoming delivery, and therefore, were likely not required to attune to specifying information given their actions were somewhat premeditated. However, under normal match conditions, batters do not have the same level of certainty of the upcoming ball's trajectory. This would also explain why greater perceptual demands have been associated with later movement timings. Pinder et al. (2009) reported batters facing a ball machine, without having pre-advanced knowledge of ball trajectory, executed their movements significantly later than when batters faced bowlers. Unlike ball projection machines, bowlers can be a source of perceptual information to the batter in advance of the ball being released (Müller et al., 2006). Similarly, batters facing a ball delivery that deviates laterally (i.e. swings) through the air results in significantly delayed onset of movements compared with a ball trajectory that does not deviate from a straight trajectory (Sarpeshkar, Mann, Spratford, & Abernethy, 2017). While it is well founded that skilled batters can perceive informative advanced visual information, the effect on their movement timings under more representative conditions remains unclear. Batters, for example, are routinely exposed to conditions where they cannot reliably predict the trajectory of the upcoming delivery before it is bowled; must constantly adapt to the different opposition kinematic information to assist their anticipation of ball trajectory; and consider the contextual factors of the game that may provide non-specifying information about the delivery. More experimental work is required utilising representative design that samples key perceptual sources of information, such as bowlers, and contextual information such as game scenarios.

A key methodological consideration of Müller and Abernethy (2006) use of the temporal occlusion paradigm is the preservation of perception and action couplings. More commonly, temporal occlusion methods have been employed so that performers view a video simulation of an opposition before it becomes 'occluded' at a specific time point. Progressive temporal occlusion method is a further extension that allowed researchers to control the duration of viewing time by occluding the action at various time points (Jackson, Warren, & Abernethy, 2006; Rowe, Horswill, Kronvall-Parkinson, Poulter, & McKenna, 2009). This body of work highlighted that those more skilful, for example tennis players (Farrow, Abernethy, & Jackson, 2005) and cricket batters (Müller et al., 2006), were able to anticipate earlier than their less-skilled counter parts. Additionally, the use of point-light displays within video-based temporal occlusion studies also demonstrated the minimal amount of visual information necessary to successfully anticipate, by replacing topographical features of an opponent with points of light that correspond to the opponents major joint centres (Shim, Carlton, Chow, & Chae, 2005; Ward, Williams, & Bennett, 2002). Finally, spatial occlusion methods, which disguise or remove key areas of an opposition movement, have demonstrated where skilful and less skilful performers are visually attuned towards (Williams, Hodges, North, & Barton, 2006; Woolley, Crowther, Doma, & Connor, 2015). In these instances, the normal perception of the opposition's movements and the action of the performer in response, has be decoupled. That is, the requisite response normally executed under game-like conditions have been replaced with a either a verbal response or simpler response movement.

Because of the decoupling of perception and action, there have been proposed some limitations when applying the findings of previous research into perception and anticipation of experts. While video-based simulations have demonstrated the superior perceptual abilities of skilled performers, two main limitations towards representing real-world tasks are proposed. Firstly, interceptive timing tasks fundamentally require a performer to perceptually track an oncoming object, and coordinate their own movement to respond at just the right temporal and spatial location. Video simulations inherently remove the action response, and subsequently, have resulted in the loss of the expertise advantage in some experiments (Connor, Crowther, & Sinclair, 2018; Mori, Ohtani, & Imanaka, 2002). This lack of 'expert advantage' will be discussed further in the following section. It's been proposed that different neurological structures could explain changes within action responses as a result of how information is perceived (Goodale & Milner, 1992). The two streams hypothesis suggests that the dorsal and ventral structures within the brain act mutually, albeit with different roles, when perceiving visual information. Thus, tasks involving perception-action coupling rely more on different neural regions of the brain compared with tasks that involve responding via verbally recognising an objects trajectory or predicting an upcoming event. Further research in this area is required, particularly in understanding how experience (i.e. expertise) might influence how the two visual systems integrate with each other during a task (Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008).

A second issue related to the exploration of expert's perceptual abilities is the heavy focus on perceiving opposition movements. A far less explored area related to real world performance is the influence of game-specific factors, such as situational probabilities or contextual information within the performance environment (Cañal-Bruland & Mann, 2015). This is particular pertinent to the study of perceptual behaviour, given that a performer's intentions can shape and guide their visual attunement (Jacobs & Michaels, 2007). Experiments that have included these additional factors to performance report expert's ability to utilise this information, culminating in subtle changes in action responses, such as earlier movements, additional/ reduced number of movements (Abernethy, Gill, Parks, & Packer, 2001; Alain & Proteau, 1980; Ward & Williams, 2003; Williams, 2000).

Perception-action coupling and performance

While experiments utilising temporal occlusion methodologies have been invaluable in helping researchers understand the advanced visual cues experts can attune towards, some limitations have been highlighted. An underlying assumption within this paradigm is that the action response, normally occurring during the perceptual process in which temporal occlusion methods capture, is distinctly separate from the perceptual strategies of performers. This assumption is contrary to the direct perception theory of Gibson (1979). Without the subsequent action response to the visual stimuli provided, it has been suggested that the perceptual information performers attune to may be different to what they would normally attune to under game performance demands (Dicks, Button, & Davids, 2010).

Mann, Abernethy, and Farrow (2010) examined this hypothesis by comparing whether maintaining perception-action coupling influenced the sensitivity of skilled and novice cricket batter's anticipatory skill. Batters were required to anticipate the direction of the ball, by either verbally responding, executing a lower body movement, a full body movement, and a full body movement with a bat (i.e. normal response). Interestingly, only skilled batters improved their response accuracy as a function of improved perception-action coupling. Further work by Travassos et al. (2013) examined the influence of requisite responses and the type of stimulus presented across a range of tasks. The results of their meta-analysis indicated that decision-making studies in sport must consider the participants ability to detect information in their environment as reciprocal to their actions performed. The following section explores a neurological explanation for perception and action coupling.

Current considerations to exploring skills underpinning expertise

Measuring skills related to a performance goal is a complex process for a number of reasons. In relatively simple coordination tasks such as throwing, skill has been accurately assessed based on the number of times the desired outcome is achieved (Royal et al., 2006). However, more complex skills, that is those influenced by a multitude of factors, are associated with greater difficulty to measure. Skills performed in dynamic performance environments are shaped by perceiving relevant information, coupled with the individual's knowledge of their own capabilities and contextual preconceptions (e.g. knowledge about the oppositions intentions), in order to produce skilful movements and achieve their task-goal. That is, the coordinative, perceptual, cognitive and emotional skills of the individual interact with each other and the performance environment to produce skilful behaviour.

In order to simplify skills tests and create a more standardised protocol, certain aspects of performance that are normally dynamic, become controlled. For example, it is common for experiments analysing the biomechanics of striking tasks to utilised ball projection machines to control for the trajectory of the ball (Weissensteiner et al., 2011). However, this approach has been criticised due to the simplification of tasks inadvertently removing the experiential effects for the expert's advantage, creating floor and/or ceiling effects, or unintentionally motivating experts to use different informational variables to accomplish a task (Abernethy, Thomas, & Thomas, 1993; Pinder et al., 2011c). In order for experimental, practice or testing designs to be more representative of real-world performance, it is critical to include the action response in their design. The same can also be said for proper sampling of informational variables from the performance environment. Failing to appropriately consider the role of perception-action coupling within a task risks the validity and generalization of behaviours being analysed. Therefore, representative learning design should be a key feature in future applied work.

Towards a theoretically underpinned pedagogy

Traditional practice approaches

While there is no framework which encompasses a traditional practice approach, it is instead argued here to be characterised by a focus on the technical development of an individual's coordination pattern. Therefore, the primary goal is to optimise the technical execution of a movement, which is presumed to ensure an ideal outcome (McPherson & French, 1991; Turner & Martinek, 1999). To achieve this, the desired movement pattern is performed under relatively simple task demands while consistently repeating the action in an attempt to ingrain the movement and remove errors. Once a stable, coordinated action achieves high levels of success, the level of difficulty within the task is increased (French et al., 1991; Vogel & Seefeldt, 1988). This cycle of practice would then continue, as the learner attempts to perfect the movement under progressively more demanding conditions. Finally, the role of the coach is to correct errors that arise within the learner's performance (Roberts, 2011).

Components of traditional practice in research design

Repetition. A key consideration in traditional technical approaches is the practice design implemented for learners. These are routinely referred to as drills, which, similar to skill classification (Gentile, Higgins, Miller, & Rosen, 1975), are further categorised as open or closed. Traditional practice approaches predominately incorporate closed drills and that are devoid of the full influence from external or environmental factors normally found within a game like environment. Therefore, there is often minimal cognitive demand, normally found within tasks that incorporate some element of decision-making, placed on the learner. This is commensurate with the proposed philosophy underpinning traditional practice; learning occurs by repetitively practicing the movement with perfect technical execution.

In contrast, open skills are those activities performed in more game-like dynamic environments with modifiable levels of unpredictability and variability (Farrow, Pyne, & Gabbett, 2008). Practice variability is considered a fundamental aspect of learning, and is one of the key requirements for effective practice (Farrow & Robertson, 2017; Williams & Hodges, 2005). Random or variable practice often results in poorer performance during practice, however, results in improved performance during retention and transfer tasks (Hall & Magill, 1995). For example, Hall, Domingues, and Cavazos (1994) compared baseball batting performance during blocked and variable practice conditions. While the blocked condition was associated with greater performance compared with the variable practice condition during practice, the opposite result was found during the retention test. Those performers practicing under the more challenging variable condition improved in both blocked and variable retention tests conditions. In contrast, those participants who practiced under blocked conditions had no improvement during the blocked retention test, and performed worse during the variable retention test. Performers practicing under random or variable practice conditions are thought to better develop attunement to more specifying perceptual variables as well as control of their coordination patterns (Newell, 1985).

A similar proposition is that as each practice trial is different to the last, learners are less likely to hypothesis test, and are therefore are more likely to develop procedural knowledge about the movement. This contextual interference effect has been well documented in the literature (Brady, 2004). However, one might not expect an inexperienced coach to make the connection between successful practice conditions resulting in poorer game-day performance, and more difficult practice, that provides learners opportunities to make mistakes and adapt, result in more successful game-day performance. Changing the behaviour of a coach is also likely to involve a significant shift in their personal coaching philosophies and preconceived notions of how motor skills are developed (Nash, Sproule, & Horton, 2008).

It is important to note that traditional technical practice approaches do incorporate some level of practice variability. Often, physical education classes will follow a simple to complex, or ‘closed to open drill’ approach (e.g. multiple structured closed drills followed by game play at the end of the lesson; French, et al, 1991). Turner and Martinek (1999) technical approach utilised this framework when they compared it with a games centred approach (GCA; specifically, TGfU) on the development of field hockey skill in novice performers. This technique approach involved students watching a demonstration of the skill, followed by closed drills that progressively increased in complexity (e.g. number of actions required to remember to perform; however, from the description provided, not practice variability), and then finished with game play. The games centred approach, in comparison, involved participants practicing under modified game rules (e.g. open drill) so that the tactical problem being addressed that session would emerge. The TGfU group was found to have improved in various skilful actions (e.g. ball control and passing decision-making) compared to both technical practice and control groups, while also generating greater amounts of declarative and procedural knowledge compared to control groups. Tuner and colleagues findings further highlighted the benefits of practice variability in more complex sporting domains.

Explicit instructions. Previous experiments adopting a self-described traditional practice routinely underpin their approach with a focus on optimising the technical execution of a movement. This is administered by the coach who provides verbal, explicit instructions relating to how to perform or correct the movement. For example, Miles, Vine, Wood, Vickers, and Wilson (2014) described their traditional practice approach as ‘technical training’ (TT) of a catch and throw task. The TT involved coaching participants with explicit verbal instructions about the movement (e.g. “See how the girl pauses before she starts a smooth even swing of her arm as she releases the ball. For a good throw, pause for the count to two in order to prepare. Then your arm needs to swing smoothly right through your release”; pg 512). Improvements were found in the secondary practice condition (visual training termed quiet eye), however not within the traditional TT group. A frequently reported detriment of explicit coaching is the subsequent shift in the learner’s attentional focus. That is, drawing a learner’s conscious attention to a movement that is performed unconsciously results in poorer performance (Wulf, Chiviacowsky, & Drews, 2015; Wulf, Höß, & Prinz, 1998). Instead, the quiet eye training approach adopted by Miles and colleagues was suggested to improve performance by directing the learner’s focus of attention towards external visual cues (Moore, Vine, Cooke, Ring, & Wilson, 2012).

Masters (1992) has conducted numerous studies exploring how the use of explicit compared with implicit instructions impacts both the performance and learning of motor skills. Within their series of experiments, the findings provide support for explicit instructions about the movement promoting an internalised focus of attention. From an ecological dynamics perspective, this internal focus on individual movement components likely interferes with the self-organisation process of performing an action. Additionally, explicit instructions may also interfere with a learners search for, and discovery of, perceptual information to guide movement (Handford, Davids, Bennett, & Button, 1997). By explicitly directly the learner to search out an invariant piece of information, it may hinder the ability of the learner to attune to other additional information, which become available at different time points, throughout the performance. In contrast, there is evidence for approaches that promote learners to exert less conscious control over their movements, such as focusing on the movement effects (Wulf et al., 1998) or implicit learning strategies (Lam, Maxwell, & Masters, 2009) are effective instructional methods.

These findings propose that those more complex perceptual motor tasks will benefit less from explicit details of the movement (Hodges & Franks, 2002). Particularly given that learners have been shown to be able to control these complex interactions between movement and perceptual information with little awareness of what actually governs their performance (Beilock & Carr, 2001). However, there have still been some experimental studies that have found no difference in learning as a result of the instructional approach adopted. Agar, Humphries, Naquin, Hebert, and Wood (2016) compared two instructional approaches when performing a novel shuffleboard task that involved shooting a puck at a target. The instructional approaches involved inducing either an internal (i.e. explicit approach) or external focus of attention across two different age groups of children. Regardless of instructional approach, older children were shown to perform better and improve faster than their younger counterparts, suggestibly due to their physical and cognitive constraints being less restrictive rate limiters to their performance. No difference was reported between instructional approaches for either groups of children. A key comment on this particular study though, is that there was no record of the learner's accumulated declarative knowledge under each of the instructional conditions; a core component of what explicit instructions are thought to induce chronically (Masters, 2000). Additionally, the task vehicle utilised for the experiment was a far aiming task, which places far less perceptual demands on the learner, for example, compared with an interceptive timing task. Suggestibly, the efficacy of explicit and implicit instructional approaches may be dependent on the task vehicle being utilised during the experiment; the attentional capacity of the learner, which is likely a reflection of skill level and cognitive ability (Buszard, Farrow, Zhu, & Masters, 2013); and how well they are able to compartmentalise information (i.e. instructions) about their movement so that it is not consciously present *during* performance.

Part-task practice. In order to allow the learner to achieve a desired degree of success, coaches must manipulate the task so that it matches the current skill level of the learner. Commonly, coaches implement a strategy of breaking down complex tasks into smaller components which are more easily taught (Magill, 2001). The benefit of this part-task approach is the reduced attentional demands placed on a novice learner. For example, cricket batting coaching often uses 'drop ball drills' which involves learners starting in what would be their final movement position, hitting a ball dropped in front of them. Therefore, rather than have to; track a horizontally moving object, coordinate their body movement to go towards or away from the ball, and meet the spatio-temporal demands of the bat contacting the ball; learners just have to swing the bat in time with a ball being dropped in front of them.

This practice organisation approach has however been questioned from a behavioural (Davids, Kingsbury, Bennett, & Handford, 2001) and neuroscientific (Goodale & Milner,

1992) perspective. Learning, specifically with tasks involving perceptual-motor skills, without the perceptual aspect prevents learners from reinforcing the reciprocal relationship between the perceptual information (e.g. from the balls trajectory) with the subsequent coordination pattern required to effectively respond (Davids, Araújo, Shuttleworth, & Button, 2003a). For example, Schmidt and Young (1987) use the example of a tennis serve, as an exemplar for schema theory, to justify the parts that could be practiced in isolation are based on estimations of 'natural boundaries'; such that one motor program was responsible for ball toss, and another program for contacting the ball at the right place and time. However, Reid, Giblin, and Whiteside (2015) examined the separation of this action and reported conflicting results. Elite tennis player's movements were captured when performing a tennis serve, and compared with a common coaching drill that isolates the ball toss action of the serve only. While preparatory mechanics were reported to be similar, the movements were significantly different in a number of ways, such as all peak angular velocities occurring significantly earlier during the serve condition, and greater peak angular velocities. Similar findings have also been reported in volleyball serve, where part-task training was dysfunctional to serving performance (Handford, 2006) This particular coaching example highlights a number of key differences that can occur when performing the complete movement, and the part-task practice drill it is designed to represent.

Similar part-task drills aimed at perfecting a movement, such as just practicing a ball toss component, have been proposed as overzealous given that elite performers do not consistently throw the ball in the exact same spot; instead, they adapt their movements to the spatial and temporal location of the ball in a prospective manner (Whiteside, Giblin, & Reid, 2014). These experiments highlight key behavioural and neurological difference that occurs as a result of part-task (i.e. deconstructing the movement during practice) practices verse whole-task (i.e. *simplifying* the task while maintain perception-action couplings) practices (Tan, Chow, & Davids, 2012). Whole-task practice activities require learners to engage in visually guided actions; that is, couple their perception of relevant visual information with the subsequent motor response in order to achieve a task-goal. It has been referred to extensively in this chapter that the separation of these process leads to questionable development and transfer of skill. Similarly, the visually-guiding role of the dorsal stream is unlikely to develop as effectively, given the part-task practice does not present the same perceptual demands. However, from a practical perspective, the question still remains how can coaches and practitioners effectively design whole-task practices that simplify the task, subsequently reducing the attentional demands on the learner, rather than relying upon part-task practice methods.

Constraints-led approach to practice

From a nonlinear dynamics perspective, the process of skill learning occurs through the interactions between key constraints, including the environment, task and the individual itself (Davids, Button, & Bennet, 2008). These constraints influence the individual's self-organising behaviour, by acting as boundaries to shape emergent actions. As such, they limit the number of possible states of configuration that can take place at any one time. As explained in more detail in an earlier section, the role of the constraints entail; individual constraints, such as the physical (e.g. anthropometrics, muscular strength, etc.) and functional (e.g. intrinsic motivation, resilience, etc.) characteristics; environmental constraints, which are the physical features such as playing surface, light, weather or ambient noise that surround the individual; task constraints, which comprise the task goals placed on the individual, as well as the equipment and rules of the task.

The purpose of manipulating constraints during practice is for a learner to develop flexible, yet stable, movement patterns that serve as a solution to their motor coordination problem (Handford et al., 1997). Drawing from its theoretical underpinnings, there are a number of principles practitioners can harness when designing practice sessions based on a constraints-led approach. These principles include promoting functional variability, ensuring the tenets of representative learning design are followed, and manipulating constraints to bring about a desired behavioural change (Renshaw et al., 2010). The following section briefly explores how these concepts can influence the skill learning process.

Manipulation of constraints. An important challenge for practitioners is to identify whether certain constraints may be rate limiters for learners at different stages of their development. For example, a physically immature cricket batter is not likely be able to strike the ball a great distance, and instead, must rely on alternative strategies to score runs. As they go through puberty and attain greater physical attributes, the current strategy may start to decay, as the physical rate limiter is removed and the ability to strike the ball greater distances emerges. Another example illustrated by Chow, Davids, Button, and Koh (2005) investigated novice participants leaning to kick a ball over a bar (height constraint) and land it on a target (accuracy constraint). Participants were found to first overcome the height barrier, before addressing the accuracy constraint. Specifically, the initial emergent height constraint began to decay as the learner became more skilled at the task. This demonstrates that constraints on behaviour are not permanent, and instead are both dynamic and can evolve over time. Coaches can leverage emergent and decaying constraints of performers by manipulating the rules or task goals to explore more functional coordination patterns at various stages of a learner's development.

Alongside any potential physical rate limiters of learners, coaches can also implement strategies to overcome functional rate limiters. These can stem from a lack of coordinative ability or psychological barrier to executing a more functional movement pattern. Commonly, task constraints are manipulated, in order to provide the learner with a representative practice task that accounts for their skill level. This can be accomplished by reducing the number of players on a field (Silva et al., 2014; Timmerman et al., 2015) or modifying equipment (Buszard, Reid, Masters, & Farrow, 2016) to bring about a behavioural change. Noorbhai, Woolmer, and Noakes (2016) measured the improvement of novice junior cricketer's bat-lift, by comparing two identical practice sessions over a 6 week period involving participants using either a normal cricket bat or a modified bat. The modified bat was 37% lighter than the normal bat, and had greater distribution of weight towards the toe end of the bat. Their findings suggested that the modified bat group adopted a more efficient bat-lift technique, and outperformed the normal bat condition group in a modified cricket game skills test.

However, this study presents a number of issues worthy of consideration. For example, the practice approach used involved participants repetitively striking a ball against a wall; a practice design that would fit within more traditional practice approaches. Therefore, given the proposed effectiveness of this traditional practice, is whether a more contemporary practice method underpinned by the principles of a constraints-led approach would also result in improved cricket batting skill. Secondly, when measuring skilful batting performance in this experiment, junior batters were required to face 3 balls for each bat condition (6 balls in total). In comparison to previous cricket batting studies, this presents a substantially low number of trials in which to compare changes in a learner's behaviour prior to the intervention and their behaviour following the intervention. The success of the modified bat group was demonstrated by the entire group outscoring their pre-intervention skills test and the normal bat practice group. Given this approach to analysing the reported data, and the limited number of deliveries batters faced during the skills test, it is unclear whether the intervention resulted in significant changes in individual learner's batting ability. It is proposed that a more effective skills test would; (1) incorporate multiple deliveries in order for batters to demonstrate whether substantial changes in their interceptive abilities; (2) replicate a game environment during the skills testing protocol, which would allow for greater action fidelity when considered the real-world performance environment; and (3) and report test-retest reliability, validity and the degree of inherent variability within the skills test.

Representative learning design. One of the key purposes to manipulating constraints is to control for the attentional demand placed on learners developing a novel skill. Much in the same way traditional practice approaches more often deconstruct a task to practice parts of the movement, a constraints-led approach instead involves simplifying the task (Chow et al., 2007; Davids, Shuttleworth, Araújo, & Renshaw, 2003c; Tan et al., 2012). When reducing the complexity of the task demands within a practice design, part-task (that is, deconstructed tasks) hinder the integration of motor-skills and contextual knowledge (Van Merriënboer & Kester, 2008). Conversely, task simplification proposes that selected parts of a complex action be learned while key perceptual information, and the resultant movement, remain coupled (Dicks et al., 2008).

For example, an interceptive timing task with a novice learner might begin with a less temporally demanding task, such as an underarm throw, coupled with a task goal that encourages the execution of a desired coordination pattern. The next stage may be to incorporate an over arm action that includes the ball bouncing on the pitch (a previously highlighted key event in cricket batting; (Müller & Abernethy, 2006; Sarpeshkar & Mann, 2011). As opposed to using a ball projection machine, the performer under these conditions can learn to attune, initially, to the ball flight information, before being exposed to pre-ball flight information from the opposition (Pinder et al., 2011c). Additionally, rather than being required to practice a single coordination pattern, this approach allows the learner to explore different functional movements to ascertain for themselves which best achieve the task-goal.

Recently, Lee, Chow, Komar, Tan, and Button (2014) compared two practice approaches grounded in linear and nonlinear pedagogies to the development of tennis skill. Over a 4 week training period junior tennis players practiced under linear (LP; e.g. repetitive drills, idealised movement patterns) or nonlinear (NP; e.g. manipulation of constraints, representative learning design) pedagogical practices. Both groups improved compared to their pre-intervention skills test, however no difference was found between groups. Interestingly, the way in which both groups developed their tennis specific skill differed between learning approaches. The NP learners demonstrated greater variability in movement patterns while improving their accuracy at the same rate as LP, who demonstrated far less variability within their selection of movement patterns. Suggestions by the authors regarding future research included implementing interventions with a greater duration than 4 weeks, and, reporting individual's intrinsic perceptions of practice (e.g. motivation, enjoyment). Additionally, exploring the effectiveness of these practice approaches in more skilled performers would improve the sphericity of current knowledge.

Functional variability. Movement variability has traditionally be seen dysfunctional (Slifkin & Newell, 1998), in line with traditional practice approaches that seek to remove all variability in order to attain highly reproducible movement. Promoting functional variability has been proposed to facilitate a (guided) discovery approach to learning by allowing learners to establish idiosyncratic movement patterns that satisfy task constraints (Davids, Bennett, & Newell, 2006; Renshaw et al., 2010). The idea of 'functional', as opposed to dysfunctional, represent movement solutions that meet the demands of the task. One proposition is that movement variability allows for greater adaptions and flexibility to sudden changes in environmental or task constraints, reduce the risk of injury, and can facilitate the onset of new coordination patterns (Bartlett, Wheat, & Robins, 2007). Therefore, rather than directing a learner to change in order to conform to a narrower view of expert performance, coaches should consider whether the individualised movement pattern may benefit the learner.

Vickers, Livingston, Umeris-Bohnert, and Holden (1999) conducted a 7-week intervention on novice, intermediate and skilled baseball batters comparing a 'behavioural' training group, involving simple-to-complex instruction and practice drills and high volumes of feedback, with a decision-training group that received complex, variable practice activities and less feedback. Interestingly, novice batters who practiced in the behavioural group were shown to have the greatest improvement in batting skill during retention and transfer tests. Concurrently, the intermediate and skilled batter's group demonstrated the greatest improvement when practicing under the decision training condition. This finding that the decision training group, provided with minimal coaching instruction, outperformed the behavioural group with intermediate and skilled batters, suggests that constraining skilled performers into an idealised movement is not as effective as providing them challenging practice activities, which allow for a search of multiple movement solutions to a task.

Another example provided earlier in the review reflects the level of movement variability considered in cricket-specific research. That is, few studies have explored horizontal bat shots or back foot shots, nor has it been examined when these movement types are employed in response to different ball trajectories, for different skill performers. Instead, almost sole attention has been given to front foot vertical bat shots. It is easy to understand that, while more ecologically valid findings could be reported as a result of allowing for movement variability, systematic methods of analysis make this inherently difficult (e.g. sample size of each movement, confounding factors such as order effects, etc.).

Following a constraints-led approach to skill learning, coaches act as facilitators to learning by implementing tasks that allow the individual to develop their own solution to motor coordination problems (Greenwood et al., 2012). This can be achieved by developing games that adhere to representative task design; through manipulating key constraints that parameterize learning dynamics (Chow, Davids, Hristovski, Araújo, & Passos, 2011; Newell, 1986), and maintaining perception-action processes. A constraints-led approach, underpinned by non-linear pedagogy, has been positioned to provide an adequate framework to analyse how individuals learn to an interceptive timing task such as cricket batting.

Comparing a traditional practice approach

The importance of motor learning intervention studies comparing a certain learning approach to a traditional practice approach is two-fold. Firstly, interventions assessing the efficacy of a practice approach require another practice approach to be compared against. Simply comparing against a control group that did not participate in any sort of practice is unlikely to reveal any theoretical or practically applicable findings. Secondly, traditional practice approaches, that focus on repetitious movements and optimal technical movement are considered commonplace within coaching practices and amateur sports (Roberts, 2011). This greatly contrasts the reported practice approaches of high level coaches employing more game-scenario and dynamic practice environments (Cushion & Jones, 2001; Light & Evans, 2013). By comparing to an already routinely utilised practice approach, researchers are more likely to generate findings applicable to coaches and subsequently, inform them about more effective practice approaches.

There is still much unknown regarding the development of various types of motor skills. For example, closed skills, which involve tasks such as far aiming and are initiated by the learner, are often adopted by researchers due to the ease in which they can be standardised and controlled. Golf putting and basketball free throw shooting have been such examples of sporting tasks utilised to explore the impact of mental imagery (Phelps & Kulinna, 2015; Woolfolk, Parrish, & Murphy, 1985), instructional learning approaches (Poolton & Masters, 2017), and types of feedback (Ishikura, 2008) on development. Open skills, such as interceptive timing tasks in contrast, are far less easily controllable while maintaining representativeness. Changes in stimuli, or changes in a performer's attunement to informational variables as a result of learning, can change of the responsive movement to those informational variables. As highlighted previously by Coehlo and colleagues (2007), the findings from closed skills do not automatically translate to skills performed in more open environments. Furthermore, it is evident that experiments conducted on simplistic motor skills lack of transferability towards more complex multi-joint movements (Wulf & Shea, 2002), while experiments conducted in laboratories do not always translate to real-world performance (Mann et al., 2010). It is therefore evident that more research is required, which adopts a representative learning design approach, to better understand the effectiveness of practice approaches in sporting domains.

A number of researchers (Hoffman, 1990; Locke, 1990; Singer, 1990) have highlighted the questionable impact motor learning research has had on coaching practices and physical educators prior to their review. It was suggested that there was a lack of findings form laboratory-based experiments that were practically applicable to coaches working within more dynamic, sport-specific performance environments. Specifically, the use of simple motor tasks to explore relevant motor learning phenomena such as instruction, feedback or mental imagery. These simple tasks include movements with minimal requisite degrees of freedom, or trivial perception-action coupling. For example, a two rapid arm-reaching task, with different levels of movement complexity (Behrman, Cauraugh, & Light, 2000), or fundamental movement skills comprising of running, jumping or skipping, have been used as task vehicles to explore the effectiveness of various motor skill phenomena (Akbari et al., 2009; Goodway, Crowe, & Ward, 2003). However, when these skills are applied to more complex sporting tasks, the resultant effect of those motor interventions change.

CHAPTER 3: DEFINING CRICKET BATTING EXPERTISE FROM THE PERSPECTIVE OF EXPERT COACHES

Introduction

Successfully intercepting a fast moving object requires individuals to develop superior skills that provide an ‘expert advantage’. Previous research across fast ball sports has highlighted that experts develop coordinative, cognitive, perceptual, and psychological advantages to assist in circumventing the extreme temporal and spatial demands associated with interceptive timing tasks (Le Runigo, Benguigui, & Bardy, 2005; Müller & Abernethy, 2012). Cricket batting is one such task vehicle commonly utilised by researchers to explore expert advantages. For example, (Regan, 1997) highlighted that at the highest level, batsmen must maintain spatial errors of less than 5cm, and temporal errors of less than 2 to 3ms for deliveries travelling at 160km^{-}h. Given the minimal error tolerance permitted in order to be successful, cricket batting is an ideal task vehicle to better understand the complex nature of expertise.

Research into cricket batting expertise has had a strong focus on the individual and their skill capabilities. For example, a cricket batter’s technical skills (Stretch et al., 2000), perceptual capabilities (with particular reference to anticipation; (Müller et al., 2006; Renshaw & Fairweather, 2000) and psychological traits (Weissensteiner, Abernethy, Farrow, & Gross, 2012) have all been areas independently investigated. Possessing superior technical abilities, such as earlier initiation of movements, are thought to allow for better execution when striking a cricket ball (i.e. spatial accuracy), and has been examined empirically by manipulating the size of the bat and comparing between different skill level batters (Weissensteiner et al., 2011). Similarly mental skills, such as the ability to manage internal pressures (i.e. anxiety, arousal, etc.), are strategies reportedly utilised by skilled cricket batters to achieve more consistent performances (Thelwell & Maynard, 2003). While these are all undoubtedly critical factors of expertise, the importance of providing context when examining skills has been an area of concern for researchers.

