

REPRESENTATIVE TASK DESIGN IN CRICKET BATTING

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Abstract

In recent years researchers have argued that in order to fully understand perceptual cognitive expertise in sports, representative tasks must be used to preserve the tightly coupled links between perception and action that experts exploit. Previously, tasks have been considered as representative or not, with little evidence existing to indicate the degree to which a task is representative enough. This thesis primarily aimed to investigate experimentally representative tasks in cricket batting and the degree to which a laboratory-based task of cricket batting was able to represent batters' emergent perceptuo-motor behaviour for perceiving bowlers' delivery length. A secondary aim was to re-evaluate perceptuo-motor behaviours thought to contribute to skilled performance and their development. In chapter 2 skilled batsmen's foot movements were recorded in response to balls bowled to a range of lengths under *in situ* and video-based laboratory conditions. Kinematic analyses quantified decision-making skill and movement scaling. Analyses revealed the laboratory condition to have a high degree of fidelity. Skilled batter's Foot movements were reliably replicated and differences were found compared to a novice group. In chapter 3, response mode, occlusion condition and skill level were compared on the representative laboratory test developed in chapter 2. Analyses identified that skilled performance was only aided by maintaining coupled responses under occluded conditions, whilst no differences were observed under un-occluded conditions. Skilled performers were also shown to possess greater anticipation skills compared with novices under both coupled and un-coupled conditions. In Chapter 4, the effects of manipulating information present *in situ*, through simulated ball flight, and fully simulated training aids were compared in a novel experimental paradigm. Skilled

batsmen faced deliveries across a range of lengths from a bowler (*in situ*), from a bowling machine (simulated ball flight) and from a ProBatter simulator (fully simulated action and ball flight). Results showed that simulated ball flight condition resulted in foot movements that were closer to *in situ* than the fully simulated condition, suggesting that if present, the link between bowling action and ball flight needs to be tightly coupled. These results demonstrate for the first time that representative tasks must not be considered unilaterally as representative or not, but instead the degree of representativeness should be quantified and evaluated against the expert behaviour under investigation. Determination of the degree of representativeness would allow researchers to apply findings to the performance environment with greater knowledge of their potential impact.

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Author Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree, and does not incorporate any material already submitted for a degree. Parts of this thesis have been peer reviewed and published as articles, a list of which is outlined in appendix 6.

Signed:

K. Stevenson

Dated:

11/10/2016

CHAPTER 1: THE STUDY OF PERCEPTUAL – COGNITIVE EXPERTISE IN SPORT

1.1 INTRODUCTION

Perceptual – cognitive skill is described as the ability to identify, acquire, and integrate environmental stimuli with existing domain-specific knowledge in order to plan and execute motor skills (Mann, Williams, Ward & Janelle, 2007). Smeeton, Ward, and Williams (2004) state that perceptual – cognitive skills are central to task performance within the sporting domain. Contrary to public perception, Helsen and Starkes (1999) showed that perceptual – cognitive skills are not related to visual hardware mechanisms (also see Ward, Williams, & Loran, 2000). Instead, Hodges and Williams (2012) state that expertise is attributed to enhanced sport-specific cognitive knowledge structures, acquired through years of deliberate practice (Ericsson, Krampe, & Tesch-Romer, 1993), and the ability to recall information from their long term working memory (Tenenbaum, 1999, & Williams, 2000).

In a meta-analysis Mann *et al.*, (2007) confirmed that experts are typically more accurate and quicker in their responses whilst employing fewer visual fixations of longer duration in order to guide successful actions. Specifically, studies have shown experts to possess more efficient visual search behaviours (North, Williams, Hodges, Ward, & Ericsson, 2009, & Rocca, Ford, McRobert, & Williams, 2011), faster detection and recognition strategies (Williams & Davids, 1998), superior recall of sport specific patterns (North, Ward, Williams & Ericsson 2011, & Williams, Ford, Eccles, & Ward,

2011), enhanced ability to pick up advance visual cues, especially from an opponent's postural orientation (Muller, Abernethy, & Farrow 2006), and are able to formulate expectations of likely events based around situational probabilities (Ward & Williams, 2003, and Williams *et al.*, 2011). Mann *et al.*, (2007) stated that these perceptual – cognitive skill-based advantages allow experts to anticipate an opponent's intention, plan and execute an effective response, and evaluate performance related feedback more effectively, leading to superior performance and further skill development. However, there have been concerns that the current understanding of perceptual-motor skill might have been compromised through experimental designs that are not representative of performance contexts (Pinder, Davids, Renshaw, & Araujo, 2011), specifically, methodologies that have employed an indirect approach to studying perception by examining vision for perception in isolation (Milner & Goodale, 1995), disregarding the the possible linkages between vision and action (van der Kamp, Rivas, van Doorn & Salvendy, 2008).

This thesis aims to investigate the 'representativeness' of laboratory and field based task designs which are being used to study and train perceptual-cognitive skill in cricket batting. Specifically, the aim of this thesis is to address concerns raised over the expert performance approach (Ericsson & Smith, 1991) by investigating the fidelity of emergent behaviours under changing ecological task constraints (*in situ*, field based, simulated and laboratory), and experimental manipulations (uncoupling perception - action and temporal occlusion) over three separate studies. This introductory chapter serves to provide a review of the frameworks and methodological approaches used to study perceptual-cognitive skills in sport, as well as a discussion of the research, which

has contributed to the current understanding and practice in the field of skill acquisition. The rationale for the research conducted in this thesis will be outlined throughout this introductory chapter, and summarised at its conclusion.

1.2 THE EXPERT PERFORMANCE APPROACH

In order to study expert performance, Simon and Chase (1973) proposed the first general theory of expertise whilst investigating behaviour in chess, identifying that experts were able to recall more pattern specific information than were novices. Simon and Chase (1973) suggested that experts were able to recall “chunks” of information, which had been stored in the long-term memory through intense domain specific learning over a period of ten years. Although credible in chess and other information recall domains, theorists argued that the theory could not account for expert performance in tasks which required the need to anticipate, plan, evaluate and reason within the capacity of an individual’s working memory (Ericsson & Kintsh, 1995). Subsequently, Ericsson and Smith (1991) developed the expert performance approach to study the development and attributions of expert performance through three successive methodological stages (see figure 1.1). First, experimenters observe expert performance *in situ* in order to identify specific domain-related characteristics of expertise, which are subsequently replicated through representative tasks that allow experts to execute their skills in a controlled and measured environment (Box 1, Figure 1.1.). Second, in order to analyse the components that mediate expert performance, experimenters use process-tracing measures (e.g. eye movement recordings, film occlusion techniques, and biomechanical

profiling) that are able to provide detailed information regarding the processing and execution of skills (Box 2, Figure 1.1). Finally, the information found during the first two stages is used to develop adaptive learning and explicit acquisition protocols, designed to train novice performers the skills required to attain expertise (Box 3, Figure 1.1).

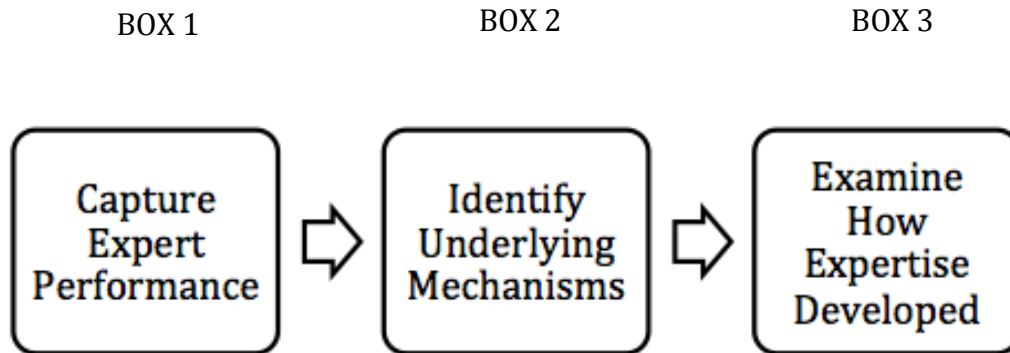


Figure 1.1 The three stages of the expert performance approach.