Exploring the different characteristics of expertise has required researchers to develop resourceful and inventive methodologies. Video simulations using occlusion techniques (Connor et al., 2018; Müller et al., 2006; Woolley et al., 2015), pattern recall experiments (Williams, Ward, Bell-Walker, & Ford, 2012) and laboratory-based experiments (Elliott et al., 1993) are examples of methods that have furthered our understanding of the different skills possessed by experts. However, the issue of ecological validity has been raised when using these methodologies (Davids, 1988; Farrow & Abernethy, 2003). Mann et al. (2010) reported how the action specificity impacts upon an experts cricket batter's anticipatory advantage; their findings highlighting the importance of utilising tasks where the perception-action couplings are preserved (Gibson, 1979), especially compared to measurement via verbal recall, when looking to better understand expertise (Van der Kamp et al., 2008). Therefore, an unresolved issue is exactly how this contextual information is utilised in a performance environment Specifically, how an expert's own individual constraints (i.e., perceived capabilities such as technical and tactical strengths and weaknesses; emotional states; intentions; fatigue level), in interaction with the dynamic environmental (i.e., pitch and atmospheric conditions) and task constraints (i.e., the current state of the game; position of fielders), influence their decision-making behaviour.

A prominent issue in capturing expertise is the importance of understanding how the dynamic interactions of constraints (Newell, 1986), such as the exemplars described above, influence the emergence of skilled behaviours. Key information sources guide performer's actions, and unrepresentative experimental designs that exclude these key information sources have shown that experts often lose their performance advantage (Oudejans, Michaels, & Bakker, 1997). Araújo and Davids (2011) described Gibson (1966) original concept of 'knowledge of' and 'knowledge about' the environment to better understand how interacting constraints and specifying informational sources guide expert behaviours (Silva, Garganta, Araújo, Davids, & Aguiar, 2013). In this instance, 'knowledge of' the environment refers to the individual's ability to perceive the performance environment in relation to themselves and their own action capabilities. In contrast, 'knowledge about' involves indirect perception to capture what information sources mean.

It is thought that attuning to more specifying information allows the expert to calibrate their actions to exploit available affordances, and subsequently achieve their performance goals (Araújo, Davids, & Serpa, 2005). However, an interesting novelty in sporting tasks is the constantly evolving performance goals and environment in which experts must navigate. For example, the immediate goals of a cricket batter at the beginning of a game is likely to be different than half way through the game; likewise the performance environment and opposition strategies. Therefore, exploring the ways in which experts attune to specifying information promotes viewing performance as a series of events that are nested within one another, rather than a series of unrelated events (Renshaw & Gorman, 2015). As opposed to a single isolated trial, emergent behaviours can be influenced by factors or situations that happened in previous events (i.e. games, rallies, deliveries, etc.). In his interview with a former expert batter and international level coach, Renshaw (2010) reinforced this ideology that performance is not solely about one key event (e.g. a dismissal), but instead is a culmination of critical nested and connected events leading up to that particular outcome.

Given the challenges of capturing the true nature of expertise through laboratory-based studies, researchers have begun to explore various other methods. One such approach has been to utilise coaches; as an untapped knowledge source, they possess a unique wealth of information regarding the specific multidimensional nature of expertise in their sport (Greenwood et al., 2012). Those professional and experienced coaches have developed and often continually refine their knowledge through mentors or peers, trial and error, previous experiences and formalised coaching courses (Irwin, Hanton, & Kerwin, 2004). Utilising this experiential knowledge to explore further the understanding of expert development (Weissensteiner et al., 2009), is therefore an alternative and complementary methodology to build on the empirical studies previously undertaken in attempts to further our understanding of expertise. The aim of this study was therefore to utilise the knowledge of expert cricket batting coaches to explore the key factors that characterize cricket batting expertise. Given the complex nature of expertise in sport, it is logical to draw upon this experiential knowledge to assist with our understanding. For example, Renshaw (2010), identified crucial concepts within the game based on the coach's unique and extensive experiences. While certain limitations surrounding the use of experiential knowledge to guide empirical research have been noted (Wulf, 2012), it is argued that they still provide an ideal platform to investigate the dynamic and complex nature of cricket batting expertise.

Material and methods

Participants

The participants were eight expert high performance Australian coaches. In order to ensure a well-rounded approach to analysing cricket batting expertise from a group of individuals with different experiences, coaches were required to meet the following criteria to be included in the study (1) have played at a state or international level as a batsmen; (2) having coached a state or international team, or be a specialist batting coach in these teams, (3) have 5 or more years of coaching experience and (4) possess a level 3 Australian cricket coaching qualification. All coaches had coached more than one state or international team, while the average duration of their coaching at their highest level was 2.8 years ± 2.25 (range; 1.5 years – 8 years). The number of participants required to reach saturation of the data was consistent with previous studies' sample size of expert coaches within a sport (Greenwood et al., 2012;

Weissensteiner et al., 2009). Ethical approval was obtained prior to the commencement of the study and granted by Victoria University's ethics committee.

Table 3.1. Coaching and playing experience of high performance coaches who participated in this study. Individual data on coaching duration is excluded due to being easily identifiable.

Participant	Highest coaching level	Highest playing level
IC IB[1]	International	International
IC IB[2]	International	International
IC IB[3]	International	International
IC SB[1]	International	State
SC IB[1]	State	International
SC IB[2]	State	International
SC IB[3]	State	International
SC IB[4]	State	International
SC SB[1]	State	State

Data Collection

A one-on-one, in-depth, semi-structured interview technique was used for the purpose of this study. While a structured interview involves all coaches being asked the same question, in the same order, and being formulated ahead of time, a semi-structured approach allows for more flexibility when asking questions. This was utilised to better explore the unique individual perspective of each coach with respect to their knowledge and beliefs on batting expertise. In-depth interviews and open-ended questions are common interview techniques and suggested as ideal for eliciting expertise from expert persons (Coté, Saimela, Trudel, Baria, & Russell, 1995; Marshall & Rossman, 1989).

Three investigators were primarily involved with the interviewing process. A series of pilot interviews were conducted with numerous coaches of various coaching levels. This was undertaken, firstly, to ensure the questions were appropriate; secondly, to narrow down the ideal coaching level of potential candidates; and thirdly, to provide the first author the opportunity to develop his interview skills specific to this study through discussion and reflection with the second and third author. The first author conducted all eight interviews with expert high performance coaches. Interviews were conducted wherever each coach felt most comfortable, which included an office, private cricket stands or a coffee shop. Each interview started with a general overview and information about the study. Following this, coaches were asked questions relating to their demographic and coaching experiences (e.g. duration, highest level). The design of the questions were based on Spradley (1987) and Cotè and colleagues (1995) three categories of open-ended questions; descriptive, structural and contrast questions. Descriptive questions are those that allow the coach to describe their activities and identify what they perceive as being important. Examples of descriptive questions include “could you describe what batting skill means to you?” or “so what makes for a skilful batter?” or “what are the keys to batting successfully?” Structural questions are those that allow the coach to explain these concepts deeper and for the investigator to understand how this information is organised. Examples of structural questions include “you talked about the necessity of a good technique, could you tell me what a good technique is and what it’s made of?” or “you mentioned experts have a good understanding of where things should be, could you explain what you mean by that?”. Finally, contrast questions are those that clarify and distinguish between concepts or ideas coaches describe. Examples of these include “what do you believe to be the differences between those who make it beyond a representative level and those who don’t?” or “what separates those at a high level, from those playing high level grade cricket?” After each interview, both the first and second author created codes, categories and themes after reading through the transcript separately.

Data Analysis

All interviews were transcribed verbatim and sentence-by-sentence coding was performed by the lead author and co-author to examine any themes identified from coach's direct quotations. Both authors created categories and sub-categories that captured the fundamental meaning or concepts being described by coaches. Direct quotations were used to support each author's interpretation of the coach's opinion regarding the ideas being discussed. Interviews continued until theoretical saturation had been reached, whereby no new ideas or concepts emerged. Similar to Weissensteiner et al. (2009), a hierarchical method was utilised to conceptualise the higher order and lower order categories, and the relationship that existed between them to form a grounded theory. A constant comparative method was used throughout the process. Two methods utilised to validate the data analysis process and ensure credibility. Firstly, the second author was involved after each interview in the form of reading through the transcript and recording their own ideas and concepts. Group meetings (between the first and second author) were conducted to discuss interview transcripts, while key quotes were shared between all authors to elucidate perceived reoccurring themes. Secondly, the first author used a journal to detail key aspects of each interview including concepts, ideas and questions from the responses of the participants.

Results

Results emerged from the data collection, and analysis, of interviews comprising 8 expert level batting coaches relating to the factors/processes that they believed underpin cricket batting expertise. The critical underpinning processes that constitute expert batting are shown in Figure 3.1. To set the key processes in context and to simplify the discussion, the findings are organised via a temporal timeline that consists of three phases, including the pre-ball phase, ball phase and between-ball phase. The following section, firstly, describes the model that emerged from the author's interpretation of the participant's views, and secondly, explores each phase of the model with direct supporting quotes from the participants.

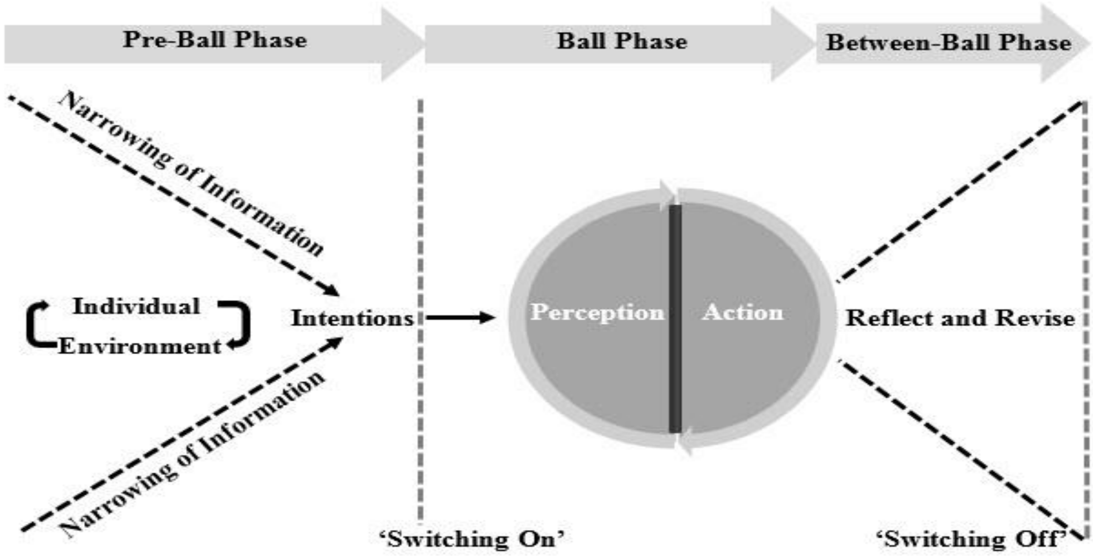

Figure 3.1. Conceptual model of the process in which an expert batter's attunement to crucial information shapes their intentions, and precedes both an evaluative and 'switch off' phase

The pre-ball phase begins at a nominal point in time when the expert batter begins to focus attention on an upcoming game. This begins with a generalized search for information about factors that might influence upcoming performance, such as environmental conditions or fixture lists. As the first ball of the batter's innings draws closer, the search for information becomes more specific. For example, as the batter walks out to bat, information such as atmospheric and pitch conditions, situation of the game and opposition field settings are all relevant in shaping the intentions of the expert batter. Most importantly, these intentions shaped by the batter are dependent on the batter's knowledge of their own batting capabilities.

The ball-phase, beginning as the bowler enters the run-up stage of their bowling delivery, includes the direct perception and action process that occur as the bowler delivers the ball and the batter is required to coordinate a motor action. Expert batters underpin their action, based on both their intentions, established in the pre-ball phase, and in the perception of key information regarding the opposition bowler's movement. In this sense, both the contextual information about the game and the key perceptual information (i.e. opposition kinematics and ball trajectory) are responsible for the subsequent coordinative action of the batter.

Finally, the between-ball phase occurs immediately after the batter has executed an action, and concludes as the bowler begins their run-up again for the following delivery. Batters begin by reflecting on the previous delivery and the shot they played in response. This is followed by a 'switching off' of attending to task relevant information, both cognitively and behaviourally. Finally, expert batters described a 'switching (back) on' point whereby batters would begin a set of consistent, routine movements to help focus their attention on the upcoming delivery.

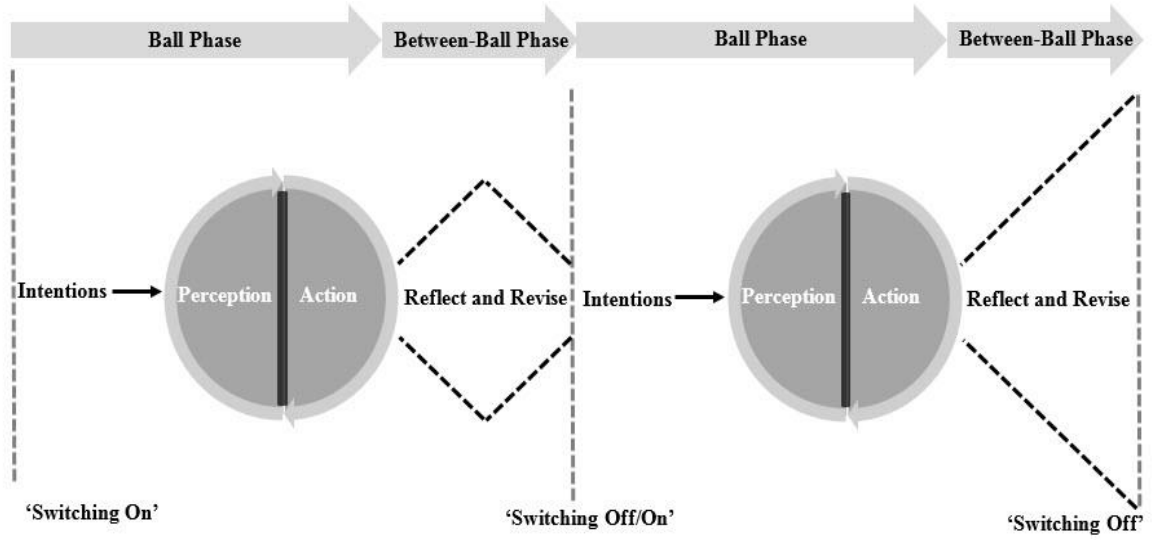

Figure 3.2. "The Plus" demonstrating the ball-by-ball cycle whereby expert batters engage in a reflective process, 'switch off' from task relevant thoughts, and 'switch on' again.

These findings indicated that expert batting is based on a continuous cycle of updating 'knowledge of' the individual batter-environment interaction, as a means to achieve their overarching goal of 'controlling the game'. This 'knowledge of' the environment enables batters to develop batting plans to frame intentions in advance of each delivery. Having clear intentions enabled batters to attune to the specifying information, provided by bowlers in their run-ups, that manifested itself as batters getting into a 'rhythm' with the bowler's approach/ run-up.

Another key finding of the study was that rather than cricket batting being about solely about the actions each ball, expert performance was significantly impacted by what batters did between balls, and thus, has been coined "The Plus" (Figure 3.2). Given the dynamic nature of the batter-environment interaction during a batting event, expert batters engaged in a systematic between-ball process of reflection to update their 'knowledge of' the batter-environment system. This allowed them to update intentions, and more finely grained attunement to specifying information to exploit key affordances and (re-)calibrate actions. In this sense, cricket batting can be viewed as a continuous reflection of the key factors that relate to the ball, "plus", all of the key factors that relate to the subsequent ball and the previous ball, "plus" all of the key factors that relate to the subsequent ball and the previous balls, and so on. This process enables batters to pro-actively manipulate individual, task or environmental constraints and allows them to meet their aforementioned goal to take control of the game.

Pre-ball phase

Search for information ex situ (outside the performance environment)

Expert batter's epistemological search for knowledge begins well before the actual batting innings (i.e. performance). During this early period, expert batters are concerned with collecting general information, funnelling down to more specific information as the time till the performance becomes closer. Gathering this information about the upcoming game allows them to begin to shape their intentions and formulate a plan against the opposition team.

> *The art of batting, there are a number of things; reading the parameters, reading the conditions, this pitch, what are my shot making parameters on this pitch today. If you're batting in Adelaide you're probably driving at everything that pitches in your half, if you're batting at the Gabba or the WACA, you're only driving at half volleys and full tosses. So understanding those parameters was the first thing that was important.* [IC IB[2]]

This funnelling of information concludes as the expert batter enters their performance environment (i.e. walks out to bat). While previous experience was noted as helpful, actually perceiving the affordances in the performance environments, and interpreting from this information what the opposition was likely to do, was the most reliable method to shape the expert batter's intentions.

Yeah you get out there, you take centre, you look around at your field. You're not looking around to say g'day boys how you going. You're working out okay I've got 4 slips and a gully, he's not going to bowl too many at my pads… So you understand what they're [opposition] trying to do, and that comes from playing against them as well. And if you play against someone you haven't seen for a while or never seen them before – look at their field. Okay he's going to try bowl outside off stump and swing it away. [SC IB[1]]

Two, three days out really is when you should be really thinking about that [tactics and game plan]. [Another] quick go over [of your game plan] when you get to the ground. Have a think about who you're facing, what they might do to you, how they usually bowl at you. But a lot of it, as an opener, especially if you haven't played them before, is looking at the fields and summing up what they're going to do when you're out there. Having a really sold plan, or base game plan about what you're going to do while your assessing that… It buys you some time to work out what they're trying to do, and then evolve your game on top of that when you're out in the middle. [SC IB[3]]

Understanding your own game

Framing intentions and formulating a plan prior to the game was crucial to expert batting performance. Experts shape their intentions around (1) their own action capabilities, (2) the affordances available in the performance environment, and (3) the task goal during a given situation of a game. The first crucial factor is that expert batters must possess superior knowledge of their own batting capabilities on various different pitch conditions in order to optimise their search for information.

That comes down to understanding your game and making good decisions around that. So like if you are a bottom hand player, and exaggerate a strong bottom hand player you have to understand driving on the up on the onside is going to be quite tough for you. So if you get on a tough wicket you feel you can't t do that, you've got to have the decision-making and planning and discipline to say right now I can't do that today or I can't do that for the first hour or 2, until the balls a bit older, or the wickets a bit flatter, or the ball is a bit closer to me. And then when the ball is under your nose you can do what you want with it then. But don't go driving on the up to something slightly outside off stump swinging around if you've got a bottom hand grip [technique]. And that's all apart of understanding your game, and putting it into you planning. [SC IB[2]]

One International coach described how four different International level cricket batsmen all devised different game plans to counter one opposition bowler. These intentions further highlight expert's knowledge of their own superior coordinative actions and scoring options, they believe might be available to them, in the upcoming performance environment;

I'll give you an example… I think it was about 2004 and we went to Sri Lanka, and we hadn't played [Sri Lankan Bowler] for a period of time… We set about, the coaching staff got divisioned together, got data together, then our first meeting in Sri Lanka we got the top six of the batting order together. And then we begin dissecting each other's batting technique. And so [Aus Batter #1] for instance believed that his best method of playing [Sri Lankan Bowler] is that he would sweep as much as he could. So he had a big reach that, far bigger than anyone else's, therefore that could upset [Sri Lankan Bowler]'s length for a start, aside for him the fact he played that shot very well. And if he couldn't sweep he decided he'd get himself right back in the crease… [Aus Batter #2], whose experiences in India were poor, said that if he played the way he played in

> *India he'd be in trouble. So basically he said he was going to use his feet as much as possible and run at [Sri Lankan Bowler] as much as he could. [Aus Batter #3] said well even though he could use his feet, [he] said I can't read him. So instead I'm just going to back myself and play deep, right in my crease and I'll read him off the wicket – and I'll back myself to do that. [Aus Batter #4] said first chance he got he would slog sweep [Sri Lankan Bowler] because he knows [Sri Lankan Bowler] didn't like being hit so [Sri Lankan Bowler] would automatically move his field and that would open up some space where [Aus Batter #4] would be more comfortable playing that way.* [IC SB[1]]

Secondly, the performance environment being cohabitated by the opposition and their own task goals meant the batters search for information, and shaping of intentions, is a continuous, ongoing process. Expert batters described how their intentions were shaped by the affordances available to them. In this particular example, previous knowledge of an opposition bowler served to direct attention to search for certain opportunities for action.

> *I knew with [former international fast bowler] he's going to be running up bowling outswing. He'll pitch most of them up and had a good bouncer. Before anything else I know that much. The next this is, what happens when he makes a mistake. His mistake were going to be too full and too wide outside off stump so there cover drive, square drives straight drives. The other thing is if it doesn't swing it'll slide onto my pads, so I've got the leg glance and the on drive. So I know what my options are going to be before he has even bowled a ball. So now you don't, you can't go to the bank on that, because I don't know what's going to come out. I've just got to make sure I'm ready and recognise straight away this is the full wide one bang. This one is not swinging its sliding onto my toes- bang! You've got to have your game plan* [IC IB[2]]

Finally, intentions were also shaped by the role of expert that would best serve the task goal. Cricket batting, being unique in that it has multiple different game formats that vary in duration, requires batsmen to balance the risk of a particular coordinative action (e.g. playing a shot in the air, or going for a quick run) and the subsequent reward (i.e. number of runs). This balance between risk and reward varies depending on the format of the game (e.g. limited-over game vs. multi-day game), the position of the game (e.g. number of runs scored/ required to win and the number of wicket lost), and the oppositions strategy (e.g. bowling plan and fielding positions). An International coach and batsmen described the role of an opening batsmen during a Limited-overs game and how their task goals can reflect more risk-taking behaviour due to the constraints placed on opposition fielders (i.e. Only a limited number of fielders can field on the boundary).

> *[Regarding different batting roles at the beginning of a T20 game] ... So you have an easy chance to clear the field and get the side off to a good start. Taking a few risks, but generally those players who bat up there, [it is] because they can play those shots. So [those shots are] not really risks – more playing their game, their role in the side if you like. But if it is nipping around a little too much, then they might have to reign it in a little. On the flip side if you go out and take him [the bowler] on a little bit, it might throw them off. In bowler friendly conditions they might start dishing up some poor balls. So there is a fine line, fine balance. That's why those top skilful players can perform both those roles if you like.* [IC IB[3]]

Importantly, coaches describe how the search for information about the upcoming performance environment subsequently shapes the intentions of the expert batsman. The information available also becomes increasingly specific as batsmen come closer to facing their first delivery. During this period, whether it be prior to the game or during the game, experts remain adaptable to changes that might influence their task goals (e.g. weather conditions, position of the game, etc.).

> *... You have to be adaptable to change the momentum of the innings – whether that is by batting through an hour or whether it is counter attacking during a period.* [SC IB[3]]

Ball phase

When describing expert batsmen during this phase, it was highlighted that their actions are highly effective due to their attunement to the bowler's kinematics. This inter-personal coupling to the opposition's movements was suggested to allow experts to overcome extreme temporal constraints;

> *He's in time with the bowler. He's got plenty of time, because he is picking up all of the information. You hear people say the difference between good players is they've got time. They've got time because they're not handicapping themselves. They're not making movements that are irrelevant. They're pre-movements are in sync with the bowler, they're picking up all the information so they do have more time than the guy who is not picking the ball up until its half way down, so of course he is rushed.* [IC IB[2]]

While attuning to information is crucial, adapting one's movements, based on newly formed intentions, was also an important component of expertise. Interestingly, this is accomplished to create an emergence and decay of possibilities for action.

> *When we say watch the ball - don't watch the ball. You should be able to know the cues in watching the ball. It should almost be there seeing what they're bowling before they even bowl the ball. So for me if they've got 3 slips and a gully they're not going to bowl*

short. If they've got back pad, leg gully, two back on the hook [shot], they're going to bowl short. So your pre movements not going to be forward, if they're going to bowl short [you move back] so you give yourself more time. That's watching the ball and understanding the game. [IC IB[1]]

It was further described that an efficient technique is achieved, firstly, by maintaining superior balance throughout the action and gripping the bat so that intuitive movements are less likely to result in a risky outcome (e.g. having a dominant bottom hand which can lead to the ball unintentionally going aerial). Secondly, coaches suggested that expert batters are less inclined to make superfluous or unnecessary movements. Interestingly, comments on technique were often intertwined within the context of intentionality (i.e. take control of the game, clear mind);

I'd say key thing is good footwork, clear mind. I think your head position – keeping your eyes horizontal are key to picking up line and length well. Tempo or whatever, footwork. I mean you can go on more the grip, the bat-lift and all sorts of things [SC IB[2]]

When asked about tempo, this coach referred to the concept of "having plenty of time" [follow up question – "What did you mean by tempo"?].

Really decisive footwork is how to put it. If you're going forward then your forward, if you're going back than you're going back. There's no stuck in the crease or in between and no second guessing yourself, your first decision is the right decision. [IC IB[1]]

Interestingly, the initial phase of the expert's batting innings is highlighted as the most difficult. In order take advantage of the affordances presented within the environment, batters are required to attune to specifying sources of information (e.g. pitch, opposition bowler and strategy) and adapt their coordinative actions to suit;

> *What we talk about as coaches, we talk about our first 20 or 30 balls… Hit the ball here, do this foot work, and your back lift is here. And some people misconstrue this, and think, well that's how I've got to bat for the whole innings. Nah, that's how you bat until you get a feel of what's going on in the middle…. Once you get in, you can actually start playing the shots you want cause you understand what the wickets doing, you understand what the balls doing, you understand what the bowlers trying to do.* [SC IB[2]]

> *So [at the start of your innings] you've generally got a period of about half an hour where it might be tough. Another time where it's overcast, you might have to work for 20 overs before it becomes simple or before you feel like you're in control of the game… So generally when there is conditions like this [a flat pitch that provides consistent ball trajectory and little to no lateral movement (swing)], you feel like you can actually hit the ball freer, you see it better and you can hit it. In conditions which favour the bowler, the ball moves, which tests your technique. So anything that moves is dangerous, and anything that doesn't move is fodder* [SC IB[4]]

Coaches describe that a batter's primary goal as being able to 'control the game'. This task was accomplished by assessing the position of the game, and taking advantage of available scoring opportunities congruent with the amount of risk involved taking them.

> *…you'd say that world best are generally making good decisions on bowlers or on state of game or on the conditions. And then tied into that would be their tactical nuance. With the state of the game, what do they do? How do they work out how to score runs?*

How do they try to put themselves in a position where they control the game and the bowler? [IC SB[1]]

Developing your game where your routine [development of game plan] is the same on every surface to start with. Then from that routine you work out, okay these are the shots I can play today. These are the types of bowler's I'm facing. This is where I'm looking to score my runs. Battings not about survival it's about scoring runs... if you have the same routine, same… philosophy at the start [of your innings], you can then gauge what you can play and what you can't play. [SC IB[1]]

Intentions shaping perception-action

During performance, experts must reshape their intentions, actions and perception continually to adapt to the situation of the game, underpinned by their overarching goal of being 'in control'. In regards to intentionality, experts are better able to recognise key nested events that offer opportunities to manipulate the opposition, by executing certain actions themselves;

I don't know whether you've heard me talk about the danger zone; that 4-6m mark; that's the danger zone, if the bowler owns that then he's on top. You [the batter] own that and you're on top. The job of the batsmen is to get control of that danger zone as quickly as possible. So if he slides a bit full to my side of the danger zone, I have to punish him. If I punish him, if I hit him back down the ground for four I can guarantee you that apart from the top 1% of bowlers, the next ball will not be up there. They'll adjust and they'll try and bowl back of the length which often comes short. And bang, the next one goes for four and guess who's under the pump? [IC IB[2]]

Coordinative actions are, similarly, reshaped to suit the demands of the performance environment. These adaptations to actions may only be temporary, until certain constraints evolve and present new opportunities for action. Examples of changing in constraints, which lead to novel affordances, may occur through a change in fielding positions, opposition bowler, or a change in ball flight characteristics (i.e. less lateral movement).

> *This only came late in my career but I visualised batting in a phone box. And I wasn't allowed hit the ball until it was right into my phone box. So say you're batting in a phone box, you can't hit the ball till it arrives there and it stops you from hitting out here [in front of your body]. And this is once again misconstrued information – it's not for your whole innings. Some days it might be, because the bowler's all over you, and the balls swinging and doing all sorts. And if the ball's swinging and you're playing out here [in front of your body] you're in [expletive] trouble.* [SC IB[1]]

Experts also modify their perceptions as the situation of the game changes. Affordances that were previously exploited, may no longer equal the risk-reward balance experts perceive. Depending on the change in constraint (e.g. loss of wicket might require more conservative behaviour), experts modify their search for affordances that present the lowest degree of risk that would still achieve the task goal. This particular coach describes some examples whereby an expert might look for a specific scoring area to exploit, or modify their intentions towards each opposition bowler they face;

> *Just if you've got, if you can see a batter whose going really well and a couple of wickets fall, is able to reign himself in and build another partnership. And then he might go through the gears again. In a one-day game, it's being able to pick [and] attack the bowlers you feel confident hitting, or what areas you feel you know you're going to hit best, and then judging an innings. If you've got to chase 300 these days there has got*

to be some good hitting in there, and have a good plan on who you may target what areas of the field are your areas, are your zones. That's just batsmanship. Or craftsmanship. That's just understanding what you've got to do. [SC IB[1]]

Finally, manipulating and exploiting affordances in the performance environment is an ongoing and continual process during a game. Two different expert batsmen can manipulate and exploit the environment in vastly different ways. While these batsmen may share the same goal, their perception of the environment, relative to their own capabilities may differ, and thus, will shape their intentions and actions differently. Coaches described how having different intentionality-style batsmen go about maintaining a sense of control over the game, through shifting perceived pressure onto the opposition, can be more effective;

Pressure [back onto the bowler] is built in different ways. Whether that's taking the game deeper into the innings by taking shine off the ball, and minimising damage [i.e. losing wicket] with the top order… or by scoring runs at a good rate. I think if you've got two guys trying to take the shine off the ball, the pressure doesn't build on the bowler at any stage, then if all of a sudden you lose a couple of wickets, the team is under pressure. But if you've got a guy taking the shine off the ball and another scoring runs than that's a good mix. [SC IB[3]]

When asked whether expert batters could interchange between different roles, the same coach further described how this intentionality-style role is often reflected by your understanding of your capabilities;

There are definitely players who are adaptable and can do both, but generally speaking its one side of the fence or the other…. I always tried to have an aggressive mindset with the way I played but I was limited in my abilities in certain areas, areas I just *didn't touch until 2 hours into my innings. And then I was able to go from there and try take the game away.* [SC IB3]

Between-ball phase

In-between deliveries were highlighted as crucial periods for expert batsmen. Constant evaluation of the performance environment, especially over periods of multiple days, required different strategies to manage certain stressors. The follow section explores the purpose and processes of a between-ball routine exhibited by expert batsmen;

The purpose of a good routine is to prepare yourself properly. To make sure that you are in the right frame of mind to receive the next delivery. [IC IB2]

A very important part of batting is how you, what you do between balls. What you think about, and how you let the previous [ball] go, and then prepare [yourself] to be ready for the next one. The art of batting is very much; the physical aspect of it is the part we see, but that's the tip of the iceberg. [IC IB2]

Following a between-ball routine suggestibly helped experts, when in their performance environment, to regulate their emotions. Coaches described how experts reconciled their thoughts to ensure they felt a sense of comfort, and, similar to the shaping of their intentions, take control of the game situation.

[Talking about having a routine to follow] But it's for us to know we can walk out there and be in that feel good comfortable space.... And the mental side [of a routine] is [utilised] for feeling confident [SC IB4]

Oh you've got to be [comfortable]. I had a few minutes with [former international batter] chatting and he said, he felt the most important thing he felt is you had to be comfortable in your environment. Comfortable in the middle – to him that was his territory. The swagger that was his, [he] had to get comfortable out there and dictate, control and make sure you know you're the boss of things. [SC IB[2]]

Between-ball routines also provided an opportunity for batsmen to reflect on the current situation of the game, and the accompanying nested events that occur throughout. This cognitive reflection can range from the previous deliveries, to the next perceived event. Taking advantage of immediate affordances was described as a crucial component of maintaining control of the game. However, forethought to next period of the game (i.e. nested event) was also a part of evaluating current demands, and therefore, intentions;

It starts ball by ball, if you're managing yourself well and you're playing each ball on its merits then you're at least even. Then it's a matter of are you taking all of the scoring opportunities? And provided you're taking most of them you're on top… He knows if I've missed a scoring opportunity. He's bowled a bad ball or less than good ball and you haven't scored of it, he knows he's dodged a bullet. And if he keeps bowling them and you keep not scoring off them then he's under no pressure. [IC IB[2]]

What's your strategy, if you went another five overs deeper would it [the game situation] change? Would they have brought on a different bowler? Or would they have been a little more tired? Would you get more loose balls if there further into their spell?... Try get them to see hey if I can wrestle [through] this period or hey they [the opposition] might go away from their plan too if they haven't got you out. [International bowler] is on for a reason – he's on to try get you out. If he's not getting wickets, what's *he going to do? He's going to change his plan. Is that plan going to be more suited to your game when they're bowling bouncers at you? Most likely. Maybe not. But it's going to be different from not being able to score right now. So being able to understand that.* [SC IB[3]]

However, it was also highlighted that, while it is important to reflect on errors, it is just as important not to dwell too long upon them;

... So as cricketers we miss them all the time [taking advantage of a perceived scoring shot], and you have to just reset and refocus. [SC IB[4]]

The physical component of the routine was described as a manifestation of taking a break from the demands of the performance environment. Various actions were employed, such as walking down the pitch and tapping the ground (i.e. gardening), talking to a teammate or looking into the crowd. As such, task irrelevant thoughts were very common during this switch off period;

I was pretty calm out in the middle, not much fazed me out in the middle. I liked to score, so when I wasn't scoring I could get a bit itchy. Especially the younger version of me... I remember looking at the score, or float around [looking at] the crowd, or wander down the wicket [and] say something to my mate, a bit of gardening… Always quite consistent, what I did. [IC IB[3]]

... Everybody has a routine. When I talk to people, particularly good player's, their routines aren't that dissimilar. There is a physical aspect to it, at the end of each ball they have a break so they might walk down the pitch and pat down imaginary things, or they might walk out towards square leg just take a few steps away and walk back in again. It might involve marking their guard either every ball or it might be they just

mark their guard again when they're back on strike or at the start of a new over. [IC IB[2]]

This 'switch off' period in-between deliveries was highlighted as crucial for expert batsmen. This strategy was suggested to assist in overcoming any mental or cognitive fatigue that might occur during performances that stretch for hours or across days.

I liken it to a motor car; you get in and you turn the motor car on. The cars in neutral – so the engine's ticking over but it's not using a lot of gas. That's between balls, that's between overs, that's waiting to go into bat. The engine's on, you're aware of what's going on. Then general awareness, but you're not using up a lot of energy… So when the bowler gets back to the top of his mark, you put it into first gear. So now you're ready to roll. But again you're not using up a lot of energy… And as the bowler gets into the load up, you stick the car into over drive. Because now, from that point to the time you receive the ball, which is probably less than a second, is the critical moment… So from then until the play was completed I was in overdrive, and that would have only have been a few seconds. Once the play was dead, I put the car back into neutral. [IC IB[2]]

Well the contest starts basically just as the bowler starts running in, so if you can be in that moment of contest and switch on for however long you're going to bat for, [then] that's your job. That's all you have to do. You have to be engaged for that moment. [SC IB[4]]

Discussion

The purpose of this study was to better understand cricket batting expertise from the perspective of individuals with knowledge of expertise originating from both coaching and playing at an elite level. The findings of this study further expand on Weissensteiner et al. (2009) initial conceptual model of expertise development in cricket batting by developing a new model based on grounded theory. Themes that emerged included exploring how an expert's perceptual skills and attunement to the environment shapes their individual technical (motor) skills; while their cognitive strategies manage their decision-making through self-regulatory behaviours, and psychological stresses. Coaches described expertise as a multi-faceted, co-adaptive relationship between the individual and the environment to gain a perceived 'control of the game'. The changing environment included the opposition bowler and their tactics, pitch conditions and the situation of the game. The model reveals that the expert batter needs to be attuned to this information, given they shape the intentions of the individual's actions (that is, technical motor skills) relative to the affordances within the environment.

The strategy by which an expert cricket batter changes from one previously-functional movement to another now-more-functional movement, based on changes occurring in the environment, can be better understood using behavioural dynamics (Fajen & Warren, 2003). Experts are regarded as possessing superior technical skills that can be considered stable behavioural patterns (i.e. actions), consistently reproducible and resistant to certain perturbations. However, they also demonstrate flexibility within their movements that allows for adaption; tailored to the performance environment. Bifurcation is the mechanism by which one behavioural pattern is no longer considered functional, and instead the expert batter adapts towards another behavioural pattern (Hristovski, Davids, Araújo, & Button, 2006). This switch between stable patterns, as described by (Araújo et al., 2009), is considered as a result of the changes in the environment. Similarly, expert batters suggestibly adjust previously functional techniques (e.g. footwork) and adapt to the changing conditions brought about by the opposition bowler and affordances within the environment.

Coaches regularly described scenarios where experts could utilise relevant and available information in their performance environment to shape their intentions, and as such, their actions. Self-regulatory behaviours, such as the planning, monitoring and evaluating actions, are suggested to explain how expert batters manage and manipulate the constant changes occurring in the performance environment. While self-regulation research itself is still developing outside of academia, it is relevant to note that it is the environment which stimulates an individual's awareness, and subsequent regulation (Dinsmore, Alexander, & Loughlin, 2008). Without this interaction of the individual and environment, the act of self-regulation does not occur. More broadly, Zimmerman (2008) surmised the concept as *"the degree to which students are meta-cognitively, motivationally and behaviourally active participants in their own learning process"*. In this instance, it is suggested that every performance can be likened to a batter being required to 'learn' what is required to succeed. The process of how expert batters go about achieving this is presented in Figure 3.1.

Developing a routine to manage stressors, both externally and internally produced, was another characteristic of expertise. Internal stressors included mental fatigue and lapses in concentration, while external are those that were exacerbated by environmental constraints such as maintaining a level of comfort and control within the performance environment. Expert batters employ routines, both behavioural and cognitive, in between deliveries to manage these pressures. Similar to the research findings on performance routines (Cotterill, 2010; Cotterill, Sanders, & Collins, 2010), this suggestibly allows experts to manage more effectively their emotions; attentional focus (Bernier, Trottier, Thienot, & Fournier, 2016; Mesagno, Hill, & Larkin, 2015); concentration (Foster, Weigand, & Baines, 2006) and enhance consistency of performance (Beilock & Carr, 2001; Mesagno & Mullane-Grant, 2010). Interestingly, a crucial aspect of the pre-performance routine literature is said to involve being able to channel attention from irrelevant thoughts to task-specific thoughts. In contrast, coaches described using irrelevant thoughts between deliveries as an effective strategy to prolong optimal arousal states. One explanation for these conflicting approaches may be that research on pre-performance routines has predominately focused on more closed skills (i.e. those with specific start and end points). Therefore, tasks that involve on going, *in-performance* routines, that occur over extremely long periods of time (in the example of Test cricket, a 5 day game involving 3 hour playing sessions before a break, 3 times per playing day) may require alternative strategies.

The final key finding was an expert's knowledge of the performance environment; that is, knowing what is required and how to achieve it based on own perceived strengths. Experts were described as being able to assess conditions and recognise which of their own repertoire of coordination patterns yield the lowest risk for most reward, depending on the situation of the game. Having effective coordinative and tactical strategies when the trajectory of the delivery promotes metastability. Pinder et al. (2012) provided evidence for a metastable performance region in cricket batters when the ball is pitched between 4m and 8m, demonstrating a mix of front and back foot, and attacking and defensive coordination patterns. Interestingly, a coach (international coach and player) highlighted how this area is crucial for a batter to maintain a sense of control over. The purpose of this is that deliveries pitched closer to the batter demonstrate a more stable movement pattern, similar to balls pitched further away, and therefore easier scoring opportunities. When pitched on this 'good length' (4m – 8m from the stumps; commo term it is referred to by coaches and players), expert batters are suggested to have 'intentions' (e.g. game plan) that help weight the execution of certain coordination patterns over others. These intentions are formed from the individual's constraints (e.g. emotions, cognitions) and available information in the performance environment.

Expertise has often been explored as a 'snapshot of the performer at a single point, or over a very short period of time (Renshaw & Gorman, 2015). However, it is becoming more common for researchers to exploit alternative methodologies that allow for a more holistic understanding. Gaining the perspective of former expert batters, who then became elite level batting coaches, provides a unique perspective on expertise. In this instance, expertise is not expressed as a snapshot during a performance; but instead as a model of how it is repeatedly characterised over multiple performances. Greenwood et al. (2012) reinforced that, while the utilisation of coaching expertise empirically is under-represented, it can complement existing evidence and provide avenues for future direction.

Conclusion

The findings from this study provide support for viewing expertise as multi-dimensional. Cricket batting is one such example where the technical, tactical, perceptual and psychological skills interact to underpin expert performance. Expert batters 'control the game' by perceiving the changing affordances in the performance environment; that is, assessing whether the performance environment favours the expert batter, and then exploiting certain bowlers or periods of time until it does so. Through an awareness of their technical strengths and perceiving the game situation, they are able to minimize the risk of being dismissed while shifting pressure back onto the opposition by scoring runs. Finally, batters possess well developed psychological strategies to manage emotions such as anxiety, and problem solve game specific challenges. Future research should endeavour to investigate individual differences between experts, and how to effectively develop these batting expertise.

CHAPTER 4: EMERGENCE OF SKILLED BEHAVIOURS IN ADVANCED, INTERMEDIATE AND BASIC SKILL LEVEL CRICKET BATSMEN DURING A REPRESENTATIVE TRAINING SCENARIO

Introduction

Analysing skilful behaviours in sport performance has long been of great interest to researchers and practitioners alike. Unlike being exposed to a novel or unfamiliar situations, observing individuals with various levels of skill or prior experience within a sporting task can reveal crucial information about skilful behaviour. Earlier experimental work typically followed a more reductionist approach, which allowed for highly standardised and controlled experiments that limited the number of variables influencing behaviour (Hoffman, 1990; Singer, 1990). However, to better understand skilful behaviour in more dynamic environments, there have been calls to progress towards methodological approaches that are representative of the performance environment (Abernethy, Burgess-Limerick, & Parks, 1994; Renshaw & Gorman, 2015). As such, skilful behaviour can be viewed as the resultant product of an individual's adaptive actions, cognitions and emotions to the evolving (i.e. dynamic) constraints in their environment. Testing environments, therefore, must contain key information that enables fidelity in the actions, cognitions and emotions of the performer attempting to achieve a specific performance goal (Pinder et al., 2011b; Seifert et al., 2013a).

Measuring expertise in dynamic performance environments presents a complex challenge for researchers. Interceptive timing tasks, such as those occurring in fast ball sports, are commonly utilised as effective task vehicles in laboratory settings. Cricket batting, as an exemplar dynamic interceptive timing task, involves batters' facing an opposition bowler and accompanying fielders whose intent is to 'dismiss' them for as few runs as possible. Differences between skilled and lesser skilled performers have been found in coordinative movements (i.e. biomechanics; (Elliott et al., 1993; Penn & Spratford, 2012; Stretch et al., 1998; Stretch et al., 1995; Taliep et al., 2007), pattern recognition of opposition kinematics (Müller & Abernethy, 2012; Müller et al., 2006; Renshaw, Oldham, Davids, & Golds, 2007) and spatio-temporal interceptive abilities (Weissensteiner et al., 2011). However, examining key processes underpinning expertise conducted outside the performance environment have been criticised for not being representative of the inherent complexity within dynamic tasks. In particular, there is a lack of research into the requisite adaptive behaviours that occur in response to the task goal, opposition actions and performance environment (Araújo et al., 2007; Pinder et al., 2011b).

Scientists have argued that studies that separation of perception-action couplings leads to a degradation and false account of the performance of experts (Mann et al., 2010; Oudejans et al., 1997; Van der Kamp et al., 2008). This stems from Goodale and Milner (1992) who proposed two, separate yet integrated, visual pathways for interceptive actions, that enables skilled performers to functionally adapt their behaviours. However, a vast amount of experimental of research into interceptive tasks may have only engaged the ventral pathway (vision for perception) during video-based tasks, while others may have only addressed the dorsal pathway (vision for action) when utilising ball machines that lack pre-ball flight information (Panchuk, Davids, Sakadjian, MacMahon, & Parrington, 2013). For example, cricket batters have been shown to execute fundamentally different movement patterns, relying on different information-movement couplings, as a result of batting against a bowling machine instead of a bowler. This is also congruent with Travassos et al. (2013) meta-analysis findings that expertise advantages over novice performers are relative to the similarity between the behaviour performed in a simulated setting, compared to the actual behaviour in the performance environment. These findings highlight the need for some experimental analysis of skilful behaviours to occur in more representative, field-based performance environments (Pinder, Renshaw & Davids, 2011).

Previous experimental work on cricket batting actions have commonly utilised ball machines, explicit task instructions or a combination of both to investigate technical aspects of the movement (Stretch et al., 1998; Taliep et al., 2007; Weissensteiner et al., 2011). While this has revealed invaluable information regarding the incredible spatio-temporal abilities of skilled performers, the lack of realistic perceptual information and task goals impacts the ability of performers to execute realistic and adaptive actions. For example, batting strokes performed with a singular front foot movement has been the primary movement investigated. However, as demonstrated by Pinder et al. (2012), cricket batters execute strokes off both the front foot and back foot. It is also unclear exactly how many foot movements' different skill level batters perform within more realistic settings. Explicit and narrow task goals given to the performer limit their ability to demonstrate their movement adaptability, therefore limiting our understanding of expertise. In realistic performance environments, movement behaviours are also perceived as either 'functional' or 'dysfunctional'; dependent on whether they are deemed by the individual to meet the task goals within their environment (Davids et al., 2003b). Task-goals that are purposely ambiguous and open ended, such as "score as many runs as possible without being dismissed", can provide a unique opportunity to analyse the way in which different skill level performers address their movement functionality, and go about achieving the task goal.

From an ecological perspective, decision-making behaviour is heavily embedded within an individual's perception and action capabilities (Araújo et al., 2006). Specifically, an individual's intentions within a task, attention to various perceptual information and resulting adaptation of motor behaviours shape emergent skilful behaviours (Jacobs & Michaels, 2007). (Araújo et al., 2005) investigated the decision-making strategies of sailors during a dynamic simulated regatta task, recording the actions and cognitions of elite and novice level sailors. They reported novice performers attended to their own individual movements (i.e. sailing manoeuvres) more often than experts, who in turn attended to more adversarial informational variables (i.e. wind conditions). This is consistent with a large body of work that has highlighted the advantages of skilled performers focusing their attention externally, during both simple tasks (McNevin, Shea, & Wulf, 2003; Wulf, Shea, & Park, 2001) and more complex interceptive timing tasks (Castaneda & Gray, 2007). This difference in cognitive focus highlights a change in behaviour that occurs at some point during skill development.

Reporting the cognitions of different skill level participants during a task, alongside their motor behaviours, has previously been seldom explored. In Araújo et al. (2005) experiment, sailors were given the task goal of moving their boat from a starting position to an end point as fast as possible. It is unclear, however, whether the individuals completing the task perceived their own performance as successful or unsuccessful, or what information within the performance environment sailors would base their assessment of 'success' upon. Given the aforementioned findings of Araújo and colleague's, one can hypothesise that individuals likely perceive successful performance upon either performing optimal technical or process-focused movements (e.g. executing flawless sailing manoeuvres), or capitalising on the available opportunities for action, based on information in the environment (e.g. outcome-based). Understanding how individuals at various skill levels perceive their own successfulness at meeting task goals would provide more insight into skilful cognitive behaviours that occur during skill development.

Finally, an individual's emotional state plays a key role in influencing movement behaviours. Certain emotions have been shown to influence the affordances perceived and acted upon by an individual when performing a task (Graydon, Linkenauger, Teachman, & Proffitt, 2012; Pijpers, Oudejans, Bakker, & Beek, 2006). For example, climbers were tasked with climbing a wall during two conditions that caused either high or low levels of anxiety. During the high anxiety inducing condition, performers were found to underestimate their action capabilities (Graydon et al., 2012), executed more actions and demonstrated a narrower focus of attention when perceiving cues (Pijpers et al., 2006). Clearly, emotions play a vital role in performance and need to be considered as an interacting constraint influencing the production of functional movements. Recently, there have been calls for research to better address this relationship between action, cognition and emotions during learning experiences (Headrick et al., 2015). It is argued that this approach can further our understanding of how individual learners interact with specific task demands and their environment, at different stages of their development.

The purpose of this study was to explore the interacting actions, cognitions and emotions produced by advanced, intermediate and basic skill level cricket batsman during a representative training scenario. Batters performance scores, actions (motor skills), cognitions (perceptions of self-performance and intentions) and a range of emotions were all recorded in situ to better understand the resultant emergent behaviour. It was predicted that advanced batters (professional state level) would outperform both intermediate and basic skill level batters, while intermediate batters would outperform those basic skilled batters, in all outcome measures and display more functional co-ordination measures (i.e. cricket specific actions). It was also predicted that those advanced level batters would perceive themselves to have 'won' more overs than their less skilled counterparts, demonstrate an external focus on outcome when evaluating prior performance and strategizing about how to score more runs for upcoming performance. In contrast, both intermediate and basic skilled batter's cognitions, would be internally focused when thinking about their own prior and upcoming performance. Finally, advanced level batters would report different emotions with lower nervousness emotion ratings at the beginning of the scenario, and higher fulfilment ratings at its conclusion, than both intermediate and basic skill level batters.

Methods

Participants

Twenty-two cricket batters were invited to participate in this study. Eight state level (Advanced skill level; age: M = 23.5yrs ± 3.8; height: M = 182.7cm ± 5.5; weight: 84.5kg ±

3.2), eight amateur senior grade club level (Intermediate skill level; age: M ± SD = 25.4yrs ± 1.7; height: M ± SD = 179.5cm ± 3.9; weight: M ± SD = 76.8kg ± 7.7), and eight junior state representative batters (Basic skill level; age: M ± SD = 14.2yrs ± 0.3; height: M ± SD = 171.5cm ± 9.4; weight: M ± SD = 62.0kg ± 14.6) were tested during their pre-season. Six amateur grade senior club level right arm pace bowlers (age: M = 24.2yrs ± 3.7; height: M = 180.8cm ± 5.9; weight: 74.3kg ± 7.1) were also recruited to bowl to all participants during testing. University ethics approval was obtained to conduct the study, and informed written consent was provided by all participants, including parental consent, prior to commencing the experiment.

Data Collection

A representative cricket batting task was developed that would allow for skilful cricket batting behaviours, to be examined. Participants used their own bats and were required to wear standard protective equipment, which included helmet, gloves, thigh guards, leg pads, and abdominal protector. The training test scenario was designed to simulate the middle period of a limited overs game and required batters to face right arm medium pace bowlers (approx. 115km/h) bowling with pre-used Australian regulation balls (156g; Kookaburra Turf Rejects). The basic skilled batters faced these same bowlers at a marginally reduced speed (approx. 100km/h – 105km/h) for safety reasons. To achieve this, bowlers simply bowled off a shorter run-up. A radar gun (Stalker Radar Pro, Plano, Texas, USA) was positioned in front of the umpire to monitor the bowler's speed for each ball and ensure that the batters were experiencing bowling of similar speeds. Markers were placed every 2 m along the side of the pitch from the batter's stumps to code ball length. A standardised field was set for all participants to visually represent the seven scoring opportunities available (Figure 4.1).

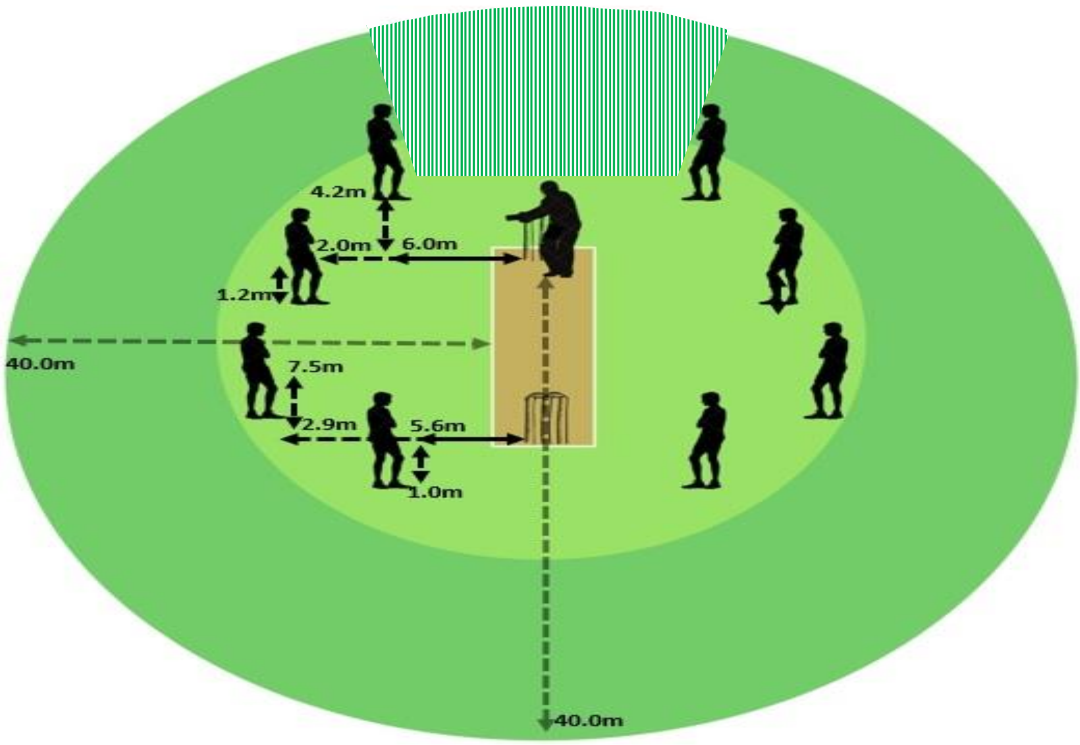

Figure 4.1. Testing setup depicting the position of each mannequin, which are mirrored on the other side of the field. Scoring zones exist in between mannequins (excluding shaded area behind the batter).

Mannequins were placed in the fielding positions with cones 1.5 m either side to signal the horizontal area the represented fielder would hypothetically cover in this scenario. Plastic poles (height = 2 m) were also placed on each cone to signal the vertical area covered. Participants were awarded ‘runs’ by hitting the ball into any one of the seven spaces between the fielders; four runs were awarded if the ball travelled to the boundary (40 m from the batter’s crease), two runs if the ball travelled more than 20m but did not reach the boundary, and one run if the ball travelled more than 10 m from the batter’s crease. If a ball was struck in the air to any one of the fielding positions, it was characterized as ‘out’ (dismissal) and the batter was told they would lose 8 runs. This was included to encourage a risk versus reward scenario similar to a game (note: the batter did not actually lose 8 runs for every dismissal when analysing results).

In order to record the skilful actions of batters, two high-speed cameras (Baslar, Baslar Ace acA2000, Germany; Casio Exilim, Japan) capturing at 300 frames per second were utilised. All camera distances were measured from the centre of the batter's crease. The front-on camera was placed on a hydraulic tripod and positioned directly in line with the batter (camera height = 5 m; distance from the centre = 60 m). A second camera was positioned side-on at a 90-degree angle from where the batter was facing (camera height = 1.5 m; distance from centre = 50 m; Figure 4.1). Video play back allowed the investigators to code each trial using subjective ratings including quality of bat-ball contact (Müller & Abernethy, 2006), force of bat-swing (Mann et al., 2010), and footwork technique rating (Table 1). In order to record the cognitions of batters, after each over, a brief confrontational-style interview was conducted with the batter, asking questions directed towards their tactical perceptions. The three primary questions used were; (1) "Who do you think metaphorically won that over, yourself or the bowler; (2) and why?" and (3) "what was your game-plan that over?" Interviews were subsequently transcribed verbatim, along with sentence-by-sentence coding and content analysis was performed. Finally, categories and sub-categories that captured the fundamental concepts being described by batters were conducted by the lead author. In order to record the emotions of batters, a Sports Learning and Emotions Questionnaire (SLEQ; Headrick, Renshaw & Davids, 2015) was administered before the start of the 18 balls and immediately at the conclusion of the experiment (See Appendix C). The questionnaire required participants to respond to a list of words that described an emotion (e.g. happy, frustrated, pressure, excited) by selecting a number between 0 (not at all) and 4 (extremely) that best represented how they currently felt.

Table 4.1. Operational definitions of the three categories utilised in each subjective rating of quality of bat-ball contact, force of bat-swing and footwork technique.

Rating	Quality of contact (QOC)	Force of bat-swing (FOBS)	Footwork technique
2	*Good contact* Ball contacts the bat face and travels in a direction consistent with the plane of the bat-swing.	*Complete swing* Complete follow-through of bat-swing after anticipated bat-ball contact.	*Deliberate movement* Transfers weight by stepping forward or backward, and foot is not in motion at time of contact.
1	*Poor contact* Ball contacts the edge of the bat or does not travel in a direction consistent with a plane of the bat-swing.	*Incomplete swing* Incomplete follow-through of bat-swing after anticipated bat-ball contact.	*Readjustment movement* Initially transfers weight forward or backward, however makes a readjustment movement in the final quarter of total ball flight time, prior to contact.
0	*No contact* Ball does not contact the bat when the batter attempts to play a shot.	*Defensive shot* No follow-through of bat-swing after anticipated bat-ball contact.	*Evasive movement* Does not transfer weight forward or backward, or jumps away from the line of the ball prior to contact.

Procedures

Each participant was presented with the same game scenario. 5 minutes prior to commencing the test, the participants were read the following script;

> "You are the first batter coming in to bat after a wicket has just fallen on the last ball in the previous over. The game is at an even position for both teams, and your

role is to score as many runs as possible without being dismissed. You are currently in the early to middle overs of a limited overs game."

A brief warm-up was then provided prior to undertaking the test, where participants faced 18 'throwdowns' (over arm throwing at approximately 80km-h) from the three bowlers to familiarise them with the pitch (i.e. playing surface) conditions. The testing procedure involved bowler's bowling 18 deliveries to each batter (in blocks of 6 balls labelled 'overs' with at least 3 minutes rest between each over), with each bowler bowling no more than six deliveries consecutively. Each bowler was randomly assigned 11 of the 66 total overs to be bowled during the skills test, and given a randomised script of what lengths to bowl each over. In each over the bowler being asked to include four good length deliveries (ball pitching approximately 4 m to 8 m from the batman's stumps), one full of a length delivery (0 m to 4 m from the stumps) and one short of a length delivery (over 8 m from the stumps, however, not bouncing above the batter's head). To help guide the bowler, they were directed to use the cones placed either side of the pitch as a guide to length. Illegal deliveries (e.g. ball bouncing over the batter's head or the ball travelling outside the wide lines) were not included and instead bowled again.

Data Analysis

Actions

Performance outcomes were calculated on the total number of runs and scoring shots participants achieved over the 18 balls test. The bat-ball contact quality rating and force of bat-swing rating both use a validated rating system that scores a 2, 1 or 0 points for each trial (Table 1). A third subjective rating was included, after viewing the trials, to address the various footwork coordination patterns employed by batters. A rating scale was developed in consultation with two experienced, elite coaches (one former international coach and one current international coach). It was designed to encompass three common movements employed by batters in this experiment. Points were assigned for movements that were perceived to be more efficient, based on coaching manuals and the perceptions of experienced elite coaches (Woolmer, Noakes, & Moffett, 2008). For example, stepping or jumping away from the ball is thought to reduce the ability of a batter to contact the ball, or strike it powerfully. In contrast, a batter transitioning their bodyweight forward or backward to move into line with the ball prior to contacting the ball has been suggested as an effective way of powerfully striking the ball. Intraclass (0.79) and interclass (0.83) correlation coefficient demonstrated acceptable levels of reliability. Batting characteristics included percentage of shots played by stepping ‘forward’ or ‘back’ (i.e. the direction of the last movement prior to bat-ball contact is either forward towards the ball or backing away from the ball), percentage of vertical or horizontal bat shots, and percentage of shots played along the ground or in the air. Finally, movement timings and durations were analysed as absolute values (ms) and relative measures (percentage of time relative to ball release and bat-ball contact).

Cognitions

For the purpose of this study, the three confrontational questions were transcribed verbatim and coded for analysis by the first author. Firstly, batter’s perceptions of each over were coded as either a ‘win’, ‘even’, or a ‘loss’ based on their response to the question “who won the over, yourself or the bowler?” A follow up question of “why do you think [their answer] won/ it was even?” elucidated five codes including: (1) the ability (or lack of) to score runs; (2) being (or not being) dismissed; (3) (good or poor) execution of the batsman or (4) bowler; or (5) an emotional cause (e.g. felt/ didn’t feel comfortable). The final question, “what was your game plan that over?”, revealed six codes which included: (1) scoring runs by describing the process or outcome in which they would be scored; (2) limit the number of dismissals; (3) refer to making a technical change during the over; (4) achieving bat-ball contact; (5); or other, which is a combination of two codes that include “assess the conditions” (coded twice) and (6) “no plan” (coded once). Descriptive statistics of the relative number of times each code appeared per skill level group are presented in the results section.

Emotions

The Sports Learning and Emotions questionnaire (SLEQ) was utilised just prior to the first ball being bowled, and again immediately following the last ball of the test. The results are presented as the total SLEQ score, and then separated into four factors which include enjoyment, nervousness, fulfilment and anger. All five scores are presented as pre-test and post-test measurements for each of the three skill groups. The reliability of the questionnaire subscales has been previously reported in a Doctoral thesis (Headrick, 2015). The reported Cronbach’s alpha (α) for each factor was found to be above .85 and therefore rated as ‘high’.

Statistical Analysis

In order to analyse the actions of batters, including objective measures (runs scored, scoring shots and batting characteristics) and subjective ratings (QOC, FOBS and footwork technique), separate one-way ANOVAs were conducted. Where further analysis of the different movements (readjustment movements vs. no readjustment movements) were required; in this instance, a two-way mixed ANOVA was conducted. Post hoc (Tukey) pairwise comparisons were then undertaken to determine which comparisons were statistically significant. Cognitions were presented using descriptive statistics. Two-way repeated measures mixed ANOVAs were used for the emotions when comparing pre-test and post-test measurements across skill levels. For all ANOVAS, the Greenhouse-Geisser correction was applied for any violations of Maulchy’s test of sphericity. P value was set to 0.05 level of significance. Effect sizes were calculated by partial eta-squared (η^2) and categorised as either small (0.01), moderate (0.09) or large (0.25).

Results

Analysis of the bowler's deliveries was initially undertaken to check that each batter received the 'same' test. Analysis revealed no difference between the different skill level batters, in terms of the three different lengths bowled, which included full of a length deliveries $F(2, 19) = 0.06$, $p = 0.94$, $\eta^2 = 0.06$ (advanced: 4.50 ± 2.07; intermediate: 4.63 ± 1.30; basic: 4.38 ± 0.92), good length deliveries $F(2, 19) = 0.57$, $p = 0.57$, $\eta^2 = 0.06$ (advanced: 9.00 ± 2.37; intermediate: 9.75 ± 1.17; basic: 9.87 ± 0.71) and short of a length deliveries $F(2, 19) = 1.89$, $p = 0.18$, $\eta^2 = 0.17$ (advanced: 4.50 ± 1.05; intermediate: 3.63 ± 0.74; basic: 3.75 ± 0.89).