Ericsson and Smith's (1991) expert performance approach has been widely used by researchers to facilitate theoretical development and investigate the perceptual-cognitive contributions to expert performance (Williams & Ericsson, 2005). Notably, Starkes, Edwards, Dissanayake, and Dunn (1995) first adopted this approach whilst studying the perceptual skills of volleyball players *in situ*. The researchers recorded process tracking measures of the player's advance cue utilisation using liquid crystal glasses to temporally occlude vision. This methodology was later adopted by Abernethy, Gill, Parks and Packer (2001) in squash, and again by Muller and Abernethy (2006) in cricket. Further *in-situ* studies have used time-motion analysis to examine expert behaviours. Triolet, Benguigui, Le Runigo, and Williams (2013) studied the role of anticipation skill in tennis by quantifying the nature and frequency of behaviours in

response to ground strokes, and James and Bradley (2004) analysed the temporal sequence of responses in elite squash players. Other notable representative tasks have used field based settings, such as simulated match play or practice scenarios (Dicks, Button, & Davids, 2010), to offer increased the external validity by allowing participants to track real ball flight characteristics (Ericsson & Ward, 2007).

Nevertheless, the majority of decision-making research has been argued to adopt a closed systems approach (Starkes, Helsen, & Jack 2001), favouring paradigms that offer administrative convenience (Mann, Abernethy, & Farrow, 2010), experimental rigour and control (Davids, 2008), whilst allowing researchers to infer causality (Araujo, Davids, & Hristovski, 2006). In attempting to capture the differences in expert versus novice performance, researchers have predominately used spatial and temporal occlusion protocols in laboratory-based representative tasks (Mann *et al.*, 2007). These methodologies aim to represent specific constraints of the performance environment (Ericsson & Smith, 1991), whilst allowing researchers to manipulate the content and duration of the information presented (Ericsson, 2003). Spatial occlusion involves the removal and or neutralisation of body parts in order to infer their respective contribution to anticipatory performance, whilst temporal occlusion is used to obstruct vision progressively at different time points around key events (e.g. ball release or ball contact). When used in conjunction, these protocols are able to infer the location and timing of information-rich areas that are used for anticipatory judgements.

Researchers using temporal occlusion protocols have consistently demonstrated expert performance advantages when using pre-event information to anticipate an opponent's intention (e.g. Farrow, Abernethy, & Jackson, 2005; Jackson & Morgan 2007;

Muller & Abernethy 2006; Muller, Abernethy, & Farrow; 2006; Williams, Ward, Knowles, & Smeeton, 2002). These findings confirm that experts rely on superior sport-specific cognitive knowledge structures in order to anticipate future performance outcomes compared to novices (Williams & Ward, 2007). Whilst insightful, these studies are not able to specify the information sources used by experts to anticipate effectively (Causer & Williams, 2013). Spatial occlusion is therefore used to reveal the information sources that contribute to anticipatory performance. When occluded, a specific body region may result in decrements in performance, inferring that it contains specifying information beneficial in identifying pre-event information used to anticipate an opponent's intention. No change in performance infers that the region does not contain specifying information (Williams & Davids, 1998). Researchers have used this protocol to study information-rich areas of performance in several tasks including, badminton (Abernethy & Zawit, 2007), catching (Panchuk, Davids, Sakadjianm Mac Mahon, & Parrington, 2013), cricket batting (Muller, Abernehty, & Farrow, 2006), and tennis (Smeeton, Huys, & Jacobs, 2013).

1.3 METHODOLOGICAL LIMITATIONS OF PREVIOUS PERCEPTUAL – COGNITIVE RESEARCH

As evidenced in the previous chapter, the expert performance approach has provided researchers with a step-by-step framework for the study of perceptual-cognitive skills in sports. Whilst previous research has been able to identify several perceptual-cognitive skill based differences between skilled and novice performers, some have argued that current understanding of perceptual motor skills may have been compromised through experimental designs that are not representative of the performance context (Pinder, Davids, Renshaw & Araujo, 2011b). Specifically, Mann *et al.*, (2007) cite the lack of ecological conditions present, stating that the use of two dimensional video simulations and dichotomous decoupled responses are not reflective of the tasks to which they are intended to generalise Williams and Ericsson (2008) argue that researchers have not embraced the expert performance approach fully, questioning if video representations accurately reflect task demands. Alternatively, they proposed if should testing be carried out in the field? Furthermore, when video is employed, is the size of display important? Finally, should the normal links between perception and action be maintained, or can representative tasks measure perceptual cognitive skill with decoupled responses?

These concerns have led to a shift in research direction, from conventional perceptual-cognitive skill based difference studies (e.g. Muller *et al.*, 2006), towards studies that investigate the effect of manipulating task constraints has on subsequent performance (e.g. Dicks *et al.*, 2010). Pinder *et al.*, (2011a), addressed a concern of Williams and Ericsson (2008), by investigating whether changing ecological task

constraints under life-sized video versus *in situ* affected subsequent movement coordination. The researchers found that when responding to a life-sized video projection, using a coupled movement response, skilled batters were able to use information from a bowlers action under two-dimensional video simulation conditions, enabling initial fidelity of movement responses consistent with *in situ*. However, without the interceptive task requirements or actual ball flight information present, there is no way of directly comparing the execution of the skills in question, only their decision-making intentionality (Araujo *et al.*, 2006). In response to concerns over display sizes, Williams, North, and Hope (2012) suggest that the size of visual display may be more important for research on certain perceptual – cognitive skills, such as cue utilisation when anticipating, compared to other skills, such as pattern recognition, which relies on relative motion, not fine detail. Mann *et al.*, (2010), were able to stress the importance of the relationship between perception-action coupling *in situ*. The researchers compared skilled and novice anticipatory skills under four response conditions of increasing perception – action coupling (verbal, lower-body movement only, full-body movement, & full-body movement including bat). Results showed that skilled anticipation improved as a function of coupling, with a response requiring even the lowest degree of body movement found to enhance anticipation compared to a verbal response. Importantly, the researchers found a full body movement using a bat elicited greater anticipation than an equivalent movement with no bat, highlighting the importance of providing opportunity to make interceptive movements in response to visual stimuli. However, these have not yet been investigated in the laboratory setting. Whilst there have been some answers to those

questions proposed by Williams and Ericsson (2008), doubts still remain over the transfer of findings from laboratory based settings to *in situ*.

van der Kamp *et al.*, (2008) state that the failure to preserve the functional couplings between perception and action has limited current understanding, citing the failure of the occlusion paradigm to uncover the full extent to which pre event kinematic information from opponents actually facilitates the online control of movement execution, and thus successful anticipation (see van Doorn, van der Kamp, de Wit, and Savelsbergh, 2009).

van der Kamp *et al.*, (2008) argue that the study of perception and action is not a unitary (indirect) perceptual processing of information as proposed by Milner and Goodale (1995), rather, visual anticipation involves the coupling of two separate, but interacting visual systems (direct perception). van der Kamp *et al.*, (2008) endorses the use of the two-visual system model for the study of perceptual-cognitive skill in sport. This model necessitates that two dissociated visual streams pick up visual information for different purposes; the dorsal stream picks up visual information for the online control of movements, referred to as ‘vision for action’, whilst the ventral stream detects and gathers knowledge from the environment, referred to as ‘vision for perception’ (for more information regarding the differences between the two systems, see Michaels, 2000, and van der Kamp, Oudejans, & Savelsbergh, 2003). . Essentially, van der Kamp *et al.*, (2008) argue that it is the synchronisation of these systems that is responsible for successful interceptive actions, as seen below in Figure 1.2, which shows that visual perception of affordances for action primarily relies upon the ventral system, whilst the visual guidance of the action is supported by the dorsal system.