Performance outcomes

Significant differences were found between skill levels for runs scored $F(2, 19) = 46.15$, $p < 0.05$, $\eta^2 = 0.83$ and the number of scoring shots played $F(2, 19) = 23.17$, $p < 0.05$, $\eta^2 = 0.71$. Post hoc tests revealed advanced level batters scored significantly more runs (44.67 ± 4.08) and played more scoring shots (11.83 ± 1.47) than intermediate level batters (26.88 ± 5.06; 7.75 ± 0.46) and basic skill level batters (14.88 ± 7.22; 6.13 ± 2.23). Likewise, intermediate level batters scored significantly more runs than basic skill level batters, however, no difference was found between the number of scoring shots played between these two groups (Figure 4.2).

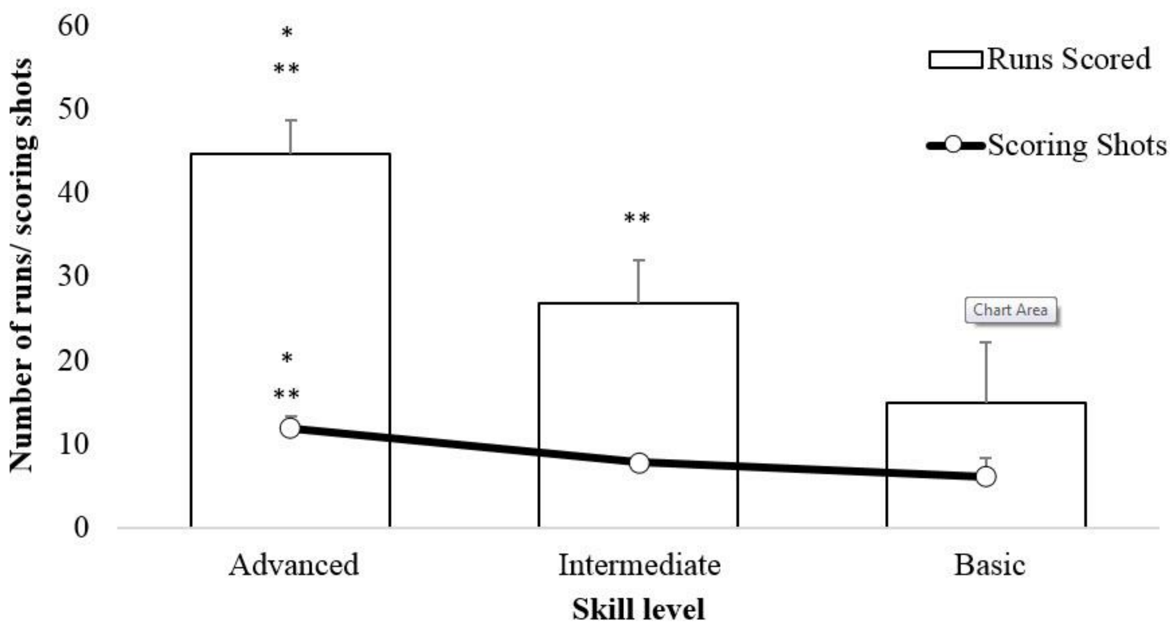

Figure 4.2. Average number of runs scored and scoring shots played by advanced, intermediate and basic skill level batters.

*Significantly different from intermediate level batters (p < 0.05); **significantly different from basic skill level batters. Error bars represent standard deviation.

Technical Factors

Analysis of technical factors revealed significant effects for quality of bat-ball contact (QoC) $F(2, 19) = 11.94$, $p < 0.05$, $\eta^2 = 0.56$, force of bat-swing (FOBS) $F(2, 19) = 11.57$, $p < 0.05$, $\eta^2 = 0.55$, and footwork technique ratings $F(2, 19) = 14.29$, $p < 0.05$, $\eta^2 = 0.60$. Post hoc tests revealed advanced batters had significantly better quality of bat-ball contact (1.68 ± 0.07) than both intermediate (1.38 ± 0.19) and basic skill level batters (1.23 ± 0.21). Both advanced (1.87 ± 0.11) and intermediate batters (1.56 ± 0.34) also had significantly greater force of bat-swing than basic skill level batters (1.11 ± 0.34). Finally, advanced batters demonstrated higher technique ratings (1.86 ± 0.20) than both intermediate (1.28 ± 0.31) and basic skill batters (1.17 ± 0.22), while intermediate batters also rated significantly higher than basic skill level batters (Figure 4.3).

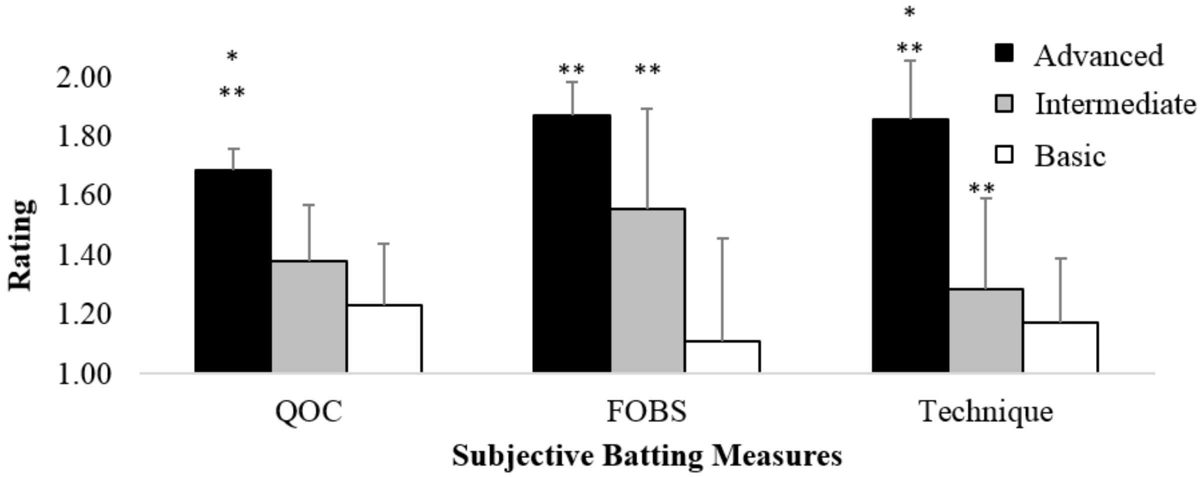

Figure 4.3. Average quality of bat-ball contact (QOC), force of bat-swing (FOBS) and technique rating.

*Significantly different from intermediate level batters (p < 0.05); **significantly different from basic skill level batters. Error bars represent standard deviation.

Batting strokes

In regards to the way in which batters executed their strokes, there was a significant difference in the percentage of shots executed off the front foot or back foot $F(2, 19) = 6.45$, $p < 0.05$, $\eta^2 = 0.40$ and percentage of vertical or horizontal bat shots $F(2, 19) = 10.52$, $p < 0.05$, $\eta^2 = 0.53$. No difference was found for shots played along the ground or in the air $F(2, 19) = 13.58$, $p = 0.10$, $\eta^2 = 0.22$. Figure 4.4a shows advanced batters played significantly more shots off the front foot (71.26% ± 16.49) compared to intermediate (45.19% ± 12.16) and basic skill level batters (47.05% ± 15.55). Basic skill level batters were also found to play significantly more vertical bat shots (90.07% ± 10.0) than both advanced level (60.00% ± 4.86) and intermediate level batters (67.50% ± 11.39; Figure 4.4c).

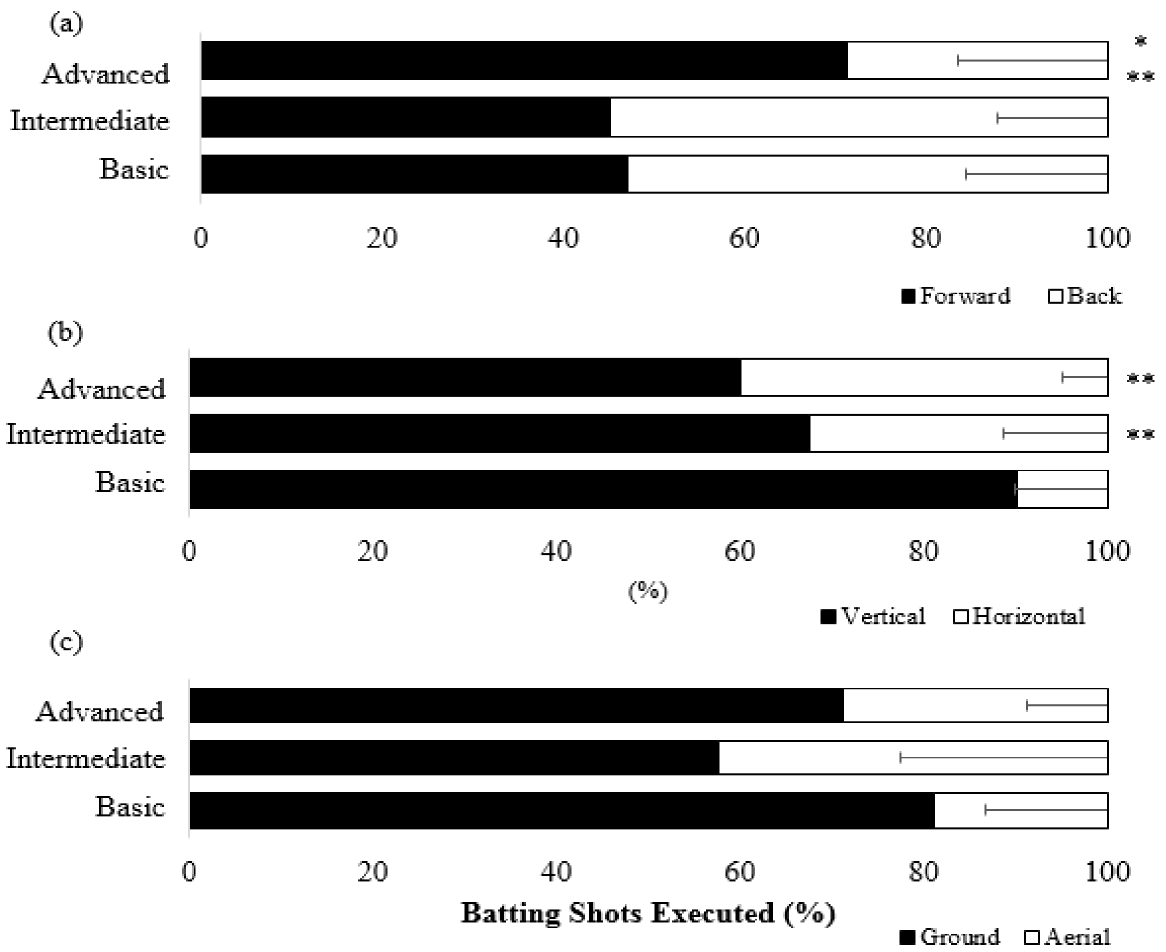

Figure 4.4. Ratio of shots played off the front and back foot (a), shots played with a vertical or horizontal bat (b) and shots played along the ground or in the air (c).

*Significantly different from intermediate level batters ($p < 0.05$); **significantly different from basic skill level batters. Error bars represent standard deviation.

Movement characteristics

There was a significant difference in the average number of movements $F(2, 19) = 11.52$, $p < 0.05$, $\eta^2 = 0.55$ executed by the batters of different skill levels. Post-hoc tests revealed that advanced level batters performed significantly less movements than both intermediate and basic skill level batters. Similarly, there was a significant difference in percentage of trials executed with a secondary movement $F(2, 19) = 3.90$, $p < 0.05$, $\eta^2 = 0.29$ and a readjustment movement $F(2, 19) = 25.32$, $p < 0.05$, $\eta^2 = 0.73$ between skill levels. Post-hoc tests revealed advanced level batters performed significantly less secondary movements than basic skill level batters, and performed significantly less readjustment movements than both intermediate and basic skill level batters.

Table 4.2. Average number of foot movements and percentage of trials where batters performed an initial movement, a secondary movement or a readjustment movement.

	Average number of movements	Initial movements	Secondary movements	Readjustment movements
Advanced	1.30 ± 0.21* **	100.0% ± 0.0	12.15% ± 13.19**	18.63% ± 12.76* **
Intermediate	1.87 ± 0.33	100.0% ± 0.0	35.31% ± 24.07	51.52% ± 15.73
Basic	2.04 ± 0.30	100.0% ± 0.0	46.65% ± 23.86	58.20% ± 10.21

*Significantly different from intermediate level batters ($p < 0.05$); **significantly different from basic skill level batters.

Further analysis of batter's movements revealed that, regardless of ball length, advanced level batters moved significantly less than their less skilled counterparts. Differences in the number of movements executed were reported for full of a length deliveries $F(2, 19) = 10.69$, $p < 0.05$, $\eta^2 = 0.73$, good length deliveries $F(2, 19) = 8.92$, $p < 0.05$, $\eta^2 = 0.48$ and short of a length deliveries $F(2, 19) = 6.47$, $p < 0.05$, $\eta^2 = 0.41$. Post hoc tests revealed advanced batters executed significantly less movements compared to basic skill level batters when facing a full of a length delivery, and significantly less movements than both intermediate and basic skill level batters when facing good length and short of a length deliveries (Figure 4.5).

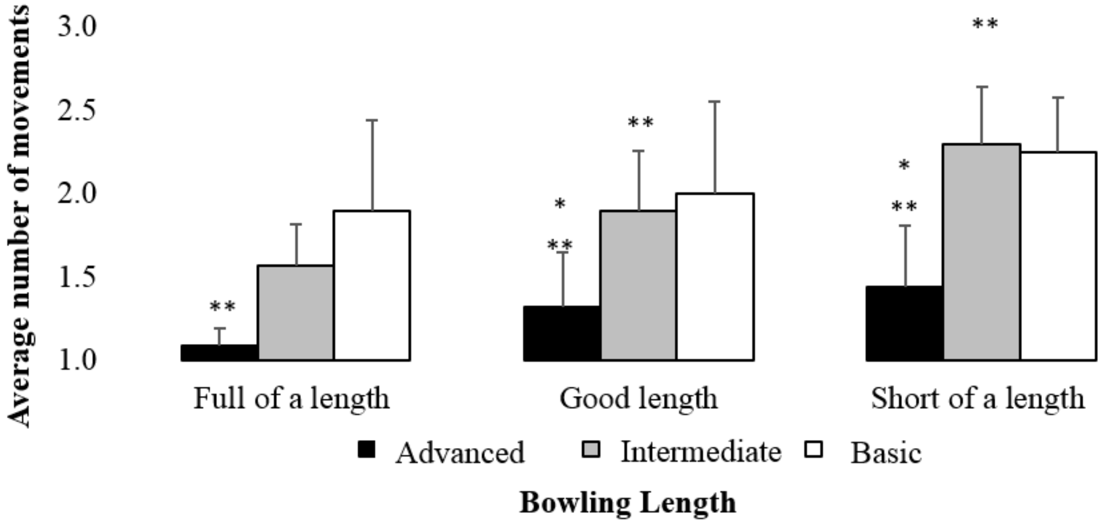

Figure 4.5. Comparison of the number of executed movements by advanced, intermediate and basic skill level batters when facing different length deliveries.

*Significantly different from intermediate level batters ($p < 0.05$); **significantly different from basic skill level batters. Error bars represent standard deviation.

There was no significant interaction between movement type (i.e. readjustment or no readjustment movement) and skill level for the quality of bat-ball contact rating $F(2, 36) = 0.49$, $p = 0.62$, $\eta^2 = .03$. Therefore, an analysis of the main effect for movement type was performed, which similarly indicated no significant main effect $F(1, 36) = 1.01$, $p = 0.32$, $\eta^2 = .03$ (Figure 4.6a). There was also no significant interaction between movement type and skill level for the force of bat-swing rating $F(2, 36) = 1.16$, $p = 0.33$, $\eta^2 = .06$. However, there was significant main effect for movement type $F(1, 36) = 7.54$, $p < .05$, $\eta^2 = .17$ (Figure 4.6b). Executing a readjustment movement (1.28 ± 0.48) resulted in batters having a lower force of bat-swing rating when compared to trials where batters did not execute a readjustment movement (1.67 ± 0.42).

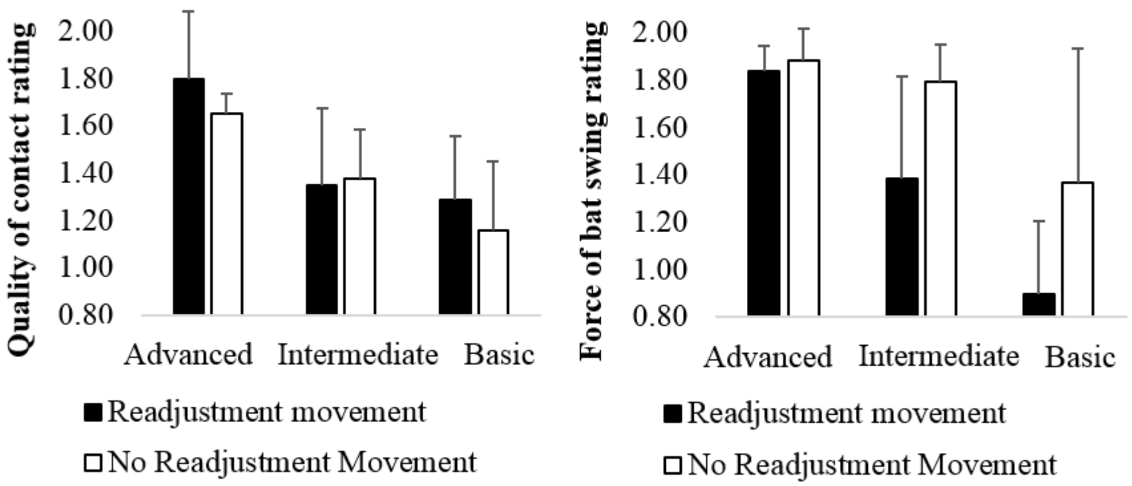

Figure 4.6. Comparison of the (a) quality of bat-ball contact and (b) force of bat-swing during trials where batters executed a readjustment movement.

Movement timings

A significant effect was found between skill level and the initial foot movement $F(2, 18) = 4.61$, $p < 0.05$, $\eta^2 = 0.35$ and initiation of the downswing of the bat $F(2, 19) = 5.58$, $p < 0.05$, $\eta^2 = 0.39$. Bonferroni post hoc tests demonstrated advanced level batters initiate their first movement (27.34% ± 2.96) later when compared with basic skill level batters (17.64% ± 6.61). Similarly, advanced level batter's initiate the downswing of their bat significantly later (73.55% ± 3.62) than a basic skill level batter (58.35% ± 12.92). No difference was reported for other key movements including bat-lift $F(2, 16) = 2.55$, $p = 0.11$, $\eta^2 = 0.24$ initial foot movement finish $F(2, 19) = 1.26$, $p = 0.31$, $\eta^2 = 0.12$ secondary movement start $F(2, 16) = 0.38$, $p = 0.69$, $\eta^2 = 0.05$ or secondary movement finish $F(2, 16) = 1.56$, $p = 0.24$, $\eta^2 = 0.16$.

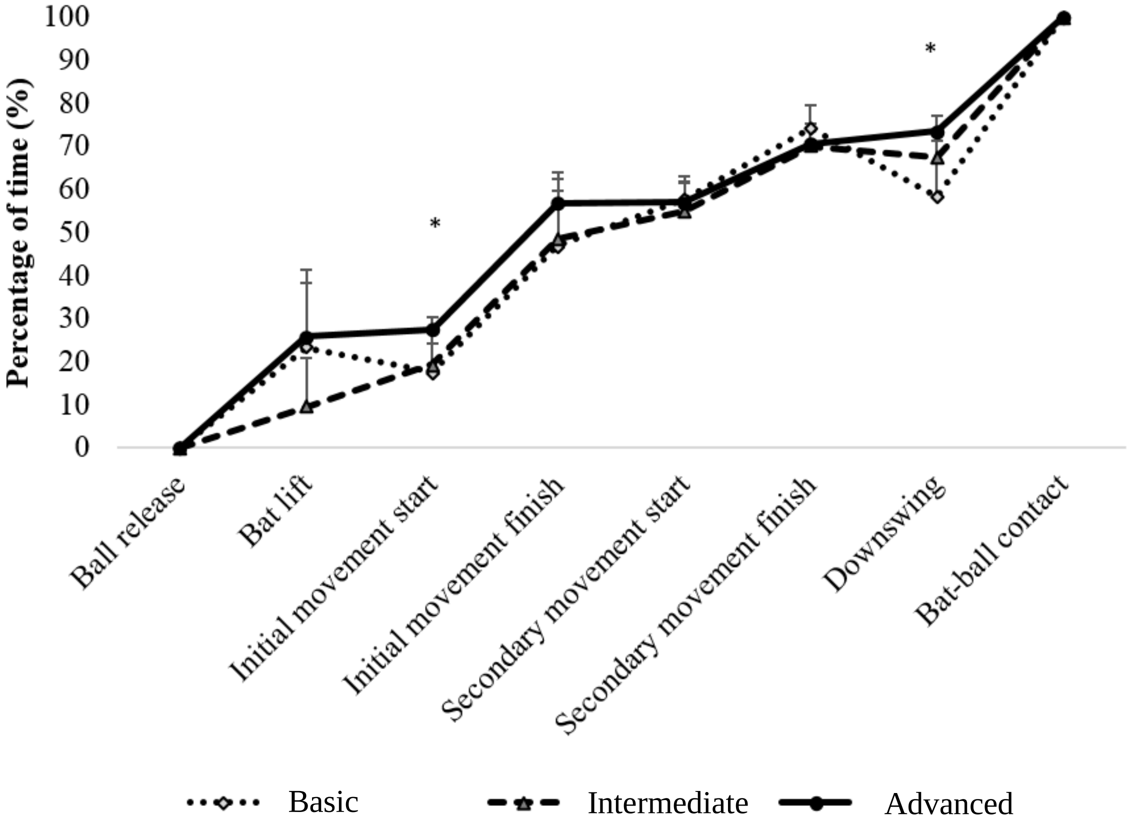

Figure 4.7. Timing sequence of movements between advanced, intermediate and basic skill level batters relative to ball release and bat-ball contact.

*Significantly different from basic skill level batters ($p < 0.05$). Error bars represent standard deviation.

Movement durations

Analysis of movement durations revealed significant differences for the total stride duration $F(2, 18) = 5.30$, $p < 0.05$, $\eta^2 = 0.34$ total backswing duration $F(2, 19) = 16.79$, $p < 0.05$, $\eta^2 = 0.46$ and downswing duration $F(2, 19) = 8.48$, $p < 0.05$, $\eta^2 = 0.47$. Advanced batters had significantly shorter total stride duration and downswing duration than basic skill level batters, while both advanced and intermediate batters had significantly longer total bat-swing duration than basic skill level batters.

In order to take into consideration the differing ball speed during the basic skill level batters condition, variables were also calculated as a percentage of time between ball release and bat-ball contact. When analysing the relative time duration, only the downswing duration maintained a significant effect $F(2, 19) = 5.58$, $p < 0.05$, $\eta^2 = 0.36$ (State: 26.45% ± 3.62; intermediate: 32.54% ± 4.99; Basic: 41.65% ± 12.92). The relative duration of the total stride $F(2, 19) = 0.26$, $p = 0.77$, $\eta^2 = 0.11$ and relative total swing duration $F(2, 19) = 2.48$, $p = 0.11$, $\eta^2 = 0.24$ (Advanced: 74.21% ± 12.37; Intermediate: 90.22% ± 11.19; Basic: 76.78% ± 18.06) did not present significant differences. Neither the duration of the first stride $F(2, 19) = 0.75$, $p = 0.49$, $\eta^2 = 0.46$ and second stride $F(2, 16) = 1.06$, $p = 0.37$, $\eta^2 = 0.09$ or the relative duration of the initial $F(2, 19) = 0.46$, $p = 0.64$, $\eta^2 = 0.05$ and secondary stride $F(2, 16) = 0.79$, $p = 0.47$, $\eta^2 = 0.09$ as a percentage, were significantly different.

It is important to note that the initial movement times and secondary movement times do not add equally to the total movement. This is because of instances where not all batters in that skill group executed a secondary movement during their testing procedure. Similarly, with total swing time, one intermediate batters and two basic skill level batters did not have bat-lift data as they did not display a discernible bat-lift movement.

Table 4.3. Duration of advanced, intermediate and basic skill level batter's foot movements in absolute (ms) and relative (%) terms.

	Initial stride duration		Secondary stride duration		Total stride duration	
	(ms)	(%)	(ms)	(%)	(ms)	(%)
Advanced	166.96 ± 40.30	29.51 ± 7.34	75.8 ± 13.07	13.49 ± 2.32	217.45 ± 47.51*	38.50 ± 10.70
Intermediate	168.66 ± 58.66	28.97 10.33	86.82 ± 26.34	14.91 ± 4.81	244.63 ± 44.87	42.02 ± 11.73
Basic	200.18 ± 71.01	27.45 16.94	107.58 ± 52.18	16.72 ± 7.57	397.76 ± 65.64	43.18 ± 13.30

*Demonstrates a significant difference compared to basic skill level batters.

Table 4.4. Duration of advanced, intermediate and basic skill level batter's bat swing in absolute (ms) and relative (%) measures.

	Bat-lift duration		Downswing duration		Total swing duration	
	(ms)	(%)	(ms)	(%)	(ms)	(%)
Advanced	270.58 ± 67.39	47.75 ± 11.64	150.16 ± 23.62*	26.45 ± 3.62*	420.74 ± 74.19	74.21 ± 12.37
Intermediate	337.43 ± 65.11	57.27 ± 10.46	189.82 ± 29.52	32.54 ± 4.99	530.12 ± 72.55	90.22 ± 11.19
Basic	238.01 ± 98.52	37.98 ± 16.12	264.97 ± 80.69	41.65 ± 12.92	482.16 ± 105.38	76.78 ± 18.06

*Demonstrates a significant difference compared to basic skill level batters. **Demonstrates a significant difference compared to intermediate batters

Cognitions

When batters were asked at the end of each over who they believed had won, (i.e. themselves or the bowler) all groups exhibited similar 'loss' responses, advanced (win 33.3%; balanced 6.7%; loss 60.0%), intermediate (win 18.2%; balanced 27.3%; loss 54.5%) and basic skill level batters (win 29.7%; balanced 12.5%; loss 58.3%) all evaluated losses occuring more often than both wins or balanced contests.

When batter's were asked to explain why they concluded that they had won, lost or drew the over, the majority of the advanced batter's responses related to outcome-goals (Figure 4.8). That is, their ability to score runs (30.4%) or whether or not they were dismissed (47.8%). Their percieved execution of shots (17.4%) or emotions (e.g. felt/ didn't feel confident; 4.4%) were less prominent factors. Interestingly, the bowler's execution was never mentioned as a contrubuting factor. Intermediate batters expressed similar response rates in regards to scoring ability (40.7%) and whether they were dismissed (37.0%), as being dominant factors. The execution of both the batter (11.1%) and opposition bowler (11.1%) were the only other factors mentioned in their responses. Finally, basic skill level batters highest response was their own ability to execute (48.3%), while their percieved ability to score (17.2%), dissmissals (13.8%), emotions (17.2%) and execution of the opposition bowler (3.5%) were regarded less when justifying their perceptions of winning or losing the over.

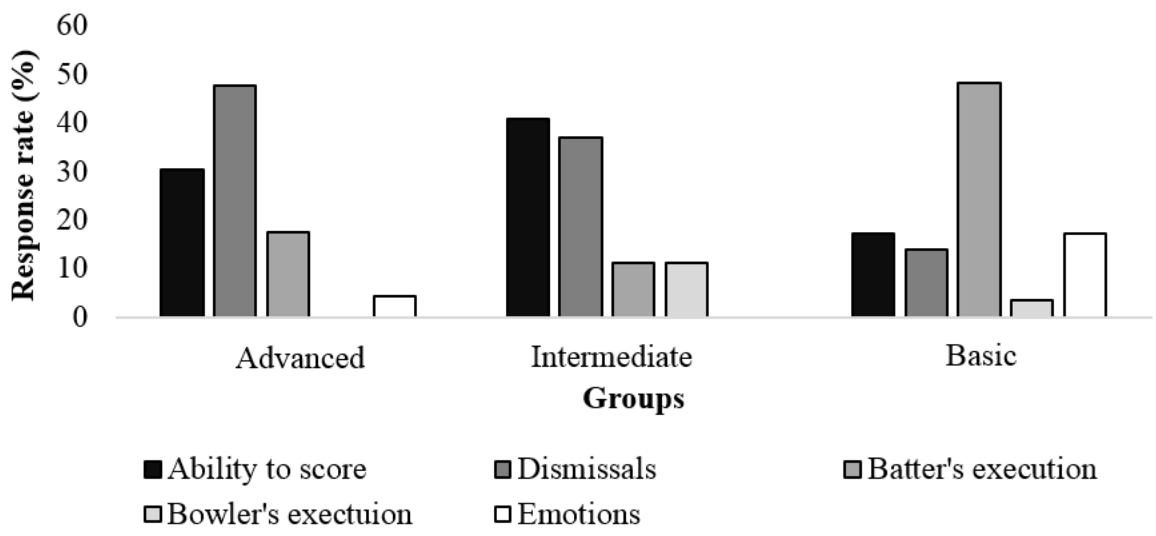

Figure 4.8. Frequency distribution of advanced, intermediate and basic skill level batter's responses when asked why they perceive that the over was won, lost or balanced.

When prompted to describe game-plans during each over, both intermediate and basic skill level batters expressed far more diverse responses when compared to advanced batters. Scoring runs (87.5%) was the highest response rate for advanced batters, with, making technical changes (12.5%). Intermediate batters included scoring runs (57.7%) and achieving bat-ball contact (26.9%) as the predominant goals in their game-plan, while limiting dismissals (11.5%) and other/none (3.9%) were briefly mentioned. Basic skill level batter's reponses were the most varied, with scoring runs (50%) and making technical changes (25%) being the most predominant responses, followed by achieving bat-ball contact (10.7%), other/none (10.7%) and limiting dismissals (3.6%).

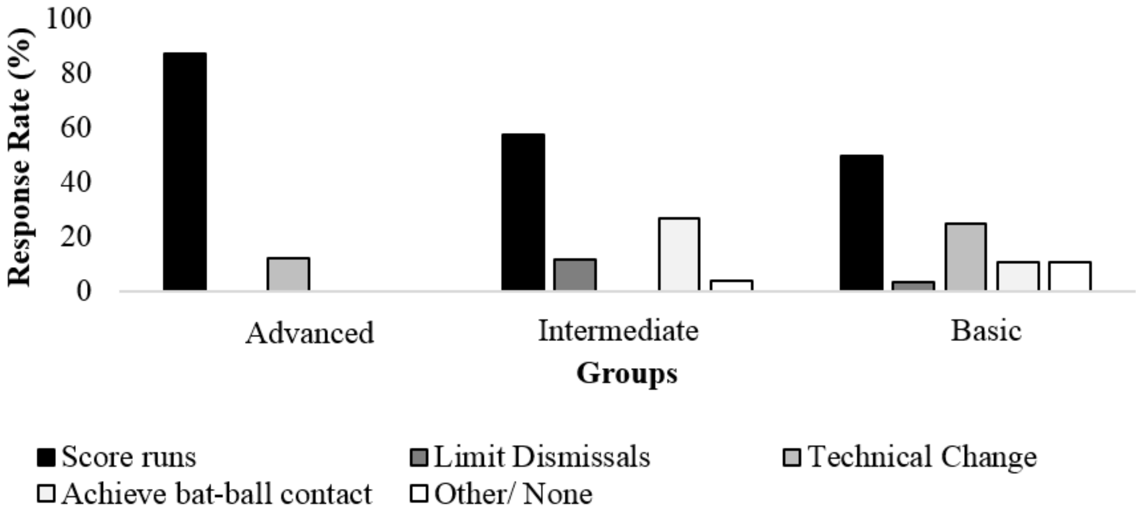

Figure 4.9. Frequency distribution of advanced, intermediate and basic skill level batter's responses regarding their game plan each over.

Emotions

The following section examines the reported emotions of different skill level cricket batters immediately prior to the commencement of the batting skills test (Pre) and then again immediately after (Post). The 5 subscales and the associated scores are presented (Table 4.5).

Table 4.5. Sports Learning and Emotion Questionnaire (SLEQ) responses from advanced, intermediate and basic skill level cricket batters.

		Enjoyment	Nervousness	Fulfilment	Anger	Total Score
Advanced	Pre	2.28 ± 0.59	0.55 ± 0.41**	2.07 ± 0.77	0.40 ± 0.59	5.30 ± 1.57
	Post	2.36 ± 0.70	0.40 ± 0.29	1.77 ± 1.03	1.05 ± 0.92	5.58 ± 1.49
Intermediate	Pre	2.83 ± 0.73	0.81 ± 0.56**	2.13 ± 0.78	0.63 ± 0.79	6.39 ± 1.76
	Post	2.85 ± 0.58	0.72 ± 0.51	2.10 ± 0.80	1.25 ± 0.97	6.92 ± 0.84
Basic	Pre	3.15 ± 0.61	1.94 ± 0.95†	2.85 ± 0.72	0.46 ± 0.46	8.40 ± 1.26
	Post	3.53 ± 0.51	0.47 ± 0.54	3.15 ±0.28	0.42 ±0.53	7.56 ± 0.39

*Significantly different from intermediate batters ($p < 0.05$); **significantly different from basic skill level batters; † significantly different from post-test.

There was no significant interaction between skill level and time for enjoyment $F(2, 19) = 1.10$, p = 0.35, $\eta2 = 0.10$; fulfilment $F(2, 19) = 0.64$, $p = 0.54$, $\eta2 = 0.06$, anger $F(2, 19) = 1.66$, $p = 0.22$, $\eta2 = 0.15$ or total emotions score $F(2, 19) = 1.48$, $p = 0.25$, $\eta2 = 0.13$. Follow up main effects were not reported as they were not of direct interest to the aims of this experiment. There was however a significant interaction for nervousness scores $F(2, 19) = 9.07$, $p = < 0.05$, $\eta2 = 0.49$. Follow-up tests revealed differences between skill level $F(1, 7) = 22.77$, $p < 0.05$, $\eta2 = 0.77$ and also between time $F(2, 19) = 8.13$, $p < 0.05$, $\eta2 = 0.46$. During the pre-test, basic skill level batters were found to have had significantly higher nervousness ratings than both advanced and intermediate level batters. Similarly, basic skill level batters also had significantly higher nervousness rating during their pre-test when compared to their post-test.

Discussion

The purpose of this study was to explore the interacting actions, cognitions and emotions produced by advanced, intermediate and basic skill level cricket batsman during a representative training scenario. The major findings were that advanced level batters, when facing bowlers during a game-like scenario, (1) demonstrate superior technical actions (e.g. bat-ball contact, footwork); (2) exhibit different movement strategies, including executing more varied vertical and horizontal bat shots while on the front foot, and later initiation of their initial foot movement and downswing of the bat; (3) cognitively evaluated their performance based on outcomes (i.e. runs scored and whether a dismissal occurred), while formulating a strategy predominately centred on how they could score runs; and (4) reported lower nervousness levels than basic skill level batters.

Actions

As expected, advanced batters, when compared with both intermediate and basic skill level batters, scored more runs, played more scoring shots, and demonstrated higher rated quality of bat-ball contact, force of bat-swing and footwork technique. These superior batting skill results are similar to those reported in the limited number of studies comparing different skill levels in cricket batting (Müller & Abernethy, 2006; Weissensteiner et al., 2011). However, a point of difference between this experiment and those previously reported findings is the representative nature of the performance environment and the task demands that the batters were measured within the current study. As opposed to executing a single, pre-determined coordination pattern (e.g., a forward defensive shot), batters were required to play a range of shots commensurate with the balance of risk and rewards inherent within a simulated game scenario. Advanced level batters were able to demonstrate an expertise advantage in this task through superior temporal and spatial coordination that resulted in effective execution

Interestingly, the emergence of a wide range of varied batting strokes (e.g. horizontal and vertical) and more functional foot work (e.g. less readjustment movements and greater technical footwork rating) was only displayed by advanced level batters. In contrast, lesser skilled batters demonstrated rigidity in their batting strokes, and more varied foot work (Figure 4.4a & 4.4b). Reinforcing the work of Stretch et al. (2000), the findings of this study demonstrate that more skilful batters are better able to perceive and act upon the affordances presented to them within their performance environment. That is, skilful batters in this experiment had more scoring shots available to them due to their superior technical coordinative ability coupled with an attunement to specifying perceptual information.

Examining the technical coordinative patterns of batters revealed those advanced level batters executed less foot movements compared to intermediate and basic skill level batters, with these less skilled batters executing more ‘secondary’ and ‘readjustment movements’ (Table 2). Further analysis revealed state batters executed less foot movements to full length deliveries than basic skill level batters, while also executing less foot movements during good length and short of a length deliveries than both intermediate and basic skill level batters (Figure 4.5). In order to more clearly understand the link between number of foot movement phases and performance outcomes, the quality of bat-ball contact (QOC) and force of bat-swing (FOBS) measures were compared for trials where a readjustment movement occurred and trials where it was not (Figure 4.6). While there was no difference between the quality of bat-ball contact and trials where a readjustment movement was performed, regardless of skill level, force of bat-swing ratings were lower in trials where batters performed a readjustment movement. This finding suggests that readjustment movements may be a functional movement solution for batters whose primary goal is to simply achieve bat-ball contact, but dysfunctional for a task-goal that requires the batter hit the ball with relative force to score runs. This emergent behaviour is unlike the movements presented in previous cricket studies (Pinder et al., 2011a; Weissensteiner et al., 2011) where batters are reported as only having one movement phase, or their movement timings are only reported as the initiation and cessation of their first and last movement respectively.

With reference to movement timings, advanced batsmen initiated their first stride movement, and the downswing of their bat, later than both intermediate and basic skill level batters. Only those basic level batter's foot movement (17.6%) and downswing of their bat (58.3%) occurred significantly later compared to advanced level batters (27.3% and 73.5%, respectively). Although intermediate batter's foot movement initiation (19%) and bat downswing (67%) were earlier than advanced batters, they were not significantly different. These finding compliment the prevailing theory that highly skilled batters delay the initiation of foot and bat-swing movements in order to perceive more specifying perceptual information (Abernethy, 1981; 1982; Abernethy and Russell, 1984; Glencross and Cibich, 1977). As a result, less-skilled batters move earlier than necessary and often must perform a readjustment movement to compensate (Figure 4.6 & 4.7). Interestingly, these results are in contrast to previous experimental work (Weissensteiner et al., 2011); albeit a ball projection machines were utilised as the delivery method, and the authors noted that unrepresentative settings often impact upon a performer's movement organisation (Pinder et al., 2011a).

No difference was found between the batsmen's skill level and the relative duration of their initial and secondary foot movements. In comparison to previous cricket batting experiments, widely different movement durations have been reported. Specifically, Stretch et al. (1998) reported an average movement time of 520ms, while Stuelcken et al. (2005) reported an average movement time of 330ms. When comparing methodologies, Stretch and colleagues conducted their study in a laboratory where batsmen performed a front foot drive have foreknowledge of the ball's trajectory and speed. Stuelcken and colleagues, in contrast, only analysed batsmen's front foot drive during an international game. In this experiment, batsmen displayed substantially shorter movement durations (advanced: 167ms; intermediate: 169ms; basic: 209ms), however unlike previous studies, batters were not constrained as to what batting shot they could execute. It is proposed that the uncertainty of the ball trajectory and, thus lack of preparatory time, constrain batters movement durations.

The duration of both the bat-lift and total swing time was also not significantly different between skill level batters, however, the duration of the bat's downswing was shorter for advanced batters compared with basic skill level batters (26.5% v 41.7%). These findings suggest that advanced batters shorten the duration of their downswing to produce a higher velocity bat swing when contacting the ball. This finding is in agreement with previous studies (Abernethy & Russell, 1984; Stretch et al., 2000), however, again contrasts Weissensteiner et al. (2011) findings where highly skilled batsmen did not differ in their downswing duration. Two explanations are put forward to explain the inconsistency between findings. Firstly, given there was no difference between intermediate and basic batters, it may be that this significantly shorter downswing movement is only apparent in highly skilled batters (i.e. advanced and professional state level) for which this study examined. Secondly, the lack of representativeness when utilising a bowling machine may alter the behaviours of skilful batsmen (Pinder et al., 2011a). Gibson and Adams (1989), in their comparison of bowlers and bowling machines, reported widely varying downswing initiation timings when batting against a bowling machine, while far more consistent downswing movements were present when facing a bowler. Therefore, bowlers are thought to be the source of crucial information for skilled batters attune to, in order to help regulate their movements.

Cognitions

Skill level differences in cognitions were found in the type of game-specific information batters utilised to evaluate performance and strategize. While advanced level batters scored significantly more runs than both intermediate and basic skill level batters, and no difference was found in the number of dismissals, all groups reported similar percentage of overs they perceived to have 'lost' to the opposition bowler. This finding is crucial to the interpretation of the following cognition data. The differences found in cognition cannot solely be explained by advanced level batters being more successful during this task than their lesser skilled counter parts. Both advanced, intermediate and basic skill level batters all reported similar perceptions of overs they perceived to have lost during the scenario. Therefore, while state batters did score more runs and demonstrate more efficient motor behaviours, their perceptions were no different to the perceptions of amateur and junior level batters and highlight the goals of the batters shaped their cognitive evaluations of the outcomes. The following discussion on the differences in cognition, at least partially, represent the way in which different skill level batters regulate their cognitions during a game-scenario.

As hypothesised, both advanced and intermediate level batters remarked that the ability to score runs, and whether they were dismissed, were key factors when evaluating their performance (Figure 4.8), however, basic skill level batters were far less concerned with these game-specific outcomes. Instead, how well or how poorly they executed during the over was the prevailing factor when evaluating their performance (40.7%). That is, basic skill level batters were more likely to respond with comments about their own ability to achieve bat-ball contact or be in an effective position when contacting the ball. One possible reason for this finding may be the coaching practices to which less skilled performers are typically exposed. For example, Roberts (2011) analysis of cricket coaching practices found that the coaches largely provided technical feedback through direct instruction (e.g. *I can see it is going wrong but I only see the technique. That is what I want to correct ...*" pg. 42). A focus of technical feedback from coaches can be harmful as direct instruction on technical movements shifts an individual's focus internally, disrupting automized movements, and leading to poorer skill execution (Wulf et al., 1998). A narrow and internalised focus has also been reported during experiments where participants are subjected to anxiety provoking conditions (Pijpers, Oudejans, & Bakker, 2005), however, this will be discussed further in a later section.

When batters were asked to verbalize their game-plan after the over, advanced level batters made responses that overwhelmingly referred to scoring runs in specific areas (e.g. *"Try* *to hit as straight as I can, and then the short [length delivery] one, just pick that gap there [referenced particular gap between two fielders]")* or using a specific strategy to score (e.g. *"The game plan is there when the ball is there. I'm kind of playing see it, hit it. But I'm looking, cause [sic] the biggest gap is straight, so if the ball is straight I'm looking to hit it straight").* In contrast, intermediate batters additionally referred to achieving bat-ball contact (e.g. *"Just hit the ball"; and "Similar to the first 6 balls, still pushing for anything full to try and hit a little harder. And anything short, just try and get a bat on it if possible"*). Basic skill level batters additionally referred to having to make technical changes (e.g. *"...I would have liked to have played off the front foot more and played some shots much straighter"; and "Yeah to move my feet and try get it [the ball] through the offside"*). Similar to the findings of Araújo et al. (2005) during their investigation of sailors, skilled batters verbalised more regularly the opportunities for action available relative to their performance environment, while those lesser skilled explored their own motor behaviour and reflected how their movements could be more functional.

Emotions

The ability to regulate emotions was another factor that distinguished between different skill level batters. Perhaps not surprising given that the bowlers were 'below' their current performance level and may not be perceived as a threat to their goals. Advanced level batters exhibited less nervousness prior to performance than their basic skill level counter-parts. In contrast, basic skill level batters were facing bowlers who were 'above' their level and therefore may have been perceived as a great threat to success. High levels of nervousness have been attributed to causing a narrowing of an individual's focus of attention, similar to that of a novice performer (Masters, 1992; Pijpers et al., 2005). This, in turn, is thought to limit the affordances perceived and acted upon by individuals, such as making them more conservative in their actions (Pijpers et al., 2006). It is suggested that this cognitive-emotions relationship is a likely contributing factor to the internalised and narrower self-evaluative cognitions exhibited by basic skill level batters. It is important to note that after this experiment, basic skill level batters reported lower levels of nervousness compared to a pre-test questionnaire. It is unclear whether this reduction is due to batters becoming more accustomed to the task, or that the task itself had finished. Future research is needed to examine whether regulating emotions (as well as characterising which emotions specifically) during performance is a distinguishing factor between skill levels in cricket batting.

The primary limitations of this study included the level of representativeness of the task, and the standardization of bowlers accurately bowling to their scripted lengths. In regards to representativeness, fielders were substituted for static mannequins. This inherently created a more static performance environment. Batters therefore found their task to be simply striking the ball into a stationary gap in the field, as opposed to striking it into a gap between fielders who could move and intercept the ball. Albeit, the ball must have been struck with some force to travel the requisite 20 metres necessary to score a run. Secondly, a clear purpose of this experiment was to go beyond earlier studies of batting technique that had relied on bowling machines by utilising real bowlers to capture true representations of batting performance. This goal presented some challenges in ensuring that each batter received the 'same' test. However, through the use of a script the results demonstrated that this was achieved. While exact standardization issues are bound to arise due to the inherent variability associated with skilled performers, we believe that the advantages far outweigh the limitations. The actions, cognitions and emotions reported as batters interacted with bowlers during this study could not have been replicated by facing a ball machine. It is also evident from the results of this study that, by removing ball projection machines and replacing them with bowlers as a ball delivery method, it enabled batters to perform multiple different co-ordination patterns in contrast to previous studies.

Conclusion

A distinction between this study, and those previously conducted with cricket batters, is the attempt to maintain the dynamic relationship inherent between a batter and bowler. Advanced level batters demonstrated superior technical proficiency and an ability to score runs, which was reflected in their cognitive evaluations and strategizing that referenced how they went about scoring runs. Conversely, basic skill level batters with their less proficient technical batting skills, in turn, exhibited cognitions directed toward achieving better skill execution. Interestingly, there was no significant difference in the number of scoring shots played by intermediate and basic skill level batters, yet intermediate batter's cognitions predominately referenced scoring runs when evaluating performance and strategizing. It's suggested that basic skilled batter's higher level of nervousness further reinforced a narrow and internalised (cognitive) focus towards their own movements. The practical implications of this study stress the importance of viewing skill learning as more than a mastery of coordinative movements. A key element to skilful performance is the ability to adapt one's actions and cognitive strategies to suit the performance environment, and mage the emotions that concurrently occur.

CHAPTER 5: A CONTEMPORARY SKILL ACQUISITION APPROACH TO DEVELOP BATTING SKILL IN SKILLED CRICKET BATTERS

Introduction

The role of practice in the development of motor skills is undoubtedly central to attaining expertise (Ericsson, Krampe, & Tesch-Römer, 1993). While there are differing views on whether the amount of practice alone can account for expert performance (Hambrick et al., 2014), both applied and theoretical research has shifted attention towards examining the effectiveness of different types of practice. Early research in motor learning has been invaluable in addressing how different practice conditions impact skill learning. For example, researchers have focused on issues such as the contextual interference effect (Magill & Hall, 1990), part or whole practice (Park, Wilde, & Shea, 2004) and knowledge of results and performance feedback (Salmoni, Schmidt, & Walter, 1984). However, many of the more traditional (e.g., psychophysical) approaches for studying skill acquisition have been quite reductionist, utilising static movement models predicated on a perceived dichotomy between experimental rigor and ecological validity (Davids, Renshaw, & Glazier, 2005). Essentially, researchers were biased away from multi-joint actions prevalent in sports and physical activities due to the inherent difficulties of replication in messy environments. Additionally, the theory underpinning research design was generally fine-focussed and concerned with enhanced cognitive representations.

While ‘traditional practice methods’ is a grounded phrase that cannot be found per se in the motor learning literature, it is common in the very real, practically applied world of teaching and coaching (Cushion & Partington, 2016; Moy, Renshaw, & Davids, 2016). Traditional coaching is characterised as a focus on optimising the technical execution of a movement, by following a criterion model of movement (Williams & Hodges, 2005). Part-task practice is one such approach commonly employed so that the complex skill can be more easily taught, albeit it’s long term effectiveness has been questioned (Anderson, Magill, & Sekiya, 2001; Lim, Reiser, & Olina, 2009; Mané, Adams, & Donchin, 1989). To achieve this, the desired movement pattern is deconstructed into smaller parts and practiced in isolation, before being brought back together to practice as a whole movement. It's proposed benefit is to reduce the overall attentional demands placed on the learner, and allow them to repetitiously ingrain the movement and remove errors or noise (Guadagnoli & Lee, 2004). Explicit instructions and feedback from the coach is employed to educate the performer on how well they are replicating the criterion model of movement, and is another hallmark of traditional practice (Miles et al., 2014).

More contemporary theoretical modelling of motor behaviour via an ecological dynamics approach is emphasising the mutuality of perception and action which is embodied within the performer-environment system, functioning in a task-specific manner dependent on nested, interacting constraints (Davids, Araújo, Seifert, & Orth, 2015; Davids, Chow, & Shuttleworth, 2005). Consequently, the value of learning skills in decomposed practice tasks in isolation from performance contexts suggests the need for more representative practice tasks (Renshaw et al., 2010). Nonlinear pedagogy is the term used to capture the essence and theoretical concepts of ecological dynamics (Chow et al., 2007). Grounded in a constraints-led approach, this pedagogy provides a framework to explain and exploit nonlinear behavioural changes that are often observed in learnt movement skills. Key principles embedded in this approach include representativeness, manipulation of constraints, attentional focus, functional variability and maintenance of perception-action couplings (Chow, 2013; Renshaw et al., 2010).

As opposed to traditional practice methods, a constraints-led approach (CLA) views learning to be more of an emergent phenomenon, and is concerned with creating strong information-movement couplings (Renshaw et al., 2010). That is, practice activities are designed with the purpose of allowing emergent decision-making to form based on the learner perceiving key information sources, and attuning their movements accordingly. The efficacy of this practice approach was examined by Lee et al. (2014), who compared two practice approaches grounded in linear (LP) and nonlinear pedagogies (NP) over a 4 week period, in novice tennis players. Interestingly, both groups improved compared to their pre-intervention skills test, however no difference was found between groups. However, the way in which both groups developed their tennis specific skill differed between learning approaches. NP learners demonstrated greater variability in movement patterns while improving their accuracy at the same rate as LP, who demonstrated far less variability within their selection of movement patterns. Future research was implored to further examine these approaches utilising longer interventions and reporting on learner's feelings of practice. It is also proposed that examining more skilful performers, rather than novices, would further benefit current knowledge regarding the efficacy of practice approaches.

A distinguishing feature of the ecological approach is the focus on individual-environment mutuality, such that a learner's behaviours must be understood with respect to their environment (Renshaw, Davids, Shuttleworth, & Chow, 2009). Applying these concepts practically, a constraints-led approach is concerned with the development of interacting intentions, perceptions and actions to exploit the affordances within the performance environment (Davids et al., 2013b). Detecting and acting upon these affordances, which is defined as the opportunities for action provided by informational properties within the environment, is critical to skill development (Seifert et al., 2013b). Adopting this perspective also means viewing skill development as a result of changes in a learners intentions, education of their perceptual system (Jacobs & Michaels, 2007) and greater functionality of actions (Davids et al., 2003b).

Examining skill development in this way requires a skills assessment that allows for information-movement to remain tightly coupled, continuous context-dependent decisions and actions, and, representative affordances (Davids et al., 2013b). These concepts are proposed to effectively replicate the dynamic performance environments in which the to-be-measured skills are performed. A representative learning design is commonly described in theory to achieve these feats, and more recently, has useful practical application. For example, Krause et al. (2018), validated the use of their own representative practice assessment tool for tennis in order to help practitioners maximise the potential of skill transfer to competitive performance environments. A considerable benefit of a representative skills test is the degree to which analysing a behaviour, represents the behaviour it is intended to reflect. It also provides learners with the opportunity to perceive opportunities for action, and couple their movements accordingly. In keeping with Brunswik's original *representative design*, vicarious functioning provides a rationale that the test environment does not need to be exactly the same each time a test is conducted. Rather, the representative environment, for example, requires randomly sampling a group of bowlers in which to use against each batter to explore their behaviours. Thus, potential changes in movements, cognitions, or emotions as a result of a practice intervention could be represented and measured using a representative learning design.

The aim of this study is to examine the effectiveness of two different learning approaches to the acquisition of cricket batting skill in junior cricket batters. It is hypothesised that both a constraints-led approach (CLA) practice group and the traditional practice approach (TPA) group will improve in batting performance measures such as the number of runs scored and scoring shots played over the 12-week period, while the CLA group will improve significantly greater than the TPA group. This is thought to be a result of the CLA group achieving greater spatiotemporal ratings (i.e. quality of contact and force of bat-swing and perceiving more opportunities for actions, through changes in their batting shot selection (e.g. changes in the percentage of vertical bat shots, front foot movement and shots played along the ground). Due to the practice nature of the TPA, it is thought that there would be no difference in technical proficiency between groups. It is also hypothesised that the CLA group will demonstrate a shift in their cognitive focus towards more external stimuli, while traditional learning approach group will shift more internally.

Methods

Participants

Twenty-four junior cricketers, who had been selected into a 9-month state academy training program were invited to voluntarily participate in this study. These batters are considered to be at an intermediate skill level for their age group. The study was conducted during the first training block of the program (2 x 2-hour sessions per week for 10 weeks), which coincided with the cricket off-season. Participants were randomly assigned to one of two groups; a Constraints-Led Approach (CLA; mean age 14.4 years ± 0.33; height 174.0 cm ± 8.97; weight 66.8 kg ± 14.39) or a Traditional Practice Approach (TPA; mean age 14.1 years ± 0.41; height 171.6 cm ± 14.15; weight 60.7 kg ± 12.42). Due to injury (outside of the training program) and illness, two participants from the CLA group and two participants from the TPA group were excluded from all data analysis. Of those participants included in the analysis, no player attended less than 80% of all sessions.

Apparatus and test procedures

An 18-ball skills test was conducted pre, mid and post-intervention to assess the holistic development of cricket batting skills. Both groups completed the skills test on the same regulation outdoor turf pitch (i.e. playing surface) and against the same group of bowlers as each other (see full procedure below). In addition to these pre/mid/post-intervention skills testing, within-practice session data to capture participant's perceptions of the training were also recorded.

A radar gun (Stalker Radar Pro, Plano, Texas, USA) was positioned in front of the umpire to monitor the bowler's speed for each ball. Pre-used, regulation size cricket balls (156g;

Kookaburra Turf Rejects, Australia) were utilised during the test. The skills-test involved a game-based scenario, where all rules and field settings replicated a previously employed batting skills test (See Chapter 4). Initially, each participant was read the following script 5 minutes prior to beginning the test;

> "You are the first batter coming in to bat after a wicket has just fallen on the last ball in the previous over. The game is at an even position for both teams, and your role is to score as many runs as possible without being dismissed. You are currently in the early to middle overs of a limited overs game."

Ball Delivery Method: In order to ensure that the participants were able to access the functional perception-action couplings they used in cricket matches, eight (adult) amateur club level, right arm pace cricket bowlers were invited to bowl to the participants during the pre-intervention, mid-intervention and post-intervention skills test. Bowlers were selected to be representative, in terms of bowling speeds, of state representative players of the same age (i.e., approximately 100km-h – 105km-h). Each bowler delivered six consecutive deliveries (i.e. one over) to participants, and were randomly assigned to bowl 9 overs of the total 72 overs each skills test. Bowlers followed a randomised ball delivery script, with length being manipulated so that bounce point of the ball varied across the 18 balls. Deliveries consisted of 3 full length (ball bouncing within 4 m of the batter's crease), 12 good length (ball bouncing 4 m to 8 m from the batter's crease) and 3 short length (ball bouncing further than 8 m away from the batter's crease). Any illegal deliveries (e.g. ball bouncing over the batter's head or the ball travelling outside the wide lines) were not included and the bowler was asked to re-bowl the ball. If a bowler did not execute the desired ball length, the script was manipulated to ensure a similar ratio of ball lengths was faced by each participant. For example, if a full length ball was bowled instead of a good length, the script was amended to replace one of the later good length balls with a full length one. Post-analysis of deliveries revealed all participants faced an equal distribution of ball delivery types.

Scoring: Participants were awarded ‘runs’ by hitting the ball into any one of the seven spaces between the fielders. Standardised field placement typical of one that would be set in a similar scenario in a game was setup using mannequins and cones, placed 1.5 m either side of the mannequin, to signal the horizontal area the fielder would hypothetically cover in this scenario. Plastic poles (height = 2 m) were placed on each cone to signal the vertical area covered. If a batter was adjudicated to be ‘out’ (bowled, leg before wicket [LBW] or caught [ball travelling to any one of the seven fielding positions without first contacting the ground, and not travelling above 2 m]) they were informed they would lose 8 runs. While this is a different rule to the normal game, it was necessary to ensure that each participant received the same number of balls in each test. However, the deduction of runs was not included in any post-hoc analysis and an out was simply scored as 0 runs for that ball.

Cognitions and Emotions: At the end of each over, participants were asked to complete the Sports Learning and Emotions Questionnaire (SLEQ; Headrick, 2015), and then conducted a brief self-confrontational interview with the lead researcher. The interview questions were designed gain insight into the batter’s intentions and focus of attention, specifically, by asking (1) who they believed won the over (e.g. themselves, the bowler or neutral); (2) why they thought themselves or the bowler won; and finally, (3) what their game plan was during the previous over.

Data Capture of Batter Actions: During the skills test, two digital video cameras were setup (Baslar, Baslar Ace acA2000, Germany; Casio Exilim, Japan) capturing at 300 frames per second. All camera distances were measured from the centre of the batter’s crease. One camera was placed on a hydraulic tripod and positioned directly in line with the batsman (camera height = 5 m; distance from the centre = 60 m) in a front-on position. A second camera was positioned side-on, perpendicular from the direction of the batter faces (camera height = 1.5 m; distance from centre = 50 m).

Player Perceptions of Training: Participants completed a brief post-training rating assessment at the end of each practice session. This included four questions, presented on a 10 point scale, centred upon the participant's perceptions of the training session relating to (a) their enjoyment, (b) the challenge level of the session, (c) the mental demands and (d) the physical demands they experienced during the batting skills component of the session.

Training procedures

Both intervention groups completed a total of twenty practice sessions over a 12-week period. The first and final week of the program was solely dedicated to the pre and post skills test. Each session lasted 2 hours, with the first hour of each session specifically focussed on batting skill practice. The second hour was identical for both groups and consisted of fielding activities, such as catching and throwing tasks. Each training session was conducted over alternating days for each group and was conducted at the same venue. All participants used their own protective equipment and bat, unless otherwise given a modified bat for the purpose of a training activity. Participants were also asked to refrain from participation in any other cricket activities during the intervention, although most (n = 4) played a team ball sport (i.e., soccer, AFL, rugby) during this cricket off-season period.

Coaches and Programme Design: The programme was designed by the first and second author in conjunction with two junior-state coaches (Cricket Australia Level 3) who then delivered the programme. Additionally, the first author attended every training session to ensure that delivery was as planned. Both coaches were familiar with the CLA as it is part of the Cricket Australia Level 2 Coaching Accreditation, however, prior to the first training session they received an additional education session from the first and second author to enhance their understanding. To ensure each session had the same intended learning outcomes s, the two coaches were asked to jointly design each practice session. The two coaches then rotated who delivered each of the sessions to the two practice groups.

Data analysis

Performance Measures: Batting performance measures, collected during the pre, mid and post- intervention skills test, included the number of runs and scoring shots played, while the subjective ratings conducted by the lead researcher included a quality of bat-ball contact (QOC), force of bat swing (FOBS) and footwork technique rating. As an example, all subjective ratings were coded a 2 for ideal execution (QOC: good contact; FOBS: full bat swing; Technique: forward or backward movement) while a 0 represented dysfunctional execution (QOC: no contact; FOBS: defensive shot; Technique: evasive or no foot movement). This coding system has been validated and used in previous cricket batting research (Connor, Renshaw & Farrow, submitted; Mann, et al, 2010). Participant's skill execution was examined by recording their batting characteristics, which included percentage of shots played forward or back (i.e. whether the last movement before bat-ball contact had the participant travelling forward or back), percentage of vertical or horizontal batting shots and percentage of batting shots played along the ground or in the air. Dismissal was recorded as zero runs for the purpose of analysis. Reducing runs based on number of dismissals would have impacted the overall run scoring score achieved by participants, and therefore, would not be directly indicative of their run scoring ability.

Intra- and Inter-Observer Reliability: A sample of 50 different random trials (equally split between CLA and TPA participants) were used to check intra and inter-rater reliability. Test-retest reliability and percentage difference in means between tests was assessed by conducting the batting skills test twice with a group of 20 skilled cricketers (not involved in the programme), prior to the beginning of the intervention (Table 5.1).

Table 5.1. Reliability analysis (ICC's) of dependent batting performance measures within the batting skills test.

Dependent batting performance measures	Inter-rater reliability	Intra-rater reliability	Test-retest reliability	% mean difference
Scoring shots	–	–	0.897	2.82
Runs scored	–	–	0.909	6.71
Quality of contact rating	0.918	0.923	0.914	0.58
Force of bat swing rating	0.805	0.890	0.799	11.87
Technical footwork rating	0.847	0.822	0.959	3.82

Cognitions and Emotions: Cognitions, collected during the pre and post-intervention skills test, were recorded by conducting a brief interview with the batter after each consecutive six balls. Interviews were subsequently transcribed verbatim, along with sentence-by-sentence coding and content analysis was performed. Finally, categories and sub-categories that captured the fundamental concepts being described by batters were conducted by the lead author. The first question, describing who batters thought had won the over, were reported as a percentage total. Similarly, the second and third questions were presented as a percentage of total codes.

The Sports Learning and Emotions Questionnaire data was also administered after each over of the pre, mid and post- intervention skills test, to produce a SLEQ score which contains four factors: enjoyment, nervousness, fulfilment and anger. The questionnaire asked participants to rate 17 words on a scale from 0 (not at all) to 4 (extremely). For example, the scores for ‘annoyed’, ‘angry’, and ‘frustrated’ are all averaged to provide an overall score for the factor of anger.

Player Perceptions of Training: At the end of each training session, participants rated the enjoyment, challenge, mental demand and physical demand of the session by rating it on a scale from 1 to 10; 10 being ‘extremely’ and 1 being ‘not at all’. For the purpose of this study, the two sessions occurring each week was averaged into a weekly score for each variable and statistically analysed.

Statistical analysis

The pre-intervention, mid-intervention and post-intervention batting skills test performance variables were separately analysed using a 2 x 3 (group x test type) mixed ANOVA. Cognitive perceptions of wins and losses were analysed using separate 2 x 3 mixed ANOVAs, while evaluations and game plans was presented descriptively as a percentage of which codes appeared. The SLEQ was analysed using a 2 x 2 x 4 (group x testing x over number) three-way mixed ANOVA. For all ANOVAS, the Greenhouse-Geisser correction was applied for any violations of Maulchy’s test of sphericity. Any post-hoc tests were investigated using Bonferroni correction where appropriate. Statistical significance was a *priori* at $p < 0.05$.