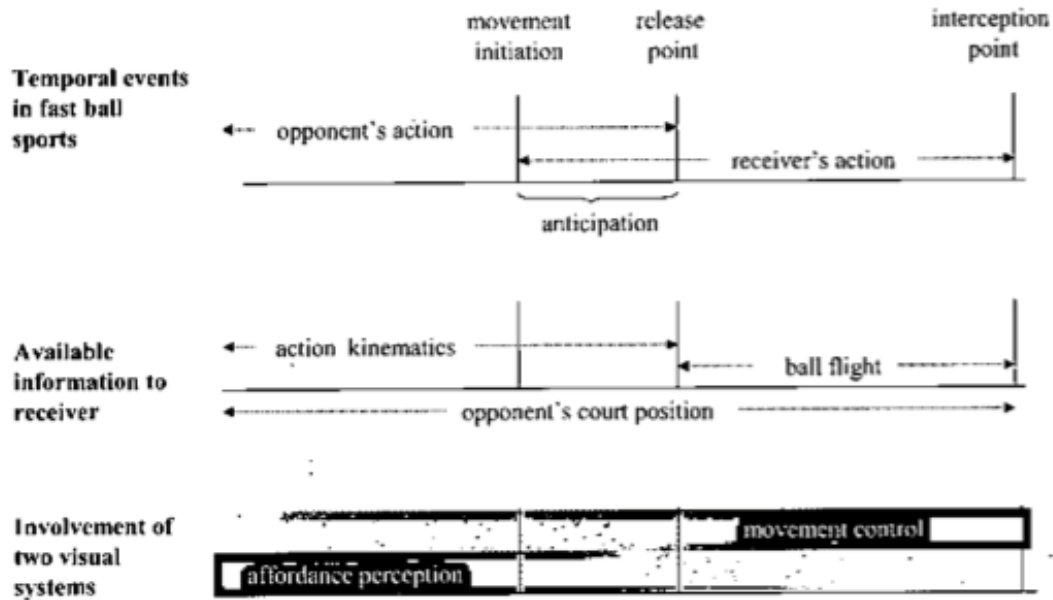


Figure 1.2 As illustrated by Van Der Kamp *et al.*, (2008), this figure shows a simplified model of the observable temporal events in fast ball sport (top), the available information sources (middle), and the proposed contributions of the two visual systems (bottom).

van der Kamp *et al.*, (2008) proposed that much of previous laboratory and field research on visual anticipation has only engaged the ventral system, whilst neglecting the integration and contribution of the dorsal system. Specifically, researchers who have used perceptual reports (e.g. error reports between estimated and actual landing positions), or dichotomous key press responses to infer interceptive skill, have not permitted the use of fast, online and implicit movement control that is produced by the dorsal system, rather altering the task, and subsequently the type processing system used to a ventrally based response (Rossetti, 1998). Additionally, when using temporally occluded methodologies, participants are asked to respond immediately after the clip terminates. However, this is always subject to a temporally delayed response, making the synchrony between the

participant's response and the events in the clip artificial, thus interfering with the interaction between the two visual systems believed to occur during movement initiation and the release point (van der Kamp, 2003). van de Kamp *et al.*, (2008) state that while it is true that similar conclusions regarding skill-based differences can have been drawn from laboratory and field based studies, there is no guarantee that these conclusions are veridical of anticipation & decision making skill *in –situ*, therefore researchers must consider the integration of the two visual systems by examining them working together.

1.4 ECOLOGICAL APPROACHES TO STUDYING PERCEPTUAL – COGNITIVE EXPERTISE IN SPORT

In light of the aforementioned concerns, researchers are adopting theoretical and methodological approaches from ecological psychology, which support the investigation of functional behaviours at the level of organism-environment relations (Brunswik 1956), in order to advance the study perceptual-cognitive skill in sport, (Araujo *et al.*, 2006). Ecological approaches attempt to maintain ‘correspondence’ between experimental task constraints and those in which they are intended to generalise. Brunswik (1956) originally proposed the concept of representative task design, which supports the sampling of perceptual variables from an organism’s environment, whilst Gibson (1979) proposed that experimental tasks should be set up in such a way that the actor can perceive in order to act, but also can act in order to perceive in his theory of direct perception. There is strong indication that the integration of these perspectives from ecological psychology and dynamical systems theory will provoke insights into the dynamic and complex nature of cognition, perception and action in neurobiological systems present within sport (Davids, Williams, Button, & Court, 2001). This thesis looks to adopt approaches from ecological psychology to overcome the aforementioned limitations of previous perceptual cognitive research in sport. However, it is important to clarify first, Brunswik’s (1952, & 1956) concept of ecological validity & methodological programme of representative design, as these have often been mistaken and used interchangeably in psychology research (Araujo, Davids, & Passos, 2007, & Pinder *et al.*, 2011b).

In keeping with his belief that the real world is an important consideration in experimental research, Brunswik (1952) proposed his theory of probabilistic functionalism, which suggested that the psychological processes are adapted to the environments in which they function. In this, Brunswik aimed to use his lens model to investigate the probabilistic laws that describe an organism's adaption by measuring the 'ecological validity' of a cue by examining the correlation between its proximal cues and the distal variable. Essentially, by studying the relations between cues, Brunswik wanted to identify the reliability of perceptual cues in order to predict future outcomes (Kirlik, 2009). The real concept of ecological validity has been popularly mistaken outside of Brunswikian researchers after Ulric Neisser's (1976) interpretation and use in his studies into memory. For example Bronfenbrenner (1977), stated "ecological validity refers to the extent to which the environment experienced by the subjects in a scientific investigation has the properties it is supposed or assumed to have by the investigator."

In attempt to advance the generalizability of research findings, Brunswik (1955) originally proposed the methodological program of representative design as an alternative methodological approach to systematic design. Brunswik (1955) argued that experiments which used systematic designs altered the to be studied processes in such a way that the obtained results are no longer representative (Dhimi, Hertwig, & Hoffrage, 2004). Further, Brunswik (1956) cautioned that the "Generalisability of results concerning the variables involved must remain limited, unless the range, but better also the distribution of each variable has been made representative of a carefully defined set of conditions" (1956, p. 53). In order to attain representativeness, Brunswik (1956) proposes that

experimental stimuli must be “sampled” from the environment in which they intend to generalise, in the same way in which subjects are used to represent the population.

In support of Brunswik’s (1956) proposal, Hammond (1966) suggested that researchers should identify the formal properties of the task to be represented via task analysis, and then recreate these in the laboratory. This process was similar to a hybrid design which was earlier proposed by Brunswik (1944), ensuring that the same population of stimuli are present in the laboratory condition, therefore the laboratory condition will be representative of the conditions towards which generalisation is intended (Hammond, 1998). Generally, researchers have generally failed to preserve the functional couplings between perception and action, which occur in the natural environment, adopting methodologies that are not representative of the performance environment (Van Der Kamp *et al.*, 2008). However, Pinder *et al.*, (2011b) have recently demonstrated how Brunswik’s (1956) concept of representative design can be adapted to provide a framework for assessing the functionality and action fidelity of experimental and learning designs in sports, branded representative learning design.

Pinder *et al.*, (2011b) emphasised the importance of designing dynamic interventions, which consider interacting constraints on subsequent movement behaviours. In order to do so, tasks must firstly maintain functionality, by ensuring that the degree of success of a performer’s action are controlled for and compared between contexts, whilst also being able to achieve specific goals by basing actions on comparable information to that existing in the performance environment. Second, tasks must maintain action fidelity, by allowing a performer to produce a response that is the same as that which is observed in the performance environment. In reference to perceptual – cognitive

skill, Araujo, *et al.* (2006) state that decision-making is a complex, temporally extended process, which is not best understood if an individual is characterized as making decisions prior to their behavioural expression. Because of the close link between decision-making and their behavioural expression, they argue that analysis of adaptive behaviours is a way of identifying the fidelity of decision-making in these environments. This notion holds relevance to Gibson's (1979) concept of affordances, which describe the opportunities for action provided by the environment for an animal, and reflects the tight coupling between perception and action, which allow for the prospective and moment-to-moment control of fast paced actions (Fajen, Riley, & Turvey, 2008). Hence, if designed correctly, representative tasks will 'afford' performers the same opportunities for action as those observed *in situ*.