Results

Batting performance measures

Runs Scored: No significant difference was found between groups during the pre-intervention skills test $F(1,18) = .01$, $p = 0.93$, $\eta^2 = .000$. There was a significant group by time interaction on the number of runs scored $F(2,18) = 4.62$, $p < 0.05$, $\eta^2 = .204$. The CLA group scored significantly more runs during the mid-intervention $F(1,18) = 5.58$, $p < 0.05$, $\eta^2 = .237$ and post-intervention skills test $F(1,18) = 8.79$, $p < 0.05$, $\eta^2 = .328$ compared to the TPA group. Analysis of time revealed significant differences $F(2,18) = 8.31$, $p < 0.05$, $\eta^2 = .480$, finding the CLA pre-intervention skills test (15.60 ± 8.53) was significantly lower than the post-intervention skills test (24.30 ± 5.66), however there was no difference between the mid-test (17.80 ± 3.33). Analysis of the TPA group found no differences $F(2,18) = 1.64$, $p = .23$, $\eta^2 = .154$ between pre-intervention (15.30 ± 6.52), mid-intervention (12.30 ± 6.57) or post-intervention skills tests (15.20 ± 7.89).

Scoring Shots: Analysis of simple main effects for groups found no significant differences between groups during the pre-intervention skills test $F(1,9) = .97$, $p = 0.35$, $\eta^2 = .097$. There was a significant group by time interaction in the number of scoring shots achieved $F(2,36) = 7.90$, $p < 0.05$, $\eta^2 = .467$. The CLA group had significantly higher scoring shots during the mid-intervention $F(1,9) = 8.68$, $p < 0.05$, $\eta^2 = .491$ and post-intervention skills tests $F(1,9) = 13.64$, $p < 0.05$, $\eta^2 = .602$ than the TPA group. Analysis of the CLA group and time $F(2,18) = 8.45$, $p < 0.05$, $\eta^2 = .484$, demonstrated that the CLA group played more scoring shots during the post-intervention skills test (8.70 ± 2.16) compared to their pre-intervention skill test (5.80 ± 1.87). No differences were found when compared to their mid-intervention skills test (6.60 ± 1.65). Analysis of the TPA group also revealed significant differences $F(2,18) = 4.478$, $p < 0.05$, $\eta^2 = .332$, with a greater number of scoring shots played during the pre-intervention skills test (6.60 ± 2.17) when compared to mid-intervention (4.80 ± 2.04), however no difference was found for either when compared to the post-intervention skills test (6.00 ± 2.31; Figure 5.1).

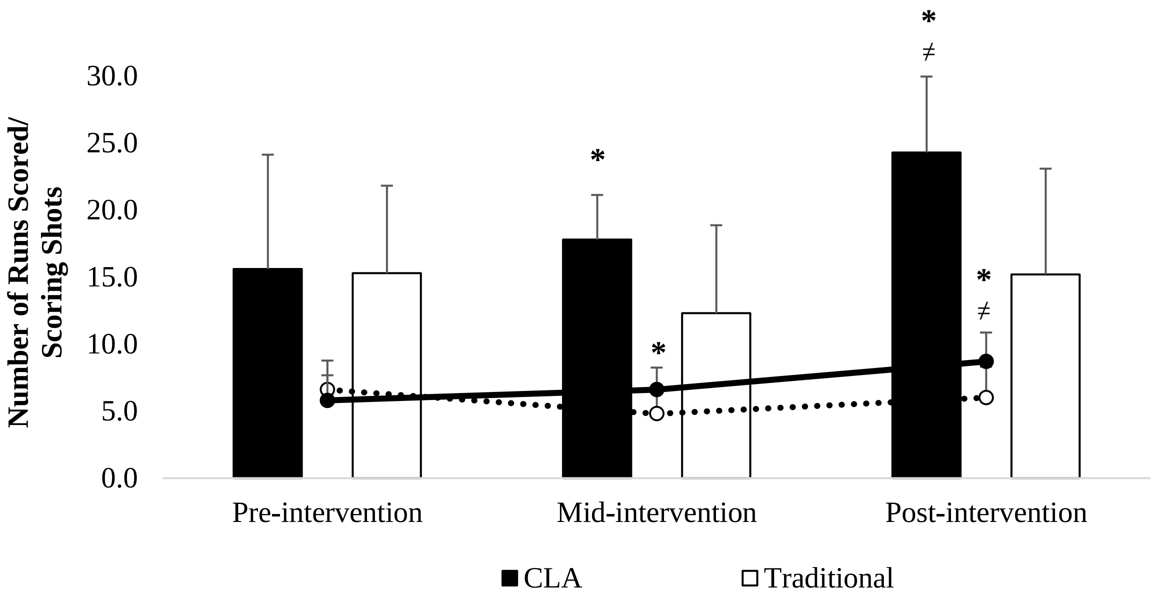

Figure 5.1. Comparison of number of runs scored (bar graph) and number of scoring shots (line graph) during three skills tests (pre-intervention, mid-intervention and post-intervention skills tests) between groups.

*Significantly different from the traditional group; ≠Significantly different from pre-intervention skills test; ≠≠Significantly different from mid-intervention skills test.

Quality of Contact: No significant difference was found between groups during the pre-intervention skills test $F(1,18) = .02$, $p = 0.89$, $\eta^2 = .001$.There was a significant group by time interaction on the quality of contact measure $F(2,36) = 3.37$, $p < 0.05$, $\eta^2 = .158$. No difference was found between groups during the mid-intervention skills tests $F(1,18) = 3.02$, $p = 0.10$, $\eta^2 = .144$, however, the CLA group had significantly higher quality of contact ratings compared to the TPA group during the post-intervention skills tests $F(1,18) = 7.84$, $p < 0.05$, $\eta^2 = .303$. Analysis of the CLA demonstrated significant differences between the CLA groups pre-intervention skills test (1.20 ± 0.19) and both the mid-intervention (1.44 ± 0.22) and post intervention skills test (1.56 ± 0.22), however not between mid-intervention and post-intervention $F(2,18) = 12.81$, $p < 0.05$, $\eta^2 = .587$. Analysis of the TPA revealed no significant differences $F(2,18) = .78$, $p = .78$, $\eta^2 = .079$ (pre-intervention 1.21 ± 0.24; mid-intervention 1.24 ± 0.28; post-intervention 1.28 ± 0.23; See Figure 5.2).

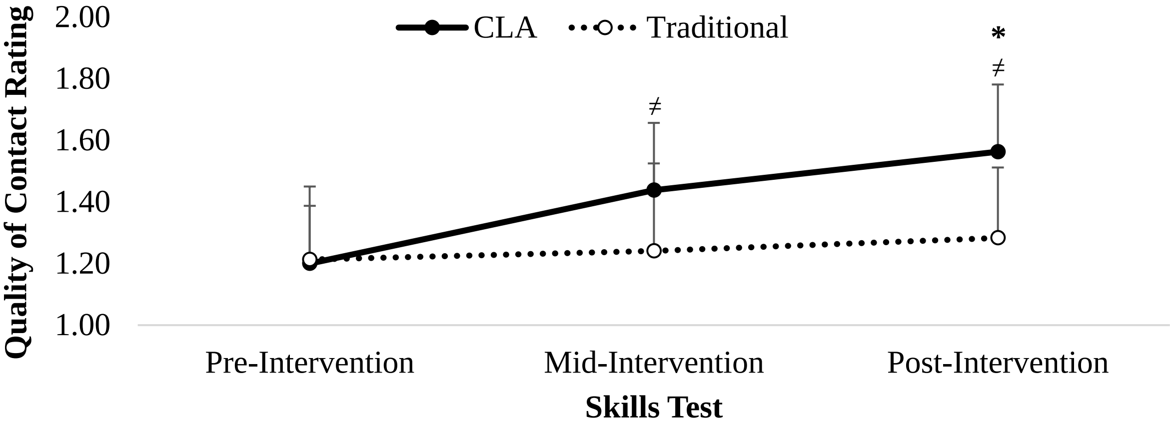

Figure 5.2. Comparison between practice approach groups and skills tests for quality of bat-ball contact measure.

*Significantly different from the traditional group; ≠Significantly different from pre-intervention skills test; ≠≠Significantly different from mid-intervention skills test.

Force of bat-swing: No significant difference was found between groups during the pre-intervention skills test (CLA 1.08 ± 0.33; TPA 1.18 ± 0.31). There was also no significant group by time interaction on force of bat swing rating $F(2,36) = .10$, $p = 0.90$, $\eta^2 = .006$. That is, there was no difference between groups during the mid-intervention (CLA 1.03 ± 0.44; TPA 1.06 ± 0.27) or post-intervention skills test (CLA 1.24 ± 0.30; TPA 1.25 ± 0.27). There was also no main effect found for time $F(2,36) = 2.32$, $p = 0.11$, $\eta^2 = .115$.

Footwork technique: There was a significant difference between CLA and TPA group footwork technique rating during the pre-intervention skills test $F(1,18) = 4.66$, $p < 0.05$, $\eta^2 = .206$, where the TPA group had a higher rating than the CLA group.

There was a significant group by time interaction on the footwork technique ratings measure $F(2,36) = 11.06$, $p < 0.05$, $\eta^2 = .381$. The CLA group had a higher footwork technique rating during the post-intervention skills test $F(1,18) = 7.58$, $p = 0.05$, $\eta^2 = .296$, while no difference was found during the mid-test $F(1,18) = 0.43$, $p = 0.84$, $\eta^2 = .002$. Analysis of the CLA group found significantly higher ratings during the post-intervention skills test compared with both the pre and mid-intervention $F(2,18) = 11.75$, $p < 0.05$, $\eta^2 = .566$. No difference was found between pre-intervention and mid-intervention. Analysis of the TPA group $F(2,18) = 6.80$, $p < 0.05$, $\eta^2 = .430$ revealed significantly lower footwork technique rating during the mid-intervention (1.23 ± .24) compared to pre-intervention skills test (1.47 ± .26), while no difference was found for during either pre or mid-intervention skills test when compared to post-intervention (1.34 ± 0.26; Figure 5.3).

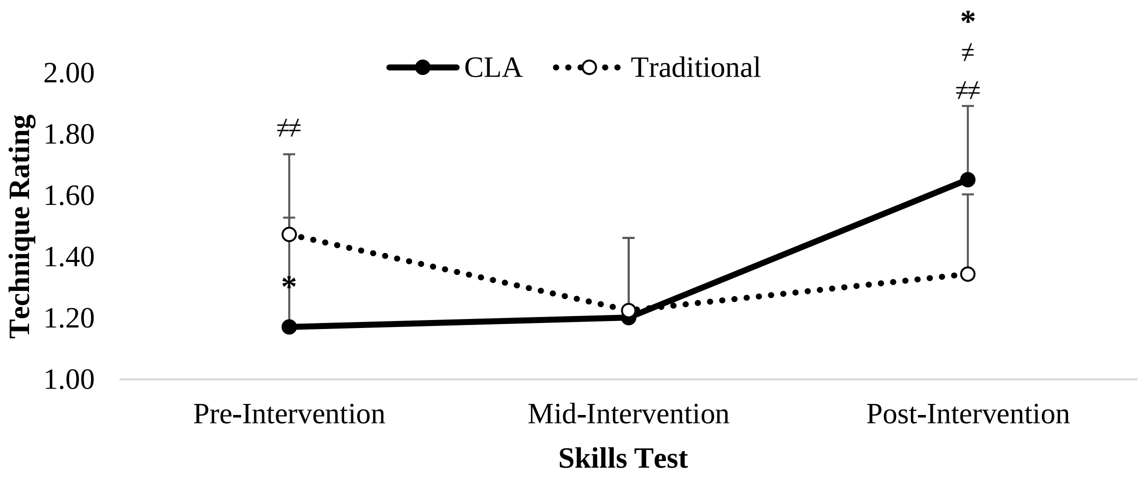

Figure 5.3. Comparison between practice approach groups and skills tests for footwork technique rating.

Table 5.2. Ratio of front foot and back foot bat shots, vertical and horizontal bat shots, and grounded and aerial bat shots between groups during the pre-intervention, mid-intervention and post-intervention skills test.

		Front foot: Back foot (%)	Vertical: Horizontal (%)	Grounded: Aerial (%)
CLA	Pre-intervention	47.36: 53.64 ± 23.43	86.70: 13.30 ± 12.50	83.79: 10.21 ± 13.62
	Mid- intervention	46.63: 53.37 ± 17.97	85.36: 14.64 ± 10.07	80.14: 19. 86 ± 16.36
	Post- intervention	67.31: 32: 69 ± 20.56	89.37: 10.63 ± 12.33	78.20: 21.80 ± 22.78
Traditional	Pre-intervention	54.53: 55.47 ± 21.56	86.03: 13.97 ± 10.93	84.90: 15.10 ± 13.15
	Mid- intervention	49.00: 51.00 ± 19.03	86.04: 13.96 ± 13.56	77.77: 22.23 ± 22.51
	Post- intervention	53.82: 46.18 ± 18.92	86.06: 13.94 ± 10.84	71.97: 28.03 ± 11.16

Batting characteristics: No significant difference was found between groups during the pre-intervention skills test for the three measures (1) percentage of front foot bat shots, (2) vertical bat shots or (3) grounded bat shots (Table 3).

Similarly, no significant interaction was found between groups and time for the percentage of front foot shots played measure $F(2,36) = 1.50$, $p = 0.24$, $\eta^2 = .236$, percentage of vertical bat shots played during the skills test $F(2,36) = .22$, $p = 0.80$, $\eta^2 = .012$ or percentage of grounded bat shots $F(2,36) = .33$, $p = 0.72$, $\eta^2 = .018$.

Cognitions

Perceptions of performance: No significant difference was found between groups during the pre-intervention skills test. Similarly, no significant interaction was found between group and the percentage of overs perceived by players to have been won $F(1,18) = .66$, $p = 0.43$, $\eta^2 = .035$ or lost to the opposition bowler $F(1,18) = .050$, $p = 0.83$, $\eta^2 = .003$. Analysis of the CPA group revealed no difference for overs won by batters (pre: 36.30% ± 24.35; post: 52.80% ± 23.07) or overs lost (pre: 52.90% ± 23.30; post: 39.70% ± 30.54). Analysis of the TPA group also revealed no differences for overs won by batters (pre: 43.30% ± 22.52; post: 46.67% ± 32.22) or overs lost (pre: 46.60% ± 17.25; post: 36.60% ± 33.16; Figure 5.4).

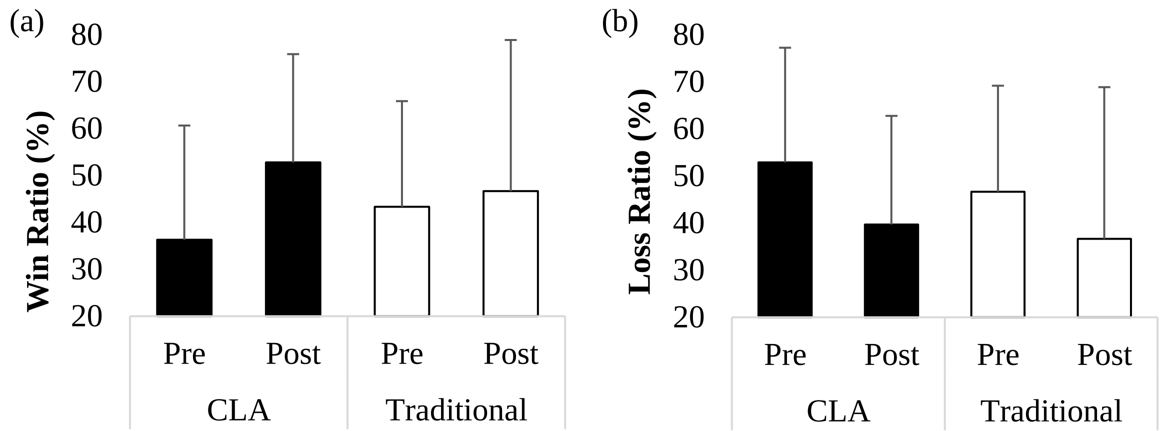

Figure 5.4. Percentage of overs perceived to have been (a) won or (b) lost by the batter during the pre-intervention (Pre) and post-intervention (Post) skills test.

Perceiving wins and losses: Batter's perceptions of why they won or lost an over during the batting skills test conducted pre and post-intervention is shown below (Figure 5.5 & 5.6). The CLA group had observable changes in the percentage of codes reported for runs scored (pre-test 17.14%; post-test 44.90%), batter's execution (pre-test 45.71%; post-test 18.37%), bowler's execution (pre-test 2.86%; post-test 12.24%), and emotions (pre-test 17.14%; post-test 6.12%). No noticeable change was present for dismissals (pre-test 17.14%; post-test 18.37%). In contrast, the only observable change for the TPA group was dismissals (pre-test: 11.63%; post-test 18.18%). No noticeable change was present for runs scored (pre-test 34.88%; post-test 36.36%), batter's (pre-test 37.21%; post-test 31.82%) or bowler's execution (pre-test 11.63%; post-test 11.36%) and emotions (pre-test 4.65%; post-test 2.27%).

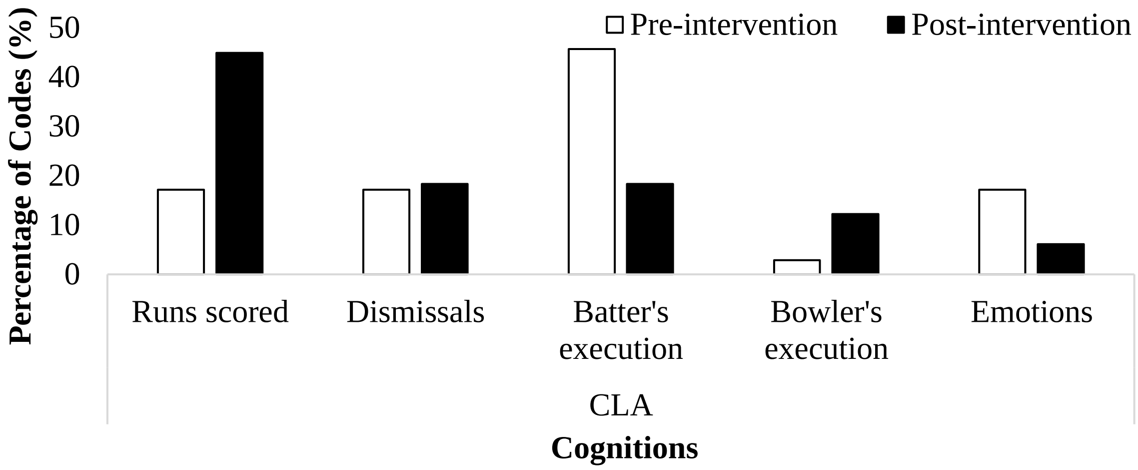

Figure 5.5. Comparison of the CLA group's cognitive evaluations regarding why an over was won or loss during the pre-intervention and post-intervention skills test.

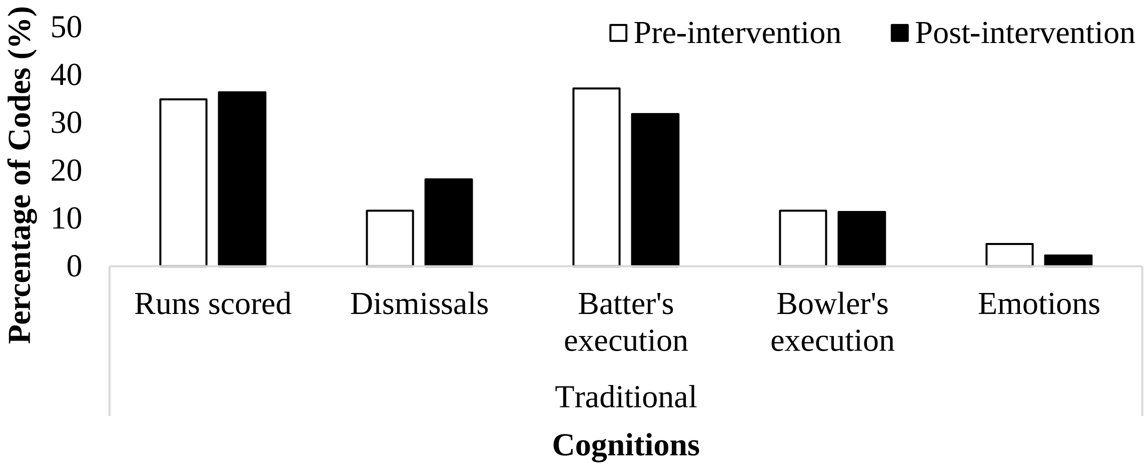

Figure 5. 6. Comparison of the traditional group's cognitive evaluations of why an over was won or loss during the pre-intervention and post-intervention skills test.

Game plans: Batter's reported game plans during each over of the batting skills test, conducted pre and post-intervention, are shown below (Figure x). The CLA group had observable changes in the percentage of codes reported, with an increased focus on outcome goals such as scoring runs (pre: 33.33%; post: 55.00%), and adapting strategies (pre: 12.00%; post: 25.00%). Conversely, there was a decrease in the focus on internal mechanisms such as percentage of achieving ‘bat-ball contact’ (pre: 21.21; post: 2.50%) and make ‘technical changes’ codes (pre: 24.24%; post: 10.00%). No noticeable change was present for limiting dismissals (pre: 0.00%; post: 2.50%) or none/ other (pre: 9.09%; post: 5.00%). In contrast, the only observable change for the TPA group was scoring runs (pre: 41.46%; post: 34.21%). No noticeable change was present for adapting strategy (pre: 7.32%; post: 10.53%), achieving bat-ball contact (pre: 12.20%; post: 15.79%), making technical changes (pre:12.20%; post: 15.79%), limiting dismissals (pre:12.20%; post:13.16%) and other/none (pre:14.63%; post: 10.53%).

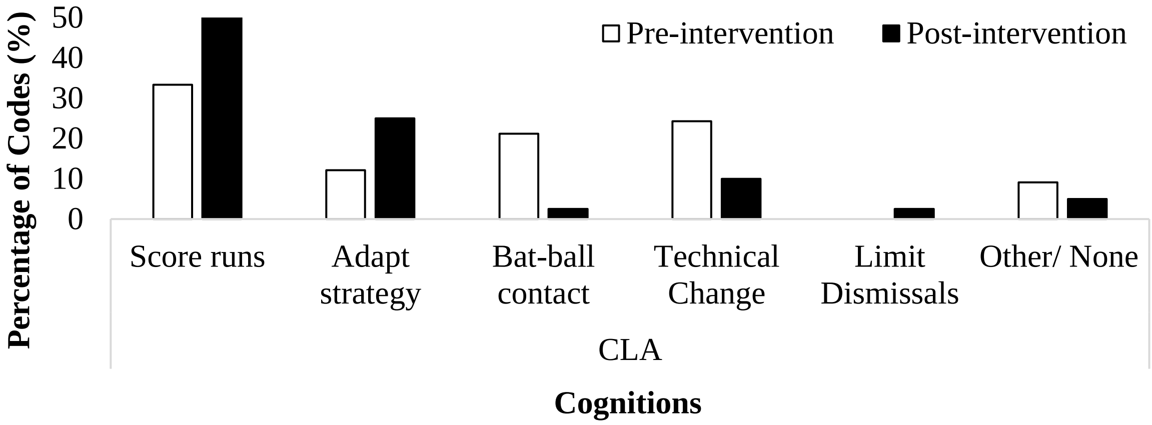

Figure 5.7. Comparison of the CLA group’s game plan during both the pre-intervention and post-intervention skills test.

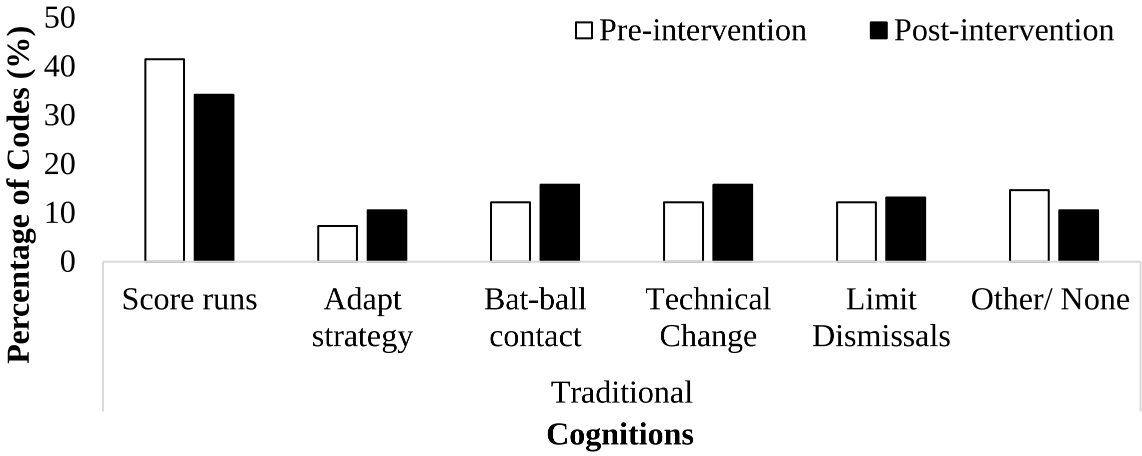

Figure 5.8. Comparison of the traditional group's game plan during both the pre-intervention and post-intervention skills test.

Emotions

For total emotions score, there was no significant three-way interaction between group, time and over number $F(3,54) = 0.75$, $p = .53$, $\eta^2 = .040$. Follow-up analysis revealed a significant two-way interaction between time and over number $F(3,54) = 3.54$, $p < 0.05$, $\eta^2 = .273$, which demonstrated that regardless of group all participants had reduced total emotions score during Pre-over 1 of the post-intervention skills test (6.29 ± 1.11) compared with the pre-intervention (7.79 ± 1.26). However, there was no significant group by time interaction $F(3,54) = 0.53$, $p = .39$, $\eta^2 = .054$, or group and over number interaction $F(1,18) = 0.79$, $p = 0.39$, $\eta^2 = .042$ (Figure 5.9)

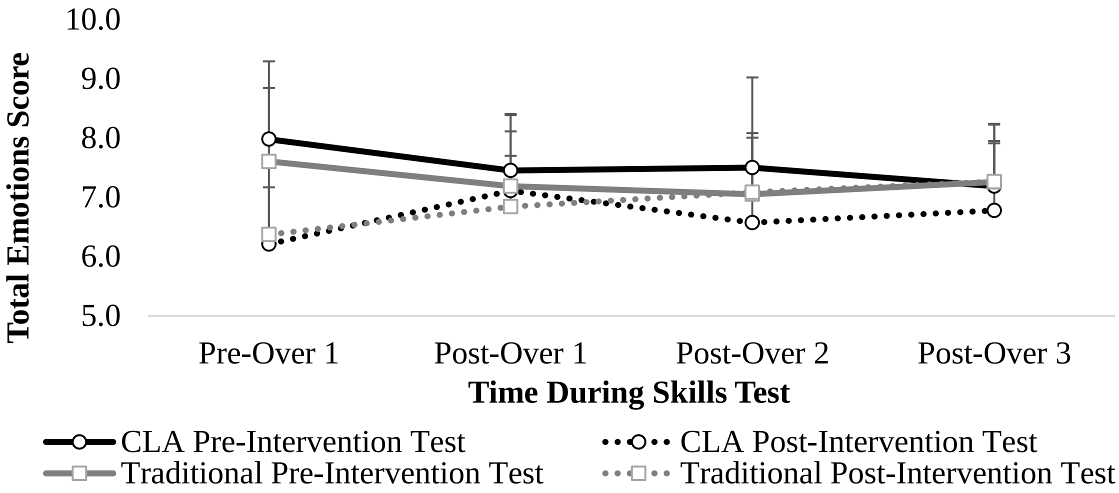

Figure 5 9. Reported total emotions (SLEQ) scores taken prior to over 1, after over 1, after over 2 and after over 3 during the pre-intervention and post-intervention skills test.

There was no significant three-way interaction between group, time and over number on nervousness rating $F(3,54) = 1.48$, $p = .23$, $\eta^2 = .076$. There was also no significant two-way interaction between the groups and time $F(1,18) = 0.38$, $p = 0.57$, $\eta^2 = .021$, or groups and over number $F(3,54) = 0.94$, $p = .43$, $\eta^2 = .050$. There was however an interaction between time and over number $F(3,54) = 1.48$, $p < 0.05$, $\eta^2 = .257$. Regardless of training approach, higher nervousness ratings were reported during the pre-intervention skills test for both pre-over 1 (1.65 ± 0.89) and post-over 1 (1.06 ± 0.74) compared to the post-intervention skills test (Figure 5.10).

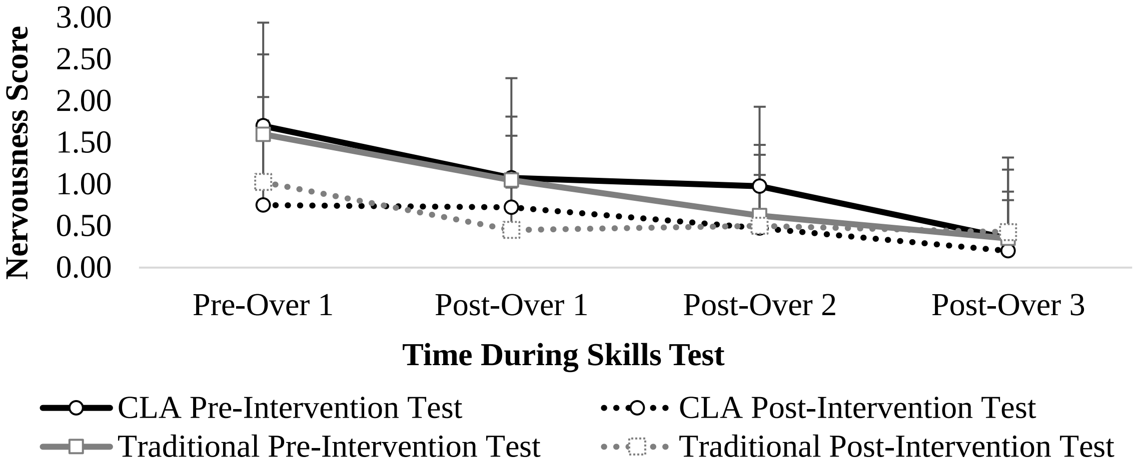

Figure 5.10. Reported nervousness scores across the 4 time points during the pre-intervention and post-intervention skills test.

For enjoyment scores, there was no significant three-way interaction between the group, time and over number $F(3,54) = 0.67$, $p = .57$, $\eta^2 = .036$. There was also no significant two-way interaction between groups and time $F(1,18) = 0.15$, $p = 0.70$, $\eta^2 = .008$, groups and over number $F(3,54) = 0.45$, $p = .72$, $\eta^2 = .024$, or time and over number $F(3,54) = 1.62$, $p =.20$, $\eta^2 = .083$. Therefore, no difference was found in enjoyment scores for either the CLA group pre-over 1 (pre: 3.14 ± 0.53 v post: 3.16 ± 0.62), post-over 1 (pre: 3.08 ± 0.67 v post: 3.08 ± 0.67), post-over 2 (pre: 3.16 ± 0.67 v post: 3.06 ± 0.65) or post-over 3 (pre: 3.48 ± 0.51 v post: 3.34 ± 0.47) or the TPA (pre: 3.26 ± 0.63 v post: 3.13 ± 0.83), post-over 1 (pre: 3.04 ± 1.15 v post: 3.34 ± 0.47), post-over 2 (pre: 3.38 ± 0.49 v post: 3.22 ± 0.58) or post-over 3 (pre3.58 ± 0.49 v post: 3.48 0.51).

For anger scores, there was no significant three-way interaction between the group, time and over number $F(3,54) = 1.24$, $p = .30$, $\eta^2 = .065$. There was also no significant two-way interaction between the groups and time $F(1,18) = 0.00$, $p = 0.95$, $\eta^2 = .000$, groups and over number $F(3,54) = 0.20$, $p = .90$, $\eta^2 = .011$, or time and over number $F(3,54) = 1.58$, $p =.23$, $\eta^2 = .076$. Therefore, no difference was found in enjoyment scores for either the CLA group pre-over 1 (pre: 0.30 ± 0.37 v post: 0.20 ± 0.36), post-over 1 (pre: 0.90 ± 0.93 v post: 0.87 ± 1.0), post-over 2 (pre: 0.67 ± 0.90 v post: 0.50 ± 0.55) or post-over 3 (pre: 0.30 ± 0.51 v post: 0.80 ± 1.27) or the TPA (pre: 0.27 ± 0.84 v post0.27 ± 0.84), post-over 1 (pre: 0.80 ± 0.96 v post: 0.63 ± 0.64), post-over 2 (pre: 0.37 ± 058 v post: 0.67 ± 072) or post-over 3 (pre: 0.37 ± 0.66 v post: 3.48 ± 0.51)

For fulfilment scores, there was no significant three-way interaction between the group, time and over number $F(3,54) = 0.07$, $p = .98$, $\eta^2 = .209$. There was also no significant two-way interaction between the group and time $F(1,18) = 1.56$, $p = .23$, $\eta^2 = .080$, or group and over number $F(3,54) = 0.89$, $p = .45$, $\eta^2 = .047$. However, there was an interaction between time and over number $F(3,54) = 3.45$, $p < 0.05$, $\eta^2 = .161$, with higher fulfilment ratings being reported during the pre-intervention (2.66 ± 0.62) compared with the post-intervention skills test (2.10 ± 0.96) for pre-over 1. Therefore, no difference was found in enjoyment scores for either the CLA group pre-over 1 (pre: 2.84 ± 0.64 v post2.10 ± 1.0), post-over 1 (pre: 2.40 ± 0.74 v post: 2.44 ± 0.90), post-over 2 (pre: 2.70 ± 0.51 v post: 2.54 ± 0.81) or post-over 3 (pre: 2.06 ± 0.31 v post: 2.66 ± 1.01) or the TPA (pre: 2.48 ± 0.58 v post: 2.1 ± 0.97), post-over 1 (pre: 2.3 ± 0.99 v post: 2.62 ± 0.67), post-over 2 (pre: 2.68 ± 0.458 v post: 2.90 ± 0.64) or post-over 3 (pre: 2.96 ± 0.56 v post: 3.06 ± 0.60)

Player perceptions

There was a significant interaction between group and time on the level of enjoyment reported $F(9,162) = 2.12$, $p < 0.05$, $\eta^2 = .105$. As it does not add to the central thesis of this study, each individual week's anova values and effect sizes are not reported. A main effect was also found for group and level of enjoyment $F(1,18) = 17.84$, $p < 0.05$, $\eta^2 = .498$, with CLA reporting higher levels (9.07 ± 1.05) than the TPA group (7.97 ± 1.00).

There was a significant interaction between groups and time on the level of challenge $F(9,162) = 2.42$, $p < 0.05$, $\eta^2 = .119$. A main effect was found for group and level of challenge, regardless of individual weeks, with CLA reporting higher levels (7.76 ± 1.16) than the TPA group (7.26 ± 0.85).

There was no significant interaction between the practice approach and time on the level of cognitive demand reported by groups $F(9,162) = 1.22$, $p = 0.29$, $\eta^2 = .063$. A main effect was found for group $F(1,18) = 9.52$, $p < 0.05$, $\eta^2 = .346$, with the CLA group demonstrating higher reported cognitive demand (7.30 ± 0.83) than the TPA group (6.30 ± 1.32). For the physical demand rating, there was no significant interaction between the practice approach and time $F(9,162) = 1.54$, $p = 0.14$, $\eta^2 = .079$. There was also no main effect was found for group $F(1,18) = 0.03$, $p = 0.87$, $\eta^2 = .002$, (CLA: 6.70 ± 0.82; TPA: 6.66 ± 1.16).

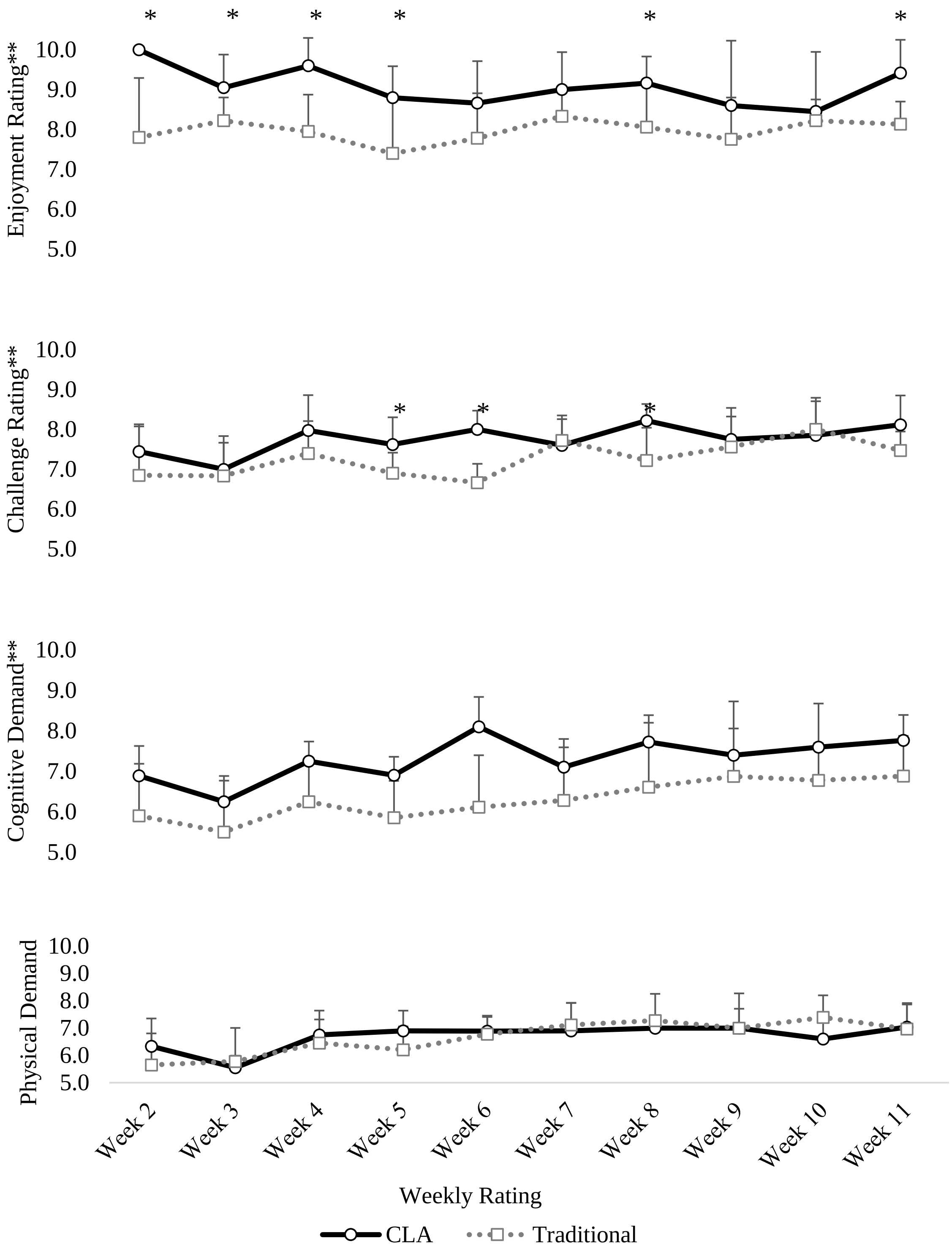

Figure 5.11. Weekly breakdown of player perceptions of the training approach including (a) enjoyment, (b) challenge, (c) cognitively demanding or (d) physically demanding. *Significantly different from traditional (simple main effects); **significantly different traditional group (main effect)

Discussion

The aim of this study was to compare the effectiveness of a constraints-led coaching approach relative to a traditional practice approach on cricket batter's skill acquisition. All participants batting skill was assessed before, during and after a 12-week acquisition phase. Within-practice session recordings of the participant's perceptions, including enjoyment, challenge, physical and mental demand were also collected. The primary finding of this study was that the CLA practice leads to better cricket batting skill acquisition than a more traditional practice approach. The CLA group outperformed the TPA group in a number of key batting performance measures, as well as leading to changes within reported game-specific cognitions. No significant changes were observed between groups for any affective measures, however, both groups demonstrated significant reductions in nervousness from pre-intervention to post-intervention, during the pre-over 1 and post-over 1 of the skills test.

Overall, it is clear from the results that the constraints-led coaching approach resulted in a more positive learning experience for participants, compared to the traditional approach. While the batting performance data showed the CLA group scoring more runs and playing more scoring shots than the TPA group during the mid-intervention and post-intervention skills test, further analysis was conducted to understand the primary mechanism that explained this finding. The CLA group demonstrated significant improvement in the quality of bat-ball contact from pre-intervention to both the mid-intervention and post intervention skills test, while also significantly outperforming the TPA in the post-intervention skills test. They also significantly improved their technical footwork from both the pre and mid-intervention to post intervention skills test. In contrast, while the traditional practice group had greater ratings during the pre-intervention compared to the CLA group, their technical foot work rating declined significantly from pre-intervention to mid-intervention. These technical factors indicate that the CLA group developed greater temporal and spatial accuracy within their batting movements, likely as a result of the emphasis on coupling perception and action during practice (Pinder et al., 2009; Renshaw et al., 2010).

Interestingly, neither group showed significant changes in their force of bat swing rating, nor did they significantly alter the type of coordination patterns produced during the skills test. That is, no difference was found in the percentage of front foot bat shots or vertical bat shots executed, or shots where the ball was played along the ground. This provides further evidence for the conclusion that the improved cricket batting skill is, at least partly, a result of greater spatial accuracy (i.e. ability to make quality bat-ball contact) when intercepting the ball, along with more efficient movement patterns (i.e. transitioning body weight either towards or away from the ball, rather than performing additional readjustment movements).

While the TPA group's training consisted of highly repetitious actions of 'technically correct' execution, the lack of representativeness with this training approach is thought to be a key reason for this finding. Specifically, the lack of information-movement coupling associated with this training approach. Part-practice training involves practicing skills underpinning expertise as sub-tasks prior to performing the task as a whole (Frederiksen & White, 1989). From a dynamic systems perspective, focusing on practicing parts of the action is unlikely to develop the features of the movement that are responsible for the transition of one part of the movement to the other. Additionally, the separation of perception-action couplings is grounded in both neurological and behavioural explanations (Goodale & Milner, 1992; Pinder et al., 2009). These criticisms are not novel, and have been noted as a consequence of part-task practice within high-organisational tasks (Mané et al., 1989). The results of this experiment do not show that developing cricket batting skill using part-task practice methods transfers to the performance environment in which behaviour is intended; where the skill is performed in its entirety and intricately linked to informational variables present in the environment (Müller et al., 2006; Müller et al., 2009; Renshaw & Fairweather, 2000).

Following a more multi-dimensional approach to skill development, the examination of the participant's cognitions was of particular interest. Surprisingly, no significant changes were observed in the perception of overs perceived to have been won, lost or drawn for either group. This is despite the CLA group scoring significantly more runs and playing more scoring shots during the post-intervention skills test. One explanation is that, as participants in the CLA group become more skilful, their expectations of what is required to 'win an over' also change. This explanation is evidenced by the substantial change in the CLA group's cognitions when asked why they believe they won, lost or drew the over. Cognitions that were coded 'runs scored' (pre 17.1%; post 44.9%) increased dramatically, while cognitions about the participants own execution reduced (pre 45.7%; post 18.4%) in contrast. Little to no change was seen in the TPA for runs scored (pre 34.9%; post 36.4%) or batter's execution (pre 37.2%; post 31.8%) cognitions. It has been shown previously that the cognitions of different skill level performers vary, as does the information in which they attune towards (Araújo et al., 2005). These findings suggest that the CLA group became less attuned towards intrinsic focuses, such as their own execution, and rather more focused on achieving their outcome-goal.

Similar cognitions were reported when participants were asked about what their game plan was during the previous over. The TPA group had little change in cognitions from pre-intervention to post-intervention. In fact, cognitions that represent internal focuses of attention (achieve bat-ball contact and make a technical change) had only a slight increase for the TPA (pre 24.4%; post 31.6%), while in comparison the CLA had large reductions in those types of cognitions (pre 48.5%; post 12.5%). Cognitions that represent external focuses, including scoring runs and adapting strategy, increased substantially for the CLA (pre: 55.6%; post: 80.0%). Little change was shown for the TPA (pre: 49.8%; post: 44.7%). This shift to an external focus during performance might aid in execution (Wulf, Shea, & Lewthwaite, 2010), while an internal focus that attempts to control self-organised movement processes likely impacts performance negatively (Stoate & Wulf, 2011; Wulf & Su, 2007).

One theory, which better accounts for the interaction between cognitions and actions, is put forward that proposes batters in the CLA group developed better attunement to the multiple affordances present; which exist in both the performance environment, and in the CLA's practice environment. As a result, batters learnt to exploit the affordances that correspond with their own capabilities. The increase in 'scoring runs' and 'adapting strategies' cognitions of the CLA group highlights this shift; from focusing on their own movements, to focusing on exploiting the affordances available within the environment. An important feature of the CLA practice that supports this development of detecting and exploiting affordances, is its adherence to maintaining coupling of perception and action.

Intentions, such as those represented as a part of the batter's game plan, help to shape the actions and perceptions of performers (Davids, Araújo, Hristovski, Passos, & Chow, 2012; Seifert & Davids, 2012). Similar findings regarding the external focus, displayed by those with greater skill, have also been reported in interceptive timing tasks such as baseball (McPherson & MacMahon, 2008) and cricket (See Chapter 4). While this experiment is unable to conclusively define exactly what is responsible for the positive learning of the CLA group – that is, a shift in focus of intentions, superior development of coordinative skills, or a combination of both – performance in real world tasks do not occur in vacuums. It is beneficial to understand whether a learning approach can improve multiple facets of skill, that ultimately result in what is considered expert performance.

While there were changes reported for both actions and cognitions, no difference was found in emotions between groups over the course of the intervention. Regardless of practice approach, all participants had significantly lower nervousness ratings before and after the first over of the post-intervention skills test, compared to before and after the first over of the pre-intervention. This higher state of nervousness may be attributed to the unfamiliarity of participating in a 3-month development program, coupled with a game-specific training task, and eagerness to impress coaches. Interestingly, no difference was reported between overs during either skills test (pre or post intervention) for either group. Both training groups were seemingly able to regulate their emotions equally well during both skills test. Further research is needed to better understand the relationship between emotions, actions, and cognitions (Headrick, 2015).

Finally, player perceptions of their training approach revealed numerous differences. While both groups rated their enjoyment extremely high, the CLA group had significantly higher ratings than the TPA group. Similarly, the CLA group had higher ratings of challenge and cognitive demand associated with the practice approach, while no difference was reported for physical demand. In line with this experiment's hypothesis, manipulating constraints, creating competitive and dynamic environments, and forcing participants to generate their own solution to a performance problem are suggested to be the primary cause the greater challenge and cognitive demand ratings. From a practical perspective, effectively manipulating constraints requires coaches to possess a mastery of knowledge and experience within their specific sport (Renshaw et al., 2010). Without this, coaches are likely to transition back to utilising approaches (e.g. traditional) with which they have greater familiarity and confidence delivering (Roberts, 2011). A number of strategies were employed to help circumvent this possibility. This included using professional, experienced coaches, whom had been educated on the theoretical background of both constraints-led and traditional practice approaches prior to the intervention, to help design and implement training sessions in conjunction the primary investigator.

The practical applications of this study extend to coaches and practitioners involved with already skilled junior performers. From a practice design perspective, the experimental findings support the notion for coaches to maintain key information-movement couplings to maximise learning outcomes. This can be achieved through simplifying the tasks so as to match the learner's attentional capacity and skill level, rather than deconstructing the movement into smaller parts. Coaches should also be acutely aware of the interaction between the intentions of the learner, and the aforementioned perception and action during a practice task. Persistent instructions and feedback centred on achieving an idealised criterion model of movement are suggested to negatively impact on the cognitions of learners during performance. In contrast, coaches should promote learners to search for their own motor solution to the practice task problem. Additionally, it would seem that 10 practice sessions over 6 weeks is not sufficient enough for substantial changes in coordinative ability; rather, more longitudinal empirical work is required to understand how long skill development may take.

Limitations associated with this experiment include the individual influence of each constraint manipulated during each session. While it can be asserted that manipulations were enjoyable, challenging, induced cognitive demand and were at least as physically demanding as traditional approaches, the overall learning benefit of each manipulated constraint is unclear. Also, while both coaches were involved in the design and implementation of the two approaches, ultimately each coach delivered the sessions with their own idiosyncrasies. Future research is required to better understand how manipulating certain constraints can result in positive, or potentially negative learning experiences. For example, Farrow and Reid (2012) examined how the bounce properties of different tennis balls can influence the behaviours of beginner tennis players during practice. Similarly, exploring how the manipulation of tasks constraints, such as rules or temporal demand, influences behaviours executed during practice would further elucidate the potential benefits of this approach.

Conclusion

The purpose of this study was to compare two common coaching approaches and their effectiveness on skilled junior cricket batters. Performers practicing under the constraints-led approach demonstrated significant improvement in their batting skill; that is, their ability to score more runs was underpinned by greater spatial accuracy when contacting the ball, body position relative to the oncoming trajectory of the ball and increased external focus during performance. In contrast, following the more traditional practice approach, inclusive of greater volume and highly repetitious execution of coordination patterns, resulted in no significant changes in batting skill over a 3-month period. Future research is encouraged to continue examining how manipulation of key task constraints influences behaviour, in order to help inform coaching practices.

CHAPTER 6: GENERAL DISCUSSION

Introduction

This thesis was directly motivated by the principled concepts underpinning representative learning design, and aimed to further our understanding of expert interceptive timing skills. This was achieved by designing representative tasks, based on indirect reports from experts in an attempt to develop a model of batting expertise, that could be used to frame skill assessment tools and practice designs. Of interest then, was to firstly explore the interaction of intentions, perception and, actions reported by expert batters using semi-structured interviews, and to then examine whether these qualities could be captured in more representative 'tests' of batting (Davids et al., 2013b). This representative batting skills test allowed for comparison of different practice approaches used by coaches, and their efficacy in developing the underpinning skills of batting expertise. The final chapter of this dissertation will summarise the collective findings from each experiment. This is followed by the theoretical and practical implications, along with recommendations for future research.

Main Findings

Defining Cricket Batting Expertise from the Perspective of Expert Coaches

Through the interview of expert cricket batting coaches, whom themselves were former international or state level batsmen, a conceptual model was developed to identify characteristics of cricket batting expertise within their performance environment. The findings from this study provide support for viewing expertise as multi-dimensional; whereby technical, tactical, perceptual and psychological skills all interact to underpin expert performance. It is suggested that every performance can be likened to a batter being required to 'learn' what is required to succeed. The process of how expert batters go about achieving this is presented in Figure 3.1. Expert batters 'control the game' by perceiving the changing affordances in the performance environment; that is, assessing whether the performance environment favours the expert batter, and then exploiting certain bowlers or periods of time until it does so. Through an awareness of their technical strengths and perceiving the game situation, they are able to minimize the risk of being dismissed while shifting pressure back onto the opposition by scoring runs. Finally, batters possess well developed psychological strategies to manage emotions such as anxiety, and problem solve game specific challenges. Self-regulatory behaviours, such as the planning, monitoring and evaluating actions, are suggested to explain how expert batters manage and manipulate the constant changes occurring in the performance environment.

The temporal model (Figure 3.1; pg. 64) developed highlights a process by which batters attune to and consolidate information from their performance environment. This begins with a general search for information about the opposition and performance environment. As a process of indirect perception, this generalized information about the upcoming game helps to shape game-specific plans and expectations. The batters search for information that then becomes far more specific, and as a result, entails a direct perceptual process. Direct perception allows batters to perceive affordances, based on opposition field settings, and other key contextual information such as role of the batter and situation of the game. Most importantly, perception and action are coupled in the sense that affordances are acted upon, dependent on the action capabilities of the expert batter (and their perception of their capabilities). These factors together shape the intentions of the batter prior to each delivery. The moment of ball delivery occurs as a result of perceiving the oncoming ball and the possible actions it affords. The role of the aforementioned intentions of the batter is to, therefore, help shape perception towards informational variables, and the subsequent motor response. Finally, a between ball routine is employed by the batter to serve as a link for the learnings of the previous delivery, with the subsequent ball delivery that follows. In this sense, cricket batting can be viewed as an accumulation of knowledge of the environment via continuous reflection on ball “plus” ball "plus" ball, and so on (Figure 3.2). The specific processes of "The Plus" include; immediate reflection on the processes and outcome of the pervious delivery; switching-off and attending to task irrelevant thoughts in an attempt to minimize the mental fatigue of cricket batting; and, switching back on and preparing mentally for the next delivery. This reflection process is particularly critical, as it represents the formation or "update" of intentions, in response to the evolving individual, task or environmental constraints. The switching-on was described as a tuning in, and coupling movements to, the rhythm of the opposition bowler; which were characterized by the batter's mental (e.g. self-talk) and physical (e.g. tapping the ground) behaviours. These findings provide future scope for the exploration of skills, underpinning expert batting performance, such as skill assessment tools and training practices.

Emergence of Skilled Behaviours in Advanced, Intermediate and Basic Skill Level Cricket Batsmen during a Representative Training Scenario

The second study was designed to explore the emergence of skilled behaviours, in the form of actions, cognitions and emotions, between advanced (professional state level) cricket batters and their lesser skilled counterparts. A key distinction of this experimental protocol was the use of a field-based testing protocol, underpinned by representative learning design. The ability to better generalize findings from this experiment to real-world performance was seen as the primary advantage of this approach.

The results demonstrated that the field-based test was successful in distinguishing between advanced, intermediate and basic skill level cricket batters. Advanced level batters played more scoring shots and scored more runs, which was underpinned by their superior display of bat-ball contact and technical efficiency, than both intermediate and basic skill level batters. Interestingly, both intermediate and basic skill level batters executed a similar number of scoring shots, however, intermediate level batters had a greater number of total runs scored off those scoring shots. As there were no significant differences in the movement timings between these two skill levels, it was suggested that biological maturation plays a role early in the development of cricket batting skill. It is often espoused that motor-skills, specifically those which are advantaged by greater production of strength or power, also benefit as a result of biological maturation (Hume & Stewart, 2018; Malina, Rogol, Cumming, Silva, & Figueiredo, 2015).

The following section further describes the holistic coordinative, cognitive and emotive behaviours of advanced, intermediate and junior skill level batters. Advanced level batters performed significantly less foot movements when executing a batting shot, while in contrast, both intermediate and basic skill level batters had significantly greater movements; specifically, performing a greater number of readjustment movements. Readjustment movements were defined as a secondary or third movement which occurred in the final moments of ball flight prior to bat-ball contact. These movements were also associated with more defensive type batting shots. This suggests that readjustment movements were performed as batters attuned to later, more specifying ball-flight information. However, as a result, the batting shots employed when a readjustment movement occurred were predominately defensive batting shots. These findings are further validated by intermediate and basic skill level batter's cognitions, when asked to evaluate their performance after each over. Intermediate and basic skill level batters responded with internalised focus-based comments such as their own ability to achieve bat-ball contact, or being in an effective position when contacting the ball. Advanced level batters almost entirely focused on scoring runs and whether they were dismissed, as key factors to their successful or unsuccessful performance. This is suggested to be partly attributed to the lesser-skilled batter’s emotions; that is, they’re higher reported levels of nervousness. These findings provide a valid and feasible approach to measuring cricket batting skill, beyond the more common movement execution used in previous studies.

Superior Skill Acquisition Following a Constraints-Led Approach to Coaching Cricket Batting

The final experiment sought to compare the efficacy of a contemporary, theoretically supported, practice approach with a more traditional practice method to the development of skills underpinning cricket batting expertise. This contrast of learning approaches was intended to investigate the influence of different practice tasks and environments on the development of cricket-specific movement skills, cognitive behaviours and emotions. Secondary factors were also explored, including junior cricket batters' perceived levels of enjoyment and perceived training demands when partaking in these practice approaches.

The contemporary practice method, underpinned by a constraints-led approach, over a 12-week training period was found to be more successful at improving cricket-specific movement skills and cognitive behaviours than a more traditional practice approach. Specifically, batters participating had significantly greater improvement in their run scoring ability, number of runs scored, quality of bat-ball contact and technical movement proficiency, when compared to pre-intervention skills test and the traditional practice group. Changes were also evident in the CLA group's cognitive behaviours. Evaluation of individual batter's performance demonstrated shifts from their internal focus (i.e. perception of batter's own technical performance) during the pre-intervention skills test, towards more outcome focus (i.e. runs scored) during the post-intervention skills test. Similar shifts in cognitions were evident in game-specific plans, as there was a sizable decrease in cognitions reflecting technical changes and their quality of bat-ball contact, which shifted towards scoring runs or adapting their strategy. No apparent changes were evident in the traditional practice group's cognitions. No significant changes in emotions were also evident between groups, as a result of practice. Finally, the contemporary CLA group reported significantly greater levels of enjoyment, challenge, and mental demand when compared with the traditional practice approach. No difference was found for the perceived level of physical demands between practice approaches.

These findings together demonstrate that a contemporary practice method underpinned by a constraints-led approach is more successful in developing cricket batting skill than a traditional practice approach. The novel use of a representative testing scenario allowed for these skills to be measured under conditions similar to those within real-world game demands.

Theoretical implications

An important contribution of these experiments is a greater understanding of the interacting skills that underpin expertise, within an interceptive timing task. Drawing from ecological dynamics theories, a representative learning design provides researchers with a means to explore these interacting skills between different skill level performers in a manner that reflects real-world performance behaviour. Underpinning practice with a constraints-led approach develops these skills more effectively than a traditional practice approach. The following section further explores these findings in relation to previous empirical work, and offers considerations for further investigation.

A particularly intriguing finding was the way in which experts utilise direct and indirect sources of perceptual information during performance (Jacobs & Michaels, 2007). This concept of intentions influencing perceptions and actions was evident in Chapter 4. Prior to the performance, when no direct perceptual information is available to the expert, information is gathered using sources such as anecdotes about the affordances available or the opposition. As shown in the temporal model (Figure 3.1), this occurs during the pre-ball phase, before the expert batter begins their innings. From an ecological dynamics perspective, this ‘knowledge about’ the environment can be useful to initially shape the intentions of batters prior to performance. However, this source of information is not sufficient enough in insolation, as pre-planned behaviours cannot account for the inherently unpredictable and dynamic performance environment.

While it is important to note that experts can, and do, use their substantial knowledge to estimate the likelihood of certain events occurring in certain situations (Alain & Proteau, 1977), this alone does not entirely explain the level of success experts achieve. Instead, experts are posited to rely upon their ‘knowledge of’ the performance environment, which refers to the opportunities for action directly perceived based on available informational constraints (Silva et al., 2013). This knowledge of ‘what to do’ and ‘how to do it’ within any game scenario allows experts to cope with novel and emergent game-specific situations. Importantly, it is grounded within the action capabilities of the expert themselves, and thus, the behaviours that emerge are individualised (Araújo et al., 2006). While ‘knowledge about’ the environment is grounded within indirect perception, ‘knowledge of’ the environment is instead based upon a direct perception of the environment and the affordances that emerge. The temporal model of expert performance (Figure 3.1) highlights that indirect perception is superseded by more relevant, direct perceptual information such as the opposition field settings and opposition bowler, who in turn, each provide their own affordances. It was suggested, based on the perspectives of expert batters, that indirect perceptual information acts a substitute for the more specifying direct perpetual information in shaping intentions, and ultimately, behaviours.

Although it is known that task-specific knowledge contributes to expert performance, it has been noted that few consider what specific aspects of task-specific knowledge are relevant to experts (Crognier & Féry, 2005). This is no doubt due to the inherent difficulty in examining expert knowledge. However, it is a particularly critical issue when attempting to understand expert behaviours, as both the performance environment and situation of the game, significantly impact upon the emergent behaviours (e.g. technical, perceptual, etc.) of experts (Araujo, Davids, Chow, Passos, & Raab, 2009). Schläppi-Lienhard and Hossner (2015) interviewed expert volleyball players in order to understand the critical decision-making factors that shaped their behaviour. Their findings revealed domain-specific knowledge, such as opposition strategies, preferences, strengths and characteristic tells, as well as external factors including the course of the game and weather conditions, were important factors that influence gaze behaviour and subsequent actions. Therefore, it is unsurprising that experiments which observe behaviours in situ can often report conflicting findings when compared with data reported from highly constrained experimental situations (Afonso, Garganta, Mcrobert, Williams, & Mesquita, 2012; Afonso, Garganta, McRobert, Williams, & Mesquita, 2014). Instead, exploring these factors of expertise, and how they interact with perception and action, is argued to require a representative approach that does not overly constrain behaviours.

The advantage of a representative learning design (Pinder et al., 2011b), are evident from the findings of the Chapters 4 and 5. Previous research into cricket batting has focused almost exclusively on a single cricket bat shot; the front foot vertical bat shot (Elliott et al., 1993; Stretch et al., 1998; Stuelcken et al., 2005). This has provided subsequent research such as this thesis with a clear framework in which to examine key movement couplings and timings (Weissensteiner et al., 2011). However, in order to further extend our understanding, and to better reflect the dynamic environment in which these behaviours are performed, it is necessary to examine these movements using a representative methodology.

Similar to the aforementioned previous body of work, there were discernible differences between advanced (i.e. state-level), intermediate and basic cricket batters in their temporal and spatial accuracy when contacting a cricket ball (Portus et al., 2010;

Weissensteiner et al., 2011). However, the far more novel findings emerged from the variability of coordination patterns employed to achieve the task goal. Previous studies on cricket batting constrained the movement in such a way that batters were *required* to perform a singular coordination pattern. This constraint is argued to impact movement behaviour in two ways. Firstly, the movement duration time of batters is theorized to be considerably longer. Evidence of this can be seen within Stretch et al. (1998), who reported an average movement duration time of 520ms, and Stuelcken et al. (2005), who reported an average movement duration time of 330ms when analysing the foot movement of cricket batters. Chapter 4 reported all skill level batters, that is, advanced (167 ms), intermediate (169 ms) and junior (209ms) batters, as displaying substantially shorter movement durations in comparison. These differences can be accounted for when considering the divergent methodological approaches undertaken. The experiment detailed in Chapter 4 involved batters who had high levels of uncertainty regarding the ball trajectory; which is replicable with what is experienced during performance. In order to overcome the inherent uncertainty and still produce effective movement patterns, batters adapt their movements to be shorter in duration and executed ‘relatively’ later within the batting event.

This finding is also consistent with others from Chapter 4, where advanced batters were shown executing their movements later and with a shorter duration than their lesser skilled counter-parts. Oudejans et al. (1997), when examining expert and non-expert outfielders catching a ball, also reported that experts do not necessarily move earlier than their less skilled counter-parts when intercepting an object, but instead, move with greater accuracy. In Chapter 4, both intermediate and basic skill level batters executed significantly more foot movements that their advanced counter-parts; which included a significantly greater percentage of readjustment movements being performed. Similarly, in Chapter 5, the CLA group improved their technical efficiency alongside improving in run scoring. The improvement in technical efficiency directly reflects a reduction in the number of readjustment movements performed. Therefore, functional movement responses in cricket batting can be characterised by less movements, occurring for a shorter duration, and being initiated later, when performed in highly dynamic and uncertain performance environments. These findings exemplify the advantage of utilising a representative learning design to explore skilful movement behaviours.