In order to assess the functionality and action fidelity of learning designs, Stoffregen, Bardy, Smart, and Paulayan (2003) suggest that researchers should measure and compare common metrics of task performance between environments. Stoffregen, *et al.*, (2003) state that action fidelity is defined in terms of relations between performance in the simulator and performance in the simulated system, and exists when performance in the simulator transfers to performance in the simulated system. The degree of action fidelity can be measured by analysing task performance in detail, with the aim of identifying whether a performer's responses remain the same in two or more contexts (Pinder *et al.*, 2011a). The recognition of these approaches has been aided by advances in technology, which have made the measurement of variables *in situ* more rigorous, allowing ecological validity to be recognised as part of a continuum, rather than a dichotomy (Davids, Renshaw, & Glazier, 2005). Namely, dynamical systems theory has

been endorsed by researchers to analyse the connections between perceptual variables and subsequent behaviours, offering a framework for identifying patterns of how coordinated movements emerge, persist, and change in relation to their environment (Araujo & Davids, 2009). Dynamical systems theory uses mathematics, physics, biology, psychology and chemistry to analyse how coordination emerges in biological movement systems (Davids, Glazier, Araujo, and Bartlett, 2003), providing the perfect framework for researchers to establish the fidelity of movement behaviours between task constraints.

Araujo *et al.*, (2006) refer to the integration of ecological psychology and dynamical systems as ecological dynamics, an approach where the relationship between individuals and their environments is defined. In their paper, Araujo *et al.*, (2006) showed that it is possible to describe the complex performer-environment interactions as a dynamical system. Araujo *et al.*, (2006) used three separate investigations to demonstrate the dynamic relationships between the performer and their environment. Araujo *et al.*, (2006) measured an attacker-defender dyad during a basketball-dribbling task, revealing that the attacker was trying to dribble past the defender, whilst the defender was attempting to maintain the initial steady state of the environment. In attempt to break steady state and force the emergence of a system transition, the attacker persisted with their dribbling actions until the symmetry of the situation was broken, and a decision emerged. Araujo, Davids, Rocha, Serpa, and Fernandes (2003) studied the dynamics of decision-making in sailing by manipulating the angle between the wind direction and the starting line in 23 consecutive sailing regattas. The researchers analysed each boat's "where to start" position, finding dominant starting positions at the extremities of the starting line with higher angle values. They also found that under neutral wind positions

there was higher variability in choice of starting positions. The authors stated that the competition between deterministic and stochastic forces shapes the actual decision making landscape of the competitors, with stochastic events dominantly influencing the decision of where to start. Finally, Hristovski, Davids, Araujo, and Button (2006) studied how distance-to-target information constrained the actions of boxers in a typical training task. The boxer – target distance was estimated as a ratio between target distance and the boxers arm length. The authors found that participants selected specific punches at distances that fitted the effective length of their arms, exploiting body-scaled distance information to decide on the most appropriate action.

In their position paper, Araujo *et al.*, (2006) clarify how decision-making processes could be understood as an integral part of goal-directed behaviour that is influenced by bodily constraints at the scale of the environment-athlete relationship. In their ecological model of decision-making, Araujo *et al.*, (2006) propose that: i) decision-making is strongly influence by the detection and the use of contextual information; ii) the acquisition of decision making skill is characterised by the narrowing of the variability of actions to achieve a goal and by the progressive attunement to relevant sources of information; iii) it is possible to explain the effect of relevant constraints on decision making as well as the extent of these effects; iv) it is possible to measure stable patterns of interaction between performers and the environment, and; v) the maintenance and the transition between stable patterns of behaviour is the result of the interaction of multiple constraints. With this in consideration, from an ecological perspective, the experimental designs for studies of decision-making should: i) maintain the noisy decision tasks towards which one intends to generalise; and ii) have information in the

task diagnostic enough to let the performer act on it in a way that supports goal achievement according to their expertise level.

In summary, it has been shown how recent influences from ecological psychology and dynamical systems theory have helped shape the direction of studies into perceptual – cognitive skill in sports. This change in approach has led to researchers increasingly using *in situ*, field – based, and simulated methodologies. These methodologies are still very much in their infancy, with future research needed to clarify their effectiveness, and in the case of simulated designs, their transfer to real world settings, whilst guidelines need to be established in order to standardise their implementation. The next section will analyse the evolution of methodological approaches used in cricket batting, which has been used as a popular paradigm for the study of perceptual – cognitive skills in sport, and forms the basis of this investigation into representative task design.

1.5 CRICKET BATTING: A POPULAR PARADIGM FOR THE STUDY OF PERCEPTION AND ACTION

Cricket batting is a highly constrained task, requiring skilled batsmen to produce complex, full-body movements in response to a bowler's delivery of the ball, with the ultimate aim of producing the most forceful stroke possible to score runs (Sarpeshkar & Mann, 2011). Land and McLeod (2000) identified that fast paced bowlers can deliver a cricket ball at speeds of up to 40 ms^{-1} (89.4 mph), taking around 600ms to reach the batsman from ball release. In response, batsmen need to be able to programme (200ms) and execute (700ms) an adequate response to within $\pm 3 \text{ cm}$ of spatial accuracy (Regan, 1992; McLeod & Jenkins, 1991) and $\pm 3 \text{ ms}$ of temporal accuracy (McLeod 1987, and McLeod & Jenkins, 1991), with any misjudgement conceivably resulting in dismissal. In order to respond effectively to these constraints, cricket batsmen will typically adopt one of two movement patterns; front foot movements, with the intention of hitting the ball immediately after it bounces (typically closer to the batsman), or, back foot movements, with the intention of hitting the ball well after it has bounced (typically further away from the batsman) (Sarpeshkar & Mann, 2011). The significant time deficits inflicted upon batsmen, coupled with the need for precision, make cricket batting an ideal paradigm for researchers to investigate perceptual – cognitive expertise (Sarpeshkar & Mann, 2011).

Since the turn of the century, there has been a noticeable growth of research into cricket batting skill, specifically the perceptual – cognitive constructs which underpin its development and characterise expertise. Pioneering studies by Abernethy & Russell (1984) and Penrose & Roach (1995) found expert batsmen were able to predict delivery

lengths better, respond earlier, and select more appropriate shots than were novices. However, Renshaw and Fairweather (2000) argued that these studies lacked experimental evidence. In a novel bid to provide applied research evidence for the use of perceptual cue utilisation, Renshaw & Fairweather (2000) assessed the discriminatory ability of professional and amateur batters against a variety of spin bowling deliveries. The researchers filmed and then backward projected life sized video footage onto a screen. The temporal occlusion paradigm was used to manipulate the information presented and paired with verbal reporting of delivery type. The researchers found that expert batsmen showed greater discrimination abilities compared to novices when faced with different spin bowling deliveries. They also found that the addition of ball flight information provided no more advantage to discrimination abilities. This study, although novel at the time, exemplifies how Ericsson and Smith's (1991) expert performance approach was adopted, but not fully embraced (Williams & Ericsson, 2008).

In an attempt to advance understanding of which visual cues contribute to anticipation skill, Muller *et al.*, (2006), investigated the ability of high-skilled and low-skilled cricket batsmen to anticipate a bowler's intention under spatial and temporal occlusion conditions. Muller *et al.*, (2006) identified significant differences between high- and low-skilled batsmen when predicting spin direction due to spatial occlusion of the bowling hand. Whilst Huys, Smeeton, Hodges, Beek and Williams (2008), have argued that information can be extracted from multiple body regions, not just the end effector, in order to anticipate the intended direction of an action; in both spin and pace conditions, Muller *et al.*, (2006) found no significant differences between skill levels when occluding the bowling arm, non-bowling arm, torso, lower body, and projected

release point at ball release. Whilst these findings advanced the current understanding of the information sources which contribute to anticipation skill, the non-action specific responses (written) used by Muller *et al.*, (2006), as well as the specified response timing, which is not representative of the task constraints of cricket batting, could have limited true expert performance advantage.