Coaching manuals commonly describe expertise through the attainment of highly repeatable movements (Penn & Spratford, 2012). From a theoretical perspective, this was commensurate with information processing theories of motor learning, which viewed movement variability as unwanted noise (Faisal, Selen, & Wolpert, 2008; Glazier, 2011). Dynamic systems theorists instead have proposed that this movement variability can serve a functional and necessary purpose in skilful movement (Davids et al., 2003b). In contrast, there is also movement variability which is dysfunctional, and can be characterised as not adequately meeting the demands of a task or the task goal (Warren, 2006). However, there remain some unresolved issues within this particular field.

Firstly, the relationship between movement variability and the acquisition or development of motor skills is not entirely understood. For example, it has been shown that within a continuous motor skill, experts often demonstrate functional movement variability when trying to swim faster, by adapting the movement couplings between different limbs; while novices, more simply, increased the frequency of movements (Leblanc, Seifert, Baudry, & Chollet, 2005; Seifert et al., 2010; Seifert et al., 2004). The findings from this series of experiments highlight the variability within cricket batter's movement at different skill levels of performance. Specifically, the type of cricket batting shot executed by advanced batters (combination of horizontal or vertical shots) and foot movement (predominately forward), was in stark contrast to those less skilled batters, who relied heavily on a single bat shot (i.e. vertical), and performed an array of forward and backward foot movements. It is proposed that variability within performance can serve a functional purpose, and aid the batters in achieving tasks goals when they are being actively opposed by an opposition. Rather than rely solely on one movement pattern, advanced batters demonstrate an ability to intercept the same trajectory (i.e. length) delivery with a plethora of different bat shots (i.e. movement patterns).

It is proposed that this movement variability is present within dynamic scenarios due to the continually updating of a performer's intentions, alongside the changing landscape of the scenario. The experiment in Chapter 3 clearly underlines the process whereby expert batters sought to attune to continually update their search for visual information constantly emerging within the performance environment. As the availability of perceptual information constraining movement behaviour has been well investigated (Peploe, King, & Harland, 2014; Pinder et al., 2011b), a far less explored area is how learners attune to different perceptual information, as a result of shifting intentions (Jacobs & Michaels, 2007). For example, the cognitions of advanced level batters almost exclusively focused on methods in which they could score runs. The subsequent action responses showed highly varied vertical and bat shots, coupled with more stable foot movements. In contrast, less skilled batters displayed cognitions that were mixed between scoring runs and achieving bat-ball contact, or making technique changes. In turn, their actions demonstrated rigid batting strokes (i.e. predominantly vertical), while variable foot movements (i.e. forward and back). These findings provide further evidence that intentions play a role alongside action in the detection and selection of affordances presented within the performance environment. For advanced batters, the variability within their movement presented greater opportunities to score runs. In contrast, less skilled batters movements allowed them to consistently make contact with the ball (Figure 4.6a), albeit at the expense of executing scoring shots (Figure 4.6b). These findings extend the work of Pinder and colleagues (2011) by highlighting the importance of considering how the task goal, and the way in which it shapes the intentions of the performer, will subsequently influence perception and action.

Examining behaviour within a game scenario that features instructions such as 'score as many runs as possible without losing your wicket', presents two parallel demands for the batters. That is, scoring runs and making contact with the ball, with the latter allowing runs to be scored. Interestingly, the highly skilled batters in these experiments demonstrated intentions about the primary tasks (e.g. scoring runs and limiting dismissals) with an external focus (where to score runs), while the lesser-skilled batters were more focused on internal processes to achieve the task goal (bat-ball contact). While the impact of these intentions on perception and action have been covered extensively, the following section will discuss in relation to previous work on focus of attention.

Distinct differences between foci of attention and skill level is well documented as a factor in successful performance (Wulf & Su, 2007). The proposed mechanism is that an internal focus of attention is synonymous with a conscious effort to control complex movements, which are not normally consciously controlled (Wulf, McNevin, & Shea, 2001). Thus, this internal focus interferes with the self-organisation of the performer's movement. While there is a dearth of literature addressing intentions of performers (given the difficulty in which it can be measured and manipulated), intentions can be thought of as the motivations of the learner, arising from such things as their needs, wishes, beliefs, emotions or external instructions (Jacobs & Michaels, 2007). Attention, however, being far more grounded in previous work, refers to the attendance of sensory information relative to the learner.

When describing perceptual learning, Jacobs and Michaels (2007) define the process as an 'education of attention' towards detecting variables that directly specify the property that the learner intends to perceive. The intentions of the learner play a role in shaping which perceptual variable is searched for and perceived, which in turn, influences the affordances acted upon. Chapter 4 provides an example of how the intentions of performers were shaped, partly, by a need to achieve bat-ball contact or make technical changes. This need is commensurate with an internal focus of attention and may partly explain the poorer performance of intermediate and basic batters (Jackson, Ashford, & Norsworthy, 2006; Janelle, 2002). That is, rather than searching for informational variables that would afford the batter the opportunity to execute a scoring shot like advanced level batters, the intentions of lesser skilled performers guided their perception towards non-specifying informational variables.

Underpinning practice with a constraints-led approach has been positioned as an effective method to developing complex motor-skills (Renshaw, 2010). The tenets of this approach and how they impact skill has been investigated acutely, such as representative learning design (Krause et al., 2018), affordances (Franchak & Somoano, 2018), and the manipulation of constraints (Limpens et al., 2018). However, few studies have undertaken more longitudinal approaches. Lee et al. (2014) examined the effectiveness a non-linear pedagogical coaching approach (NLP) over a 4 week period – and while reporting no differences in skill development compared with a linear pedagogical approach (LP) – they did find that NLP resulted in greater exploration by learners of their own coordination patterns. The results of Chapter 5 provide further evidence for the efficacy of a constraints-led approach to developing skills underpinning expert performance from a longitudinal perspective. Specifically, the superior cognitive development that occurred during the simulated cricket scenario, evidenced by the change in intentions and focus of attention of the constraints-led approach practice group. It is proposed that viewing emergent behaviours as the result of a complex system of interacting constraints, and designing practice environments with this perspective in mind, allows for the simultaneous development of the underpinning technical, perceptual and cognitive skills. Understanding what constraints can be manipulated, and what should remain invariant to ensure transfer of learning, can be guided by a representative learning design. This approach requires consideration of the fidelity of actions and the functionality of these movements towards achieving the task goal during practice.

Practical implications

The practical implications of this study extend to coaches and practitioners, particularly those involved in developing interceptive timing skills. The superior technical abilities displayed by skilled performers are a product of their superior attunement towards key information within a constantly evolving performance environment landscape. This, coupled with the expert batter's superior knowledge of their own action capabilities, role within the team, and situation of the game, are proposed as defining attributes of expertise. Thus, these findings place greater emphasis on factors of skill that cannot be entirely observed through the execution of movement. Coaches and practitioners seeking to develop these underpinning skills could utilise methods such as manipulation of task constraints underpinned by representative learning design principles, and open-ended questioning approaches, in order to challenge learners to search for their own movement solutions to a specific task problem. Developing functional behaviours in response to a task goal also provides opportunity for batters to exploit the environment and the multiple affordances available.

In order to consistently attune to new affordances in the evolving performance environment, as well as resist the mental fatigue caused by long performances, expert batters were described to adopt routines in-between deliveries. Development of "The Plus" is crucial to ensure practice environments promote batters to engage in routines that allow them to 'switch off'; subsequently, engaging in task irrelevant thoughts so as to minimise the accumulative mental fatigue occurring during batting performances. Additionally, the act of 'switching on', by employing behavioural routines (e.g. tapping the bat, readjustment protective equipment, etc.) to help engage in task relevant thoughts again, can also be introduced as a learning outcome during practice.

Interestingly, this finding is in contrast to some previous studies on performance routines. Moran (1996) defines pre-performance routines as ‘a sequence of task-relevant thoughts and actions which an athlete engages in systematically prior to his or her performance of a specific sports skill’ (p. 177). However, a key element of the in-between ball routine was the phase in which batter’s switch off, and engage in task irrelevant thoughts, prior to switching back on. It should be noted that the physical and cognitive behaviours of experts described in Chapter 3 occur prior to, and within performance. Whereas research investigating routines often isolate the skill outside of the performance environment in which it is performed (Lonsdale & Tam, 2008; Phelps & Kulinna, 2015). Definitions, such as Foster et al. (2006) ‘cognitive and behavioural elements that intentionally help regulate arousal and concentration’ (p. 167) encapsulate the psychological aspects of the routine, however, it seems no current description includes the perception of task-relevant information within the performance environment. Between-ball (or more general, between-performance) routines may be a separate psychological intervention that has yet to be fully explored empirically.

The importance of between-ball routines, coined here as “The Plus”, is proposed to be a fundamental skill that coaches should endeavour to develop in their learners, as it provides performers with an opportunity to update their attunement to specifying perceptual information within a dynamic, constantly changing performance environment. A constraints-led approach, underpinned by representative learning design, would inherently include greater opportunities for this reflection to occur based upon representative, game-like scenarios. A core tenet of representative learning is the maintenance of perception-action couplings, such as the opposition bowler (Pinder et al., 2009). Incorporating bowlers and contextual information within practice settings would provide batters with the opportunity to practice “The Plus”; that is, the reflection and attunement to perceptual information, depending on their intentions and task-goal. In contrast, more traditional practice approaches lack the dynamic environment where learners can exploit affordances, and thus, do not afford batters the same opportunity to practice “The Plus” as it relates to a game-specific task. Additionally, the specifying perceptual information in which batters are required to attune towards during performance is often absent within this practice approach.

Further information for coaches seeking to know more about the adaptive motor-skills of skilled cricket batters can be found in Chapters 4 and 5. General recommendations to coaches and practitioners about creating representative practice environments means encouraging batters to; explore new, emergent actions as they search for functional movement solutions to the task problem; focus attention externally, so as to perceive informational variables that relate to the task-goal; and finally, develop between-ball routines to better manage emotions, delay the onset of mental fatigue and ensure batters continually update their perception of the situation of the game so as to align their task-goal with one that serves the purpose of winning the game. A constraints-led practice approach better enables these skills to develop thanks to its underpinning principles. Firstly, the systematic manipulation of constraints that shape behaviour can guide batters to explore more functional movement behaviours. In order to ensure transfer of learning, a representative learning design that addresses action fidelity and functionality of performance provides a framework for coaches to intelligently manipulate constraints. Thus, preserving the perception-action couplings within performance environments provide the learner opportunities to perceive new affordances, that are replicable with the affordances that appear in the performance environment (Renshaw et al., 2010). In contrast, a traditional practice approach does not consider the role of the performance environment as critical to skill development. Instead the performer must engage in a significant amount of practice to remove unwanted variability within their movements. Clearly, there are significant advantages to placing learners in realistic learning environments to holistically develop the interacting skill underpinning expertise.

Finally, experiment 3 also provides a logistically sound, evidence-based coaching framework to improve the cricket batting skill in skilled junior batters. As opposed to traditional practice methods of deconstructing a skill into sub-movements or part practice, in order to reduce the attentional demands placed on the leaner, a constraints-led approach instead proposes task simplification as a more effective coaching strategy. Coaches can manipulate task constraints, such as equipment or rules of an open drill, to match the skill level of the learner and promote a search for a functional movement pattern. Ensuring that the key perceptual information is retained ensures representativeness, and subsequently, optimise transfer to real-world game performances.

Limitations and future research

Qualitative methods, such as face-to-face, in-depth interviews, are associated with certain limitations. The interviews rely on participants responding accurately and honestly to describe or recall any details, thoughts, opinions and behaviours that occurred throughout their playing careers. Therefore, this may be prone to inaccurate reflections of events, feelings or thoughts. Analysis of data can also be potentially influenced by interviewer biases. Remedies were adopted in this study by incorporating two researchers to review all transcripts and develop codes and themes together (Alshenqeeti, 2014). This use of constant comparative method aims to enhance the validity of key findings (Boeije, 2002). Further studies could continue to employ self-confrontational interview method when applying the temporal expert performance model, to further validate various concepts, such as the search for information and the behavioural strategies employed during between ball routines.

Naturally, while the representativeness of task towards the real-wold in which it represents is considered an advantage, it is also associated with limitations and challenges to experimental designs. For example, there are assumptions that are made when utilising bowlers during an experimental design. The first assumption is that bowlers recruited for experiments all have similar bowling actions, and therefore, similar perceptual cues made available to batters. To address this, bowlers were recruited from the same club league and were invited specifically for their orthodox bowling action (as opposed to a slinging-type bowling action). Secondly, the variations in ball length were taken into consideration by categorising the ball length as a full length, good length or short pitched delivery. This categorisation was dependent on where the ball landed on the pitch relative to the batter. There is evidence from previous experiments that ball lengths within 2 m to 4 m do not result in obviously identifiable changes in coordination patterns (Pinder et al., 2012; Stevenson, Smeeton, Filby, & Maxwell, 2015). Finally, cricket bowlers often possess the capability to create minor deviations in ball trajectory (termed off and leg-cutters). This was addressed by giving standardised instructions to bowlers that their task goal was to bowl their normal, stock ball as accurately as possible, while ball speed was accounted for using a speed-radar gun. Future research is suggested to explore how batters adapt their movements to increasingly difficult temporal demands (i.e. ball speed) utilising bowlers. Correspondingly, there is also a need to design experimental tasks that allow batters to produce functionally variable batting shots so as to replicate real-world settings.

With reference to the learning intervention experiment, efforts were made to account for batters participating in cricket batting training outside of the intervention. Such that participants were instructed to forgo off-season or formalised social cricket practice. However, non-formalised practice, such as playing in the backyard or schoolyard with parents or friends, could not be controlled for. The level of coaching knowledge regarding CLA and TPA were addressed by education both coaches in the tenets underpinning each approach. The primary author also oversaw the development of each training session for quality assurance purposes. Additionally, both coaches and the primary author oversaw the implementation of both training approaches by being involved in the delivery of practice sessions.

Another limiting factor is the duration of time available to conduct this learning study. While it is considerably longer than some other previous learning studies (Lee et al., 2014; Vickers et al., 1999), it does not account for the 6 months or more of practice junior cricketers would usually undertake during the course of a cricket season. While the volume of practice achieved during the intervention is commensurate with current club practices, it is unclear whether a ceiling effect would occur with a CLA after a certain period of practice volume. Also, without a control group, there is an inability to confirm that a CLA results in significantly greater development than no practice, albeit given there was improvement between pre and post-intervention, this is unlikely. Instead, a control group would have indicated exactly how much benefit CLA practice has over both TPA and no practice. Finally, a retention test was not possible due to the timing of the experiment. The final week of the experiment (post-intervention testing) fell just prior to the start of the junior cricketer's pre-season training. Therefore, it was not logistically possible to conduct a retention test (duration was approximately 45 – 60 mins per pair of batters) prior to their initial club training.

Future research within sporting tasks is encouraged to continue adopting a representative learning design approach to explore behaviours that are more characteristic of real world performance. Similarly, any experimental designs seeking to represent the behaviours to the environment in which they are intended are encouraged to follow Brunswik's lead in developing a 'hybrid' model of representative design (Brunswik, 1944; Dhami, Hertwig, & Hoffrage, 2004). With reference to the development of skills underpinning expertise, better understanding the interplay between intentions, perceptions and actions could be achieved by adopting more mixed-methods analysis during experimentations.

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APPENDICES

APPENDIX A: Information statement to participants involved in the experiments detailed in Chapter 3, 4 & 5

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled *Identifying the relationship between current coaching philosophies and practices in cricket batting*.

This project is being conducted by student researcher Jonathan Connor as part of a PhD study at Victoria University under the supervision of Professor Damian Farrow from the College of Sports & Exercise Science and Professor Bruce Abernethy from the University of Queensland.

Project explanation

The aim of this study is to assess what current cricket coaches believe to be the most effective method of practice to develop batting skill relative to the nature of current batting practices used.

What will I be asked to do?

You will be asked to be interviewed about your own personal coaching philosophies and current practices. The interview will consist of approximately 18 verbal and 5 written questions, with all responses being recorded. The interview process is expected to take approximately 45 minutes of your time. Any self-identifying information will be kept strictly confidential.

What will I gain from participating?

Coaches will be given an opportunity to reflect on their own coaching philosophies and current practices when training batting skill. A copy of the final report can be provided upon request.

How will the information I give be used?

The information obtained from this study will be used to determine whether there is a difference between how coaches believe batting skill should be practiced, and how it is currently practiced. Secondly, we wish to identify what limitations coaches face when coaching cricket batsmen of any age or skill level. This information will provide rationale and guidance for Cricket Australia in seeking to support effective cricket batting skill practices.

What are the potential risks of participating in this project?

There is minimal risk from participation in this research project. However, if your participation does cause distress in any way, Dr. Harriet Speed from Victoria University (harriet.speed@vu.edu.au; Ph: 399195412) can be contacted for advice regarding counselling services.

Who is conducting the study?

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Jonathan Connor
PhD Provisional Candidate
Victoria University & CA National Cricket
20 Greg Chappell Street | Albion Queensland 4010 |
Mobile: 0407 735 553

Any queries about your participation in this project may be directed to the Chief Investigator listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled *Examining Cricket Batting Skill.*

This project is being conducted by student researcher Jonathan Connor as part of a PhD study at Victoria University under the supervision of Professor Damian Farrow from the College of Sports & Exercise Science.

Project explanation

Current methods of assessing batter's skill level within cricket predominately rely on game performances and subjective analysis by experienced coaches. However, research on technique analysis strong advises to avoid relying on performance scores as an indicator of skill level. Performance as an outcome measure does not explain the process of achieving success, and therefore provides limited information regarding ways to improve or detect technical deficiencies. Therefore the aim of this study is to examine the nature of cricket batters decision-making and technical execution during an 18 ball skill test.

What will I be asked to do?

You will be asked to participate in two common training activities that require you to face 18 deliveries and score as many runs as possible. Both tasks will take place on a centre wicket practice area.

Task 1

The first task will involve facing 18 throw down deliveries at approximately 80km-h and playing as many scoring shots as possible by hitting the ball into gaps.

Task 2

The second task will involve facing 18 deliveries at approximately 115km-h from live bowlers. The task and scoring zones are the same as the first to task, to play as many scoring shots and score as many runs as possible without getting out.

What will I gain from participating?

Participants will be provided with their skill assessment score from the test to assist in improving their game and identify potential weakness within their batting.

How will the information I give be used?

The information obtained from this study will be used to determine the reliability of the proposed 18 ball skill. Secondly, the information will inform coaches around the importance of representative practice activities in relation to ball speed. Results may be provided to the national sporting organisation, presented at conferences or published in peer review journals. The identity of participants will be protected in the reporting of data.

What are the potential risks of participating in this project?

The possible risks to the participants would be the same for every training session. This can include musculoskeletal injury from chronic overuse, or possible soft tissue damage if the ball were to make contact with the batter. However, all batters will be required to wear full protective equipment and a physiotherapist will be onsite if needed. If your participation does cause distress in any way your team psychologist or welfare officer can be contacted for advice regarding counselling services.

Who is conducting the study?

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INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled *Developing Cricket Batting Skill and Situational Decision-Making in Junior Representative Players.*

This project is being conducted by student researcher Jonathan Connor as part of a PhD study at Victoria University under the supervision of Professor Damian Farrow from the College of Sports & Exercise Science.

Project explanation

Current cricket batting training methods are based on tradition and a coach's experiential knowledge. This is often derived from how they, as a coach, trained as a player. While this method has been very successful for Australian Cricket at an elite level, this study will assess its effectiveness at a junior representative level. This training approach will then be compared to a more games-based training approach, which has been designed from high performance coaching recommendations and skill acquisition research.

The secondary aim of this study is to examine whether different aspects of batting skill are developed better in different training environments. Specifically, investigating and monitoring the development of skill execution, decision-making and mental toughness in players. This will be the first study to quantify these measures and observe what influence different training approaches have on their development.

Queensland Cricket will be conducting their annual Emerging Players program. The research involved in the program is designed to investigate which training approach is more effective at developing skill at a junior representative level. Player's batting skill test performance scores will be used to examine which program resulted in better development.

What will I be asked to do?

You will be asked to participate in a 12 week training program run by Queensland Cricket's Emerging Players program. This will include two training sessions per week that will take approximately two and half hours of your time. Anthropometric measurements (i.e. height, weight, and skinfolds) will also be conducted with the player's permission. Training will consist of batting against live bowlers, side-arms, throw-downs and bowling machines in nets and on a centre wicket. Players will partake in goal-orientated activities designed to further develop their skill execution and situational decision-making. One group will participate in a traditional skills training approach, while the other will participate in a more games-based approach.

The 12 week training will include three four week blocks focusing on improving different elements of batting skill. The first is a remedial training block to assist in the development of fundamental cricket batting strokes. The second is a skill execution block designed to improve anticipation and stroke play (i.e. power). Finally, a game sense training block will involve activities that expose players to scenarios designed to improve decision-making.

Batting performance scores will be used for the purpose of evaluating the effectiveness of the two training programs. Video filming may be used when conducting the batting skills test to help coaches provide feedback. Players have the option to choose not to have their performance filmed, fill out the Mental Toughness and Sports Learning and Emotions Questionnaire or have their anthropometric measurements taken. Players also have the option of not having their batting performance scores used for research purposes. Withdrawal from the training program or any of the above measurements will in no way negatively impact the player or have any consequence on their future career. Coaches and the student researcher will be the only people with access to individual player's performance results.

What will I gain from participating?

Players are being offered a free 12 week training program, being run at a high performance facility, by state level coaches. It will provide them with an opportunity to experience taking part in a high performance sports program.

How will the information I give be used?

The information obtained from this study will be used to determine the effectiveness of two common training approaches to developing batting skill. This will inform Cricket Australia decision-makers to potentially update coach education programs with evidence based practice and improve high performance training programs. Secondly, the information collected will inform coaches and players around the importance of representative practice activities to develop decision making. Results may be provided to the national sporting organisation, presented at conferences or published in peer review journals. The identity of participants will be protected in the reporting of data.

What are the potential risks of participating in this project?

The possible risks to the participants would be the same for a normal cricket training session. This can include musculoskeletal injury from chronic overuse, or possible soft tissue damage if the ball were to make contact with the batter. However, all batters will be required to wear full protective equipment and a first aid officer will be onsite if needed. If your participation does cause distress in any way a psychologist or welfare officer can be contacted for advice regarding counselling services.

Dr. Phil Jauncey (Queensland Cricket Psychologist) T: +61 3 3351-5435 E: drphilj@bigpond.net.au

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APPENDIX B: Consent form to participants involved in the experiments detailed in Chapter 3, 4 & 5

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study identifying what current cricket coaches believe to be the most effective method of practice to develop batting skill. Secondly, to examine the nature of current batting practices in various skill levels and age groups from coach's perspective. As a coach, you are invited to participate being interviewed one-on-one about your own personal coaching philosophies and current practices, which will be recorded and take approximately 45 minutes of your time.

CERTIFICATION BY SUBJECT

I, ___________________________

of ____________________

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:

Identifying the relationship between current coaching philosophies and practices

being conducted at Victoria University by Prof. Damian Farrow.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by Jonathan Connor and that I freely consent to participation involving the below mentioned procedures:

- Give my cricket coaching and playing details that will be kept confidential
- Be interviewed by the student researcher
- Fill out a questionnaire
- Answer question relating to my coaching philosophies and practices

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: _________________________

Date: ____/____/______

Any queries about your participation in this project may be directed to the researcher

Prof. Damian Farrow
Professor of Sports Science
Contact: 0408-445-701
If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study investigating current training practices of high level cricket batters. The purpose of this study is to examine decision-making behaviour and technical execution during common training activities. This will be used to determine the reliability of a proposed 18 ball skill test. Furthermore, it will also inform coaches and players about the representativeness and potential effectiveness of the different training activities currently being practiced. These activities include facing throw downs and facing live bowlers in a game environment. As a ***batter***, you are invited to participate in both of these activities while having your training session filmed.

CERTIFICATION BY SUBJECT

I, ___________________________

of _____________________

CERTIFICATION BY GUARDIAN

I, ___________________________

of _____________________

certify that I am voluntarily giving my consent to participate in the study:

Examining Cricket Batting Skill.

being conducted at Victoria University by Prof. Damian Farrow.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by Jonathan Connor and that I freely consent to participation involving the below mentioned procedures:

- Participate in 2 training activities representative of a cricket game
- Face 36 deliveries from throw downs and a live bowler on a centre turf wicket during a practice training session
- Have performance outcomes recorded and movements filmed

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: __________________________

Date: ____/____/______

Any queries about your participation in this project may be directed to the researcher

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CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

Developing Cricket Batting Skill and Situational Decision-Making in Junior Representative Players

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study investigating the development of cricket batting skill and decision-making using different training approaches. This study is being run in conjunction with Queensland Cricket's 15 years and under Emerging Players program, and as such training will take part at Queensland Cricket's training facility and Cricket Australia's Bupa National Cricket Centre. The primary purpose of this study is to compare two common training approaches to developing batting skill and decision-making in junior representative players. Secondly, to actively monitor player's performance during the course of the 12 week training program. The results of this study will be used to provide Cricket Australia with evidence based practice to improve player development and coaching methods. As a junior representative player, you are invited to participate in this 12 week training program aimed at further developing your batting skill. You will also be given access to your own performance data (i.e. skill test results) to help assist with your development.

CERTIFICATION BY SUBJECT

I, ___________________________

of _____________________

certify that I am voluntarily giving my consent to participate in this study being conducted through Victoria University by Prof. Damian Farrow.

CERTIFICATION BY PARENT/GUARDIAN

I, ___________________________

of _____________________

certify that I am giving my consent to for my child to participate in this study being conducted through Victoria University by Prof. Damian Farrow.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by Jonathan Connor and that I freely consent to participation involving the below mentioned procedures:

- Participate in a 12 week (24 session) developmental training program
- Participate in cricket training activities designed to assist with my batting skill development
    - Practicing against live bowlers, side-arms, throw downs and bowling machines
    - Practicing in common game and netted environments
- Participate in a batting skills test

- Have performance outcomes recorded and movements filmed using high speed cameras
- Have anthropometric measurements taken
- Complete questionnaires designed to assess my mental toughness and previous participation in cricket
- Have game performance scores collected during the cricket season immediately after the intervention

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: ________________________

Date: ____/____/______

Any queries about your participation in this project may be directed to the researcher

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APPENDIX C: Questionnaires utilised in experiments detailed in Chapter 3, 4, & 5

INTERVIEWER SHEET

Name: **Date:**

DOB:

Playing Experience (yrs): **Highest Level:**

Coaching Experience (yrs): **Highest Level:**

Current Coaching Level: **Duration (yrs):**

Coaching Format (Please circle any that apply):

4/5 Day **2 Day** **50 over** **40 Over** **T20**

Average number of training sessions per week:

1. How do you currently develop batting skill?
2. Can you give me an example of someone you've worked with?
3. What are the keys to successful batting?
4. What do you think encompasses expert batting?
5. Can you give me an example of how have you developed it in your players?
6. What does a skilful batter look like to you?
7. What is it that separates those players that continue on from grade cricket to state/international level and those who do not?
8. In your opinion, what is the most effective way to develop batting skill?

Confrontational Interviewing Questionnaire

1. Who won that over, yourself or the bowler, and why?
2. What can you tell me about the bowler's skill execution that over?
   E.g. Tell me what you think he did right or wrong?
3. Did you think the bowler had a game plan? If so, what did you think of it?
   E.g. was it successful?
4. Did you have a target in goal? Did that change at any point during the over?
5. What can you tell me about your game plan next over?
   E.g. will you do anything different OR how do you plan on scoring runs?

SPORT LEARNING & EMOTIONS QUESTIONNAIRE (SLEQ)

Instructions:

Below is a list of words that represent a range of feelings that might be experienced during learning in sport. Please carefully read each word and indicate on the scale (0-4) how you feel ***right now, at this moment in relation to the current task / session***. There are no right or wrong choices. All selections should be based on your feelings alone.

	Not at all	A little	Moderately	Quite a bit	Extremely
Happy	0	1	2	3	4
Nervous	0	1	2	3	4
Satisfied	0	1	2	3	4
Annoyed	0	1	2	3	4
Fun	0	1	2	3	4
Stressed	0	1	2	3	4
Fulfilled	0	1	2	3	4
Angry	0	1	2	3	4
Joy	0	1	2	3	4
Pressure	0	1	2	3	4
Successful	0	1	2	3	4
Frustrated	0	1	2	3	4
Enjoyment	0	1	2	3	4
Fear	0	1	2	3	4
Accomplishment	0	1	2	3	4
Excited	0	1	2	3	4
Achievement	0	1	2	3	4

	SCORING INSTRUCTIONS (for researcher only)	**Score**
Enjoyment	= (happy + fun + joy + enjoyment + excited) / 5	
Nervousness	= (nervous + stress + pressure + fear) / 4	
Fulfilment	= (satisfied + fulfilled + successful + accomplishment + achievement) / 5	
Anger	= (annoyed + angry + frustrated) / 3	
	Total SLEQ	

APPENDIX D: Description of coach intervention components detailed in Chapter 5

Program Phase and Objective	Session Principles (Activity design, coach instruction, environment and feedback approach)	
	CLA	Traditional
Phase 1: Front foot bat shots Time: Week 1 - 3 Objective: (1) Develop cricket batting-specific shots played off the front foot, (2) against various ball delivery speeds Phase 2: Back foot bat shots Time: Week 4 – 6 Objective: (1) Develop cricket batting-specific shots played off the back foot, (2) against various ball delivery speeds Phase 3: Batting against spin bowling Time: Week 7 - 9 Objective: (1) Develop cricket batting-specific shots to various forms of spin bowling, (2) variations and speeds Phase 4: Scoring runs Time: Week 9 - 11	Session Outlines: *Activity Design* - ‘Simplified’ approach to developing appropriate coordination patterns - Contested activities whereby the batter was actively competing against opposition (bowler or thrower) - Small-sided (contested) games whereby the game boundaries, equipment and task goals are manipulated to ensure learning outcome is achieved in a game-like, representative manner - Always involved interceptive actions against various ball delivery methods (e.g. over arm throw, side-arm or bowler) *Coach instruction:* - Differentiated; regarding the rules and task constraints associated with the game for each individual. These constraints would be manipulated ad hoc - to ensure learning outcomes were being achieved at a skill level matching the ability of the participant – by making the task easier or harder (e.g. rotate bowler of greater or lesser skill level against skilful or less-skilful batter). *Environment*	Session Outlines: *Activity Design* - Part-practice (segmentation) approach to developing appropriate coordination patterns - Predominately non-contested activities designed to repetitively practice a specific coordination pattern, progressing from simple (under-arm throw) to more challenging task-demands (bowler), ensuring the correct coordination pattern is achieved - Involved various interceptive methods ranging from stationary ball (simple) to more complex (e.g. bowler delivering ball) *Coach instruction:* - Directive; Prescriptive information given to all participants regarding how to execute the desired movement *Environment* - Predominately closed; participants were encouraged to address their own performance production factors rather than outcomes *Feedback approach:* - Use of direct instructional approaches to assist participants in achieving learning outcome (e.g.

Objective: Develop cricket batting-specific shots with sufficient force that it results in runs being scored	- Open; participants could always perceive their performance outcome *Feedback approach:* - Use of questioning to assist participants identify learning focus (e.g. technical, game cognition or psychological) - Provided constructive feedback (positive and negative performances)	technical, game cognition or psychological) - Provided constructive feedback (positive and negative performances)

APPENDIX E: Flowchart of data collection detailed in Chapter 5

	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7		Week 8		Week 9		Week 10		Week 11		Week 12
Session #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Skills Testing	Pre											Mid											Post
Skills Intervention		Phase 1					Phase 2						Phase 3					Phase 4					