Subsequently, Muller and Abernethy (2006) employed a temporal occlusion paradigm to examine the information pick up and interceptive skills of high-skilled and low-skilled cricket batsmen. Notably, as a result of technological advancements, the researchers used liquid crystal occluding glasses *in situ* to retain the usual coupling between the visual-perception and action components of cricket batting, enhancing external and ecological validity (Muller & Abernethy, 2006). The researchers occluded the liquid crystal glasses to produce three conditions, i) prior to ball release, ii) prior to ball bounce, and iii) un-occluded, measuring the batsman's subsequent foot movement direction (forwards vs. backwards) accuracies as well as bat-ball interception qualities. Analyses revealed a superior capability of the more skilled players to make use of earlier ball flight information to guide successful bat-ball contact. Whilst the use of liquid crystal glasses was subsequently criticised by the authors due to its lack of precision and high variability of occlusion, this study is the first of its kind to acknowledge the importance of carrying out experiments in a natural setting, and called for the convergence of both laboratory based and *in situ* examinations in order to maintain control (laboratory), but also representativeness (*in situ*).

In response, researchers in the field have gone on to research the perceptual – cognitive constructs, which underpin development and characterise expertise.

Weissensteiner, Abernethy, Farrow, and Muller (2008) carried out a cross examination of the practice experiences which contribute to anticipation skill in cricket batting. Skilled and lesser skilled batsmen of U15, U20, and adult ages had their practice and developmental histories analysed, and took part in a temporal occlusion paradigm, which required written responses to three fast bowling delivery types. The researchers found skilled adult and U20 players to possess greater anticipation skill compared to any other group, and skilled players of all ages were found to have accumulated more hours of cricket-specific practice. However, hours of cricket specific practice only explained a modest percentage of the variance in anticipatory skill. McRobert, Williams, Ward, and Eccles (2009) examined how advance cue information influences anticipation using a simulated cricket batting task. The experimenters used an eye movement registration system to record participants visual search patterns, alongside verbal reporting and written responses to both fast and spin bowling conditions. McRobert *et al.*, (2009) found skilled batters to be more accurate at anticipating ball position than less skilled batters, showing that skilled batters search and encode scenes at a richer and more sophisticated level than less skilled players, concluding that visual behaviour is constrained by the task parameters and participant skill level. Using the same methodology, McRobert, Ward, Eccles, and Williams (2011) investigated the effect of manipulating context specific information, finding skilled batsmen to be more accurate, demonstrate more effective search behaviours, and provided more detailed verbal reports of thinking under high context conditions. These findings, whilst novel have all employed laboratory-based methodologies, which have been described (see chapter 1.2) as being un-representative. However, they have been able to integrate technology in a bid to bridge the gap between

in situ investigations that offer high ecological validity, and laboratory based studies that provide control.

Most recently, researchers have turned their attentions away from the laboratory and are using methods that integrate ecological psychology and dynamical systems theory. Mann *et al.*, (2010) used a field based temporal occlusion paradigm to study the relationship between perception – action coupling and anticipation skill. In a bid to overcome the previous methodological limitations of using liquid crystal occlusion glasses, Mann *et al.*, (2010) used a validated protocol to regulate the onset of occlusion by using a force platform as a trigger. The researchers studied the anticipation skill of skilled and novice participants under four response conditions, each with different levels of action specificity; verbal, foot movement, shadow batting (without a bat), and batting (with a bat). Mann *et al.*, (2010) found skilled, but not novice anticipation to improve as a function of coupling, with a response requiring even the lowest degree of body movement (foot movement) found to enhance anticipation ability compared to verbal predictions. Significantly, a full-body movement using a bat elicited greater anticipation than an equivalent with no bat. These findings, although in the field, verify the importance of using experimental conditions and task demands that closely reflect the natural performance environment in order to reveal the true nature of the expert advantage.

Mann *et al.*, (2010) provided insight on the effect of changing levels of action representativeness on anticipation skill. Renshaw, Oldham, Davids, and Golds, (2007) sought to understand how changes in the ecological constraints of practice alters movement behaviours. Renshaw *et al.*, (2007) studied the timing and co-ordination of the forward defensive stroke in cricket under representative ‘real’ bowler and representative

bowling machine conditions. The researchers observed significant adaptation of coordination and timing between conditions. For example, initiation of the batsman's backswing was later and downswing was faster with a different ratio of backswing – downswing against a bowler (54%: 45%) compared to the bowling machine (47%: 53%), as well as shorter mean front foot strides under bowling machine conditions. Pinder, Renshaw, and Davids, (2009) carried out a similar study with developing cricketers, also finding earlier initiation of the back swing, as well as earlier front foot movement, down swing, and front foot movement placement when facing a bowler compared to a bowling machine. In a bid to understand the representativeness of video based tasks, Pinder *et al.*, (2011a) investigated further by studying the movement organization of cricket batsmen under 'live', bowling machine, and life-size video conditions. Results showed that each distinct set of task constraints led to significant variations in the patterns of movement control; under bowling machine conditions, removal of advance information from a bowler's action caused significantly delayed responses, reduced peak bat swing velocities and reduced ball contact qualities. Under video conditions, batsmen were able to use pre-delivery information, enabling fidelity of initial behavioral responses consistent with the live condition. These findings provide support for Pinder *et al.*'s (2011b) representative learning design framework, and Stoffregen *et al.*'s (2003) concept of action fidelity, in order to provide researchers and practitioners with a measure of how the studied task reflects the context to which it is intended to generalize.

These studies have been able to elicit differences in skilled behaviours under changing ecological task constraints, however, further research is needed in order to understand the perceptual-cognitive mechanisms responsible for the alterations in

movement control, specifically, how changes in task constraints affect decision making skill. These can only be understood when task specific movement responses are interpreted as a measure of decision-making intentionality (Araujo *et al.*, 2006). Most recently, Pinder, Davids, and Renshaw (2012) used dynamical systems theory to identify if stable and or distinct movement patterns emerged across performance regions (ball bounce locations). Pinder *et al.*, (2012) measured the shot type (direction), foot movement response, quality of bat-ball contact, and forcefulness of bat-swing of six moderately skilled junior cricket batsmen in response to medium pace ($28 \pm 0.96 \text{ms}^{-1}$) bowling. Each bowler was instructed to aim at four pre-described performance regions; region one, 2.5-3.5 m from the stumps, region 2, 5-6 m from the stumps, region 4, 8-9 m from the stumps, and region 3, predicated on experiential knowledge as forcing greater uncertainty of response, 6.5 – 6.7m from the stumps. Pinder *et al.*, (2012) demonstrated that, at a pre-determined distance to the ball, participants were forced into a meta-stable region of performance, where rich and varied patterns of functional movement behaviours emerged. Although the researchers observed higher levels of variability in movement timings, interestingly, these had no effect on the subsequent interceptive performance outcomes. The researchers also observed stable, but different patterns of movement responses in regions 1 & 2 (dominant front foot movement) versus region 4 (dominant back foot movement). These findings show that cricket batting is characterised by the ability to adapt to changes in task constraints.

This chapter has summarised how studies into cricket batting skill have evolved over the years as a result of overcoming previous methodological limitations and increasing influences from ecological psychology. Whilst the vast and varied research

into perceptual-cognitive skill in cricket batting has contributed a great deal towards current understanding, future studies are needed to address fully the aforementioned concerns of theorists (Van der Kamp *et al.*, 2008), as well as to evaluate the effectiveness of Pinder et al's (2011b) new and adapted representative learning design framework.

1.6 RESEARCH DIRECTIONS AND THESIS AIMS

This thesis aims to provide a link between the two prominent methodological approaches, which have emerged as a result of previous limitations (Van Der Kamp *et al.*, 2008) and influences from ecological psychology (Pinder *et al.*, 2011b). Muller and Abernethy (2006) previously called for the convergence of laboratory based and *in situ* examinations in order to maintain control, but also representativeness when studying perceptual cognitive skills. This standpoint still holds significance in the current literature, whereby researchers are treading a fine line between producing research that holds a high degree of experimental control, using representative methods, allowing for greater generalizability to the performance environment in question. Although Pinder *et al.*, (2011b) have provided guidance through the introduction of their representative practice design framework, the question “What is representative enough”? is pertinent to the effectiveness of representative tasks, and forms the basis of this thesis.

In attempt to answer this question, an understanding of what characterises skilled performance (decision making) *in situ* need to be established. Whilst previous studies have been able to provide insight, none have been able to model the emergence of adaptive behaviours under a sufficient range of task constraints. Whilst some may suggest that this has been reported by Pinder *et al.*, (2012), their use of anecdotally prescribed delivery lengths at specific regions underestimates the sensitive nature of how behaviours emerge, and fails to provide a complete picture of how stable behaviours emerge and dissolve across a fuller range of a task constraint. Thus, in order to make data driven assessments of what is representative enough, this thesis’s initial aim is to identify

the evolution of adaptive behaviours that emerge naturally across a range of delivery lengths *in situ*. Through measuring the behavioural expressions of batsmen *in situ* in order to infer decision-making intentionality as recommended by Araujo *et al.*, (2006), the data will be able to detail what patterns of movement behaviour are naturally occurring, providing a benchmark of what is considered ‘representative’ or not.

Establishing a benchmark for skilled performance *in situ* will inform the aim of Chapter; to assess the level of representative task design of a laboratory based task. This direction of study has been embraced by previous researchers in a different context, with the aim of identifying how manipulations in task constraints affect subsequent movement co-ordination (Renshaw *et al.*, 2007; Pinder *et al.*, 2009; Pinder *et al.*, 2011a). Whilst these studies have been able to show that each distinct set of task constraints leads to significant variations in the patterns of movement control, they have not been able to quantify the relationship of decision-making behaviours between contexts. Chapter 2’s aim is to advance these previous findings by providing data driven assessments as to the degree to which experimental tasks are able to represent *in situ* task demands, providing referent of the generalizability and transfer to the natural performance environment. Chapter 2 will use Pinder *et al.*’s (2011b) framework of representative practice design, and Stoffregen *et al.*’s (2003) concept of action fidelity to assess the level of functionality and fidelity of emergent behaviours under laboratory based conditions. The reliability and construct validity of laboratory based representative tasks will also be investigated. The findings of which will have implications for future research design, and subsequent measurement of external and internal validities.

In Chapter 3 of this thesis, the same methodological approach will be used to review the effect of skill level, action specificity, and temporal occlusion on laboratory-based performance. The aim is to describe how manipulating the level of task representation affects subsequent adaptive behaviour, with the intention of prescribing the most appropriate methodological approach to studying representative skilled, and/or, novice performance under controlled laboratory-based conditions. Findings will be discussed in relation to previous laboratory-based studies, which have employed basic representative task designs, incorporating dichotomous un-representative response modes and the occlusion paradigm to research perceptuo – motor skills between skill levels.

Finally, in Chapter 4 the question “Can simulation-based training aids ‘represent’ *in situ* task demands?” is asked. In a bid to investigate the dual visual systems framework proposed by Van Der Kamp *et al.*, (2008), as well as advance previous knowledge on changing conditions (Pinder *et al.*, 2011a), the effects of uncoupling perception and action on adaptive behaviours are examined, as well as the action fidelity of batsman’s adaptive behaviours across three different training conditions; live (real action & real ball flight), simulated (simulated action & real ball flight), and bowling machine (no action & real ball flight). These investigations intend to provide insight into the interdependent functioning of the dorsal and ventral streams, and their subsequent contributions to perception and action. The results of which may also be of interest to those in the applied field of skill development, providing knowledge into the effect simulated training aids have on performance, and subsequent skill learning.

In summary, this thesis aims to advance current methodological approaches by providing data driven assessments of the level of task representativeness under changing

field based and laboratory-based conditions. Ultimately, the aim is for researchers and practitioners to develop standardized measures and methodologies, which incorporate external validity whilst maintaining a level of experimental control.

CHAPTER 2:

ASSESSING REPRESENTATIVE TASK DESIGN IN CRICKET

BATTING: COMPARING AN *IN SITU* AND LABORATORY – BASED TASK

2.1 ABSTRACT

It has been argued that representative tasks are needed to understand the processes by which experts overcome their less skilled counterparts. Little is known, however, about the essential characteristics of these tasks. This study identified the degree to which a laboratory-based task of decision making in cricket batting represented *in-situ* performance. The *in-situ* task required skilled batters to play against a bowler across a range of delivery lengths. Skilled batsmen produced a transitional pattern of foot movements with front foot responses being dominant for balls landing 0 – 6m from the wicket and back foot responses for balls landing 8 – 14m from the wicket. In the laboratory-based task, the same batsmen viewed video footage of the same bowlers. Again, skilled batsmen responded with similar patterns of foot movement transitions. Novice batsmen produced a generic forward movement in response to all deliveries. In conclusion, for decision-making about delivery length, the laboratory-based task has a high degree of fidelity and reliability. The implications of these results are discussed in relation to the importance of establishing the necessary degree of fidelity of representative task designs in order to study perception and action more accurately.

2.2 INTRODUCTION:

There has been much debate about methodological approaches used to study perception and action in sport (Araujo & Davids, 2009). When used in a laboratory setting, the occlusion paradigm can offer experimental rigor and a high degree of control (Davids, 2008), as well as administrative convenience (Mann *et al.*, 2010). However, there has been a shift in research design towards a more ecological approach, which offers potentially greater predictive value when generalizing results to the intended environment.

Ericsson and Smith (1991) proposed the first descriptive and inductive framework for the study of expertise in sport, the 'expert performance approach'. This approach shares common underpinnings with the work of Starkes *et al.*, (1995) who were the first to study perceptual skills of volleyball players in a game setting. This study was made possible through technological advancement, allowing the researchers to occlude temporally using liquid crystal occlusion glasses. This increased external validity by providing participants the opportunity to track real ball flight characteristics as opposed to two-dimensional representations.

A decade later, some argued that concerns regarding assessment of decision-making under game-like conditions had still not been fully addressed (e.g., Mann, *et al.*, 2007; Williams & Ericsson, 2005). van der Kamp *et al.*, (2008) stated that the failure to preserve the functional coupling between perception and action in the design of experimental tasks has limited the expert performance approach (see also Araujo *et al.*, 2006) and that current understanding of perceptual motor skill might have been compromised through experimental designs that are not representative of performance

contexts (Pinder *et al.*, 2011b). These discussions, concerning valid task designs for the study of expert performance, have led to the question, what type of ‘laboratory’ task is representative enough?

Brunswik (1956) first defined representative design as the study of psychological processes at the level of organism-environment relations. Understanding the interaction between key organism, task, and environmental constraints for the emergence of adaptive behaviour provides a powerful theoretical framework for designing representative tasks; regardless of whether they are performed in the laboratory or the field setting. There have been some recent empirical attempts to bring about such task representation across a range of sports including; soccer (Dicks *et al.*, 2010), rugby (Correia, Araujo, Cummins, & Craig, 2010), baseball (Ranganathan & Carlton, 2007) and tennis (Williams, Ward, Smeeton, & Allen, 2004).

Brunswik’s original concepts concerning task representativeness have more recently been re-interpreted in the context of sport science (Pinder *et al.*, 2011b). They proposed the notion of representative learning design as an important methodological feature for the study of how processes of perception, cognition, decision-making, and action underpin intentional movement behaviours in dynamic sporting environments. In order to achieve representative learning design, Pinder, *et al.* (2011b) suggest that practitioners should, a) design dynamic interventions that consider interacting constraints on movement behaviours, b) use tasks that allow for adequate sampling of informational variables from the specific performance environments to allowing detection of affordances for action, and c) ensure coupling between perception and action is maintained to support functionality and fidelity of performance.

In order to evaluate the level of functionality of performance, Stoffregen *et al.*, (2003) proposed the concept of action fidelity, which is the degree of transfer of performance from the simulator to the simulated system. Pinder, *et al.* (2011b) suggested that when developing representative laboratory tasks, practitioners should examine the degree of fidelity between actions that emerge from the individual's interactions with the experimental task and the performance setting. However, the task of assessing adaptive behaviour in a performance context is difficult, especially in fast interceptive actions that require sub-second, externally-paced responses to environmental stimuli (Muller *et al.*, 2006). Araujo, *et al.* (2006) stated that decision-making is a complex, temporally extended process, which is not best understood if an individual is characterized as making decisions prior to their behavioral expression. Because of the close link between decision-making and their behavioral expression, they argued that analysis of adaptive behaviours is a way of identifying decision-making in these environments.

Previous laboratory-based studies into cricket batting have shown that skilled batsmen have a superior ability to extract advanced cues from a bowler's movements (Renshaw & Fairweather 2000, Müller *et al.*, 2006, & Weissensteiner *et al.*, 2008). They do this by using more efficient visual search strategies, compared to novices, in order to make informed decisions (McRobert *et al.*, 2009). Although these studies provide insight into how highly skilled participants respond compared with less skilled participants, they may not be representative of the constraints found *in situ*. Specifically, in these studies there may be a low degree of perception-action coupling that is a function of the controls adhered to in the laboratory setting, such as video footage, instead of a live bowler, or

verbal responses, rather than an actual bat swing (for critique see Van der Kamp, *et al.* 2008, Davids, 2008, Warren, 2006).

In answer to some of the issues raised with laboratory tasks, Mann *et al.*, (2010) studied the effect of differing levels of movement coupling by comparing four response methods (verbal, foot movement, shadow batting, and total batting) between skilled and novice cricket batsmen *in situ*. Skilled, but not novice, anticipation was found to increase with response modes that more closely represented the natural movement. Mann, *et al.* (2010) suggested that allowing an athlete to engage in the opportunity to make bat-ball contact increases the ability to differentiate between skilled and novice performers. This finding endorses Pinder *et al.*'s (2011b) framework of representative learning design, highlighting the importance of using experimental procedures that reflect the task demands of the natural performance environment, maintaining coupling to support functionality of natural movements.

Junior cricket batsmen were also studied *in situ* across pre-determined delivery lengths (Pinder *et al.*, 2012). Using the language of ecological dynamics, the authors aimed to examine a point at which the movement system changed from one dominant movement solution to a second movement solution, in order to satisfy task goals. At a pre-determined delivery length of 7.5m, batters were forced into a region of performance where rich and varied patterns of functional movement behaviours emerged. This study highlights the importance of studying a movement system across a range of performance variables, allowing adequate sampling of information variables in order to understand how (and when) adaptive behaviours emerge. Nonetheless, the use of pre-determined, anecdotally prescribed delivery lengths and unrepresentative delivery speeds raises

questions as to whether or not the participant's responses can be considered as representative in a decision making context.

This study aims to identify if a laboratory-based task is able to sustain the emergence of adaptive behaviour by simulating (representing) interactions between the organism, task, and the environment compared to *in situ*. In order to address the aforementioned methodological limitations that have been cited in the literature, the adaptive behaviours present in cricket batting that emerge across a range of delivery lengths *in situ* were identified. This was to be used as a benchmark of the representative task. It was expected that skilful emergent behaviour to be represented by a dominant front foot movement response to deliveries that pitched closer to the batsman, transitioning into an area of high foot movement variability (Pinder *et al.*, 2012), followed by a dominant back foot movement response to deliveries that pitched further away from the batsman. Second, the degree of fidelity of adaptive behaviour in the laboratory-based task was established by comparing it with those found *in situ*. If the pattern of adaptive behaviour observed in the *in-situ* task were also found in the laboratory task, then it was assumed that the necessary links between perception and action were present in the laboratory task (Mann *et al.*, 2010; Pinder *et al.*, 2011a). The level of test versus re-test reliability of skilled batsmen's adaptive behaviour under laboratory conditions was also studied. To assess the construct validity of the task, skilled batsmen were compared to novices on the laboratory-based batting task (e.g. Ericsson & Smith, 1991). If skill-based differences were found then the task was considered to be representative of skilful batting in response to varied delivery lengths.

2.3 METHODS

2.3.1 PARTICIPANTS

Thirteen skilled right-handed male cricket batters (age: 23.2 ± 3.8 years), with 11.5 ± 2.33 years playing experience, and twelve novice right-handed male participants (age: 25.3 ± 3.2 years) were recruited for the study. Skilled participants were included in the study if they had at least eight years of formal playing experience and were playing at a regional, first division level for the past two years (in the UK). Novice participants were required to have no competitive cricketing experience. Two right-arm bowlers (age: 21.6 ± 1.7 years) with 8.6 ± 1.5 years playing experience with similar conventional bowling actions and physical attributes (average height of release: 2.09 ± 0.06 m; average bowling speed: 32.63 ± 0.78 m.s⁻¹) were also recruited. Participants provided informed consent prior to testing and ethical clearance was received from the local institutional ethics and governance committee.

2.3.2 DESIGN & PROCEDURE

Batters' foot movements were analysed in three separate conditions to evaluate fidelity from *in-situ* to the laboratory. An *in-situ* movement condition was completed first to allow the experimenters to model adaptive behaviours across a range of delivery lengths (Araujo *et al.*, 2006). Second, the experimenters recorded video footage of the

same two bowlers from the *in-situ* environment to create two laboratory-based conditions.

After a familiarization protocol, the skilled participants completed the two separate, counterbalanced laboratory conditions. The first laboratory-based condition was used to evaluate fidelity between laboratory and *in-situ* emergent actions. The second condition was used to evaluate the within-day reliability of the laboratory-based task. It was decided that within-day variability analysis was appropriate for this study, because performance was assessed without the confound of further cricket training. Novice participants completed only one laboratory condition to assess if laboratory task performance was different between skill levels of performers (i.e., a construct validity test). For the skilled participants, 72 *in-situ* trials and 100 laboratory trials per participant were analyzed for fidelity of *in-situ* versus laboratory performance and 100 trials per participant were analyzed for test versus re-test reliability. For the novice participants (in comparison to the skilled), 50 trials per participant were analyzed for differences.

2.3.3 SKILLED *IN SITU* BATTING

An indoor artificial cricket net was set up according to the International Cricket Council (ICC) pitch regulations. Prior to analysis, a sport specific warm-up and a 12-ball (6 deliveries per bowler) familiarization protocol were carried out. None of the 13 batsmen had previously faced any of the two bowlers, but had faced bowlers of a similar speed and ability in training. Batsmen were instructed to play naturally whilst keeping (i.e., protecting) their wicket; they were set a standard medium – fast pace field setting

scenario in attempt to replicate on-field demands. The bowlers were instructed to bowl a variety of delivery lengths. Each analysis consisted of 12 blocks of 6 trials, alternating blocks between bowlers (72 deliveries total, 36 deliveries per bowler). Two high definition (1080p) video cameras (Canon LEGERIA HF R46, Tokyo, Japan, & Sony Handycam HDR-TD10E, Tokyo, Japan) were positioned parallel to the pitch (see Figure 2.1) to record the batsman's movement kinematics in the frontal plane. Delivery length was measured as the distance from the point of ball bounce to the base of the stumps at the batsman's end of the wicket. Calibration was attained using horizontal and vertical references of known distance.

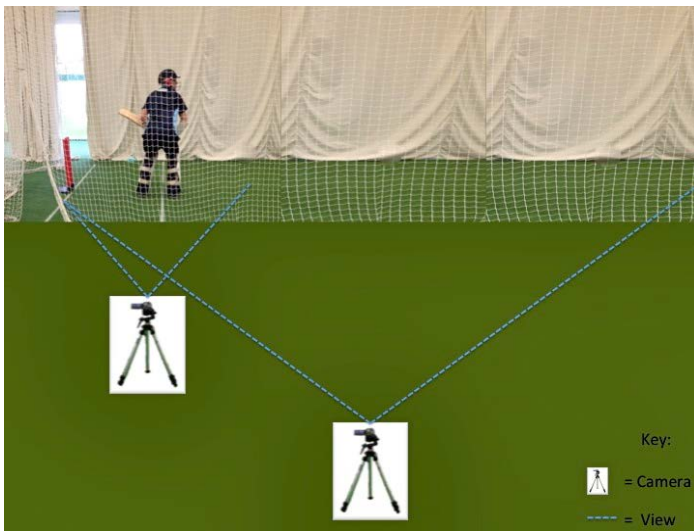


Figure 2.1 A schematic showing the positioning of cameras used to record the *in-situ* movement analysis.

2.3.4 LABORATORY BATTING

A ceiling mounted projector was used to display the experimental footage onto a projection screen (L = 1.35m, W = 1.35m, see Figure 2.2). A batting crease was set up according to ICC regulations and positioned such that a life size image of the bowler was seen. Participants were instructed to respond to the video with natural batting strokes aimed at making bat-ball contact whilst keeping their wicket. An initial familiarization protocol was used to allow participants to adapt to the laboratory settings, after which the participants viewed two 50-delivery test tapes. Participants were given the same playing instructions as given *in situ*. Participants' movement kinematics were recorded using the same procedure as *in situ*.



Figure 2.2 A participant taking part in the laboratory-based cricket-batting test.

2.3.5 VIDEO PRODUCTION AND TEST CONSTRUCTION

The same bowlers from the *in-situ* analysis were instructed to bowl from the popping crease (located 18.90m from the bowling crease at the batsman's end) towards the stumps and land the ball at five ranges of delivery lengths from the batsman's stumps, identified by the *in-situ* analysis. These consisted of a) "Very Full" (0-3m), b) "Full" (3-5m), c) "Neutral" (5-7m), d) "Short" (7-10m), and e) "Very Short" (10-14m), with 12 deliveries for each delivery length. The representative video footage of the bowlers was filmed (Sony Handycam HDR-TD10E, Tokyo, Japan) from the batter's preparatory position on the batting crease and at a height of 1.76m. This camera was positioned, zoomed, and focused to replicate a batsman's natural viewing perspective. Another high definition video camera (Canon LEGERIA HF R46, Tokyo, Japan) was positioned in the same location as the *in-situ* set up to record the ball flight characteristics of the bowlers' deliveries. Delivery length was measured from the point of ball bounce to the base of the stumps at the batter's end. The footage was then edited into 50 single deliveries (5 deliveries x 5 delivery lengths x 2 bowlers), starting from the initiation of the bowler's run up, until the point at which they had finished their delivery follow through and the ball was no longer visible on the screen. Single deliveries were used to construct the experimental test tape in randomized delivery lengths. A re-test experimental tape was constructed from the same deliveries as the test tape, but was presented in a different order, again randomized for delivery length. The test tapes contained a balanced number of deliveries, consisting of ten deliveries, five from each bowler, in each length category.

2.3.6 DATA COLLECTION

A high definition video camera was used to record participant's movements *in situ* and in the laboratory. This footage was then calibrated for distance using Silicon Coach Pro 7 software (Dunedin, New Zealand). Once calibrated, each front and back foot movement distance was measured. Each foot was fitted with a marker at the head of the talus. This anatomical marker was used to measure absolute foot movement. Each measure was taken from the last frame before the foot had lifted off from the ground, until the first frame that the foot had been fully placed onto the ground. Inter- and intra-rater reliability were assessed on the same 100 trials. Strong correlations were found for both intra- ($r = .92$) and inter-rater ($r = .89$) reliability.

2.3.7 MEASURES

2.3.7.1 Foot movement response proportion. Foot movement response proportions were calculated for front foot and back foot separately as well as forwards and backwards movements. For each foot and foot movement direction, the number of movements made within that 1m-delivery length region was calculated as a percentage of the total number of deliveries landing in that 1m region. This allowed for the identification of typical responses across the fourteen 1m regions.

2.3.7.2 Foot movement magnitude. Foot movement magnitude was defined as the forwards-backwards direction (+/-) and distance (metres) that each foot moved during shot execution.

2.3.7.3 PROBIT foot movement transition. PROBIT analysis (Finney, 1952) was used to model the probability that a foot movement, forwards or backwards, would be observed for a given delivery length. It was important to identify the delivery lengths at which participants changed the direction of their movement (i.e., foot movement responses), with the following probabilities; 95%, 50% and 5%. These would reflect 'dominant', 'neutral', and 'non-dominant' movements respectively.

2.3.8 DATA ANALYSIS

The *in-situ* and laboratory performance data were grouped by 5 delivery lengths (0-3m, 3-5m, 5-7m, 7-10m, 10-14m). Intra-class correlation coefficient analyses were used to measure the degree of agreement between *in-situ* and laboratory foot movement response proportions and magnitudes across delivery lengths. Furthermore, two-way, within-participant ANOVAs with Condition (*in-situ*, laboratory) and Delivery lengths (0-3m, 3-5m, 5-7m, 7-10m, 10-14m) were used to analyze participants' foot movement response proportions and magnitudes separately. To examine differences between skill groups, data were grouped into 14, one metre regions. Two-way, mixed design ANOVAs with Skill (skilled, novice) and Delivery length (0-14m) were used to analyze participants' foot movement response proportions and magnitudes separately. The

assumptions of ANOVA were tested for and no violations were found. Significant effects of ANOVA were followed up using Bonferroni corrected independent and dependent samples t-tests. Effect sizes were reported as Partial eta-squared (ηp^2) values.

PROBIT analysis was used to transform foot movement response proportions across delivery lengths into a response probability curve. This analysis involves the application of an inverse cumulative distribution function that is applied to binary response variables across a continuous variable. The continuous variable is categorized across its range and a probability of a response occurring is given across the continuous variable based on the number of responses/category of the continuous variable and the total number of events a response can be given. In accordance, metre-region categories were created for delivery lengths 0-14m. A binary response was recorded when the dominant foot movement was made forward for front foot movements and backwards for back foot movements. These variables were analyzed in order to identify the delivery length that resulted in 95th, 50th, and 5th percentile probability of foot movements being made. To aid visualization of the magnitude of the foot movements, the binary response variable (forward/backward) has been converted back to the absolute foot movement distance (m) and has been plotted alongside the response probability curve (Figures 2.4 and 2.5).

2.4 RESULTS

2.4.1 IN-SITU VERSUS LABORATORY

2.4.1.1 Front foot response proportions. A significant main effect was shown for condition, $F(1,12) = 5.66, p < 0.05, \eta p^2 = .32$. A larger percentage of front foot movements was observed in the laboratory compared with the *in-situ* task. A significant main effect was also found for delivery length, $F(4,48) = 142.75, p < 0.05, \eta p^2 = .92$, with significant differences ($ps < 0.05$) between all distances except 0-3m and 3-5m (as shown in Figure 2.3). There was also a significant Condition x Length interaction, $F(4,48) = 3.85, p < 0.05, \eta p^2 = .64$ (see Figure 2.3). Front foot response proportions under *in-situ* and laboratory protocols significantly differed between the 0-3m and 7-10m delivery lengths only.

2.4.1.2 Back foot response proportions. No significant main effect for condition was shown, $F(1,12) = 0.72, p > 0.05, \eta p^2 = .057$. There was, however, a significant main effect of length, $F(4,48) = 108.79, p < 0.05, \eta p^2 = .90$. As with the front foot, all lengths were significantly different, except between the 0-3m and 3-5m distances (see Figure 2.3). A significant Condition x Length interaction effect was shown, $F(4,48) = 5.38, p < 0.05, \eta p^2 = .31$, with the significant differences across conditions being at the 3-5 and the 7-10m delivery length conditions. A larger percentage of back foot movements were observed in the laboratory at the 3-5m delivery length, whilst a smaller percentage of movements was observed at the 7-10m delivery length compared with *in-situ* (see Figure 2.3).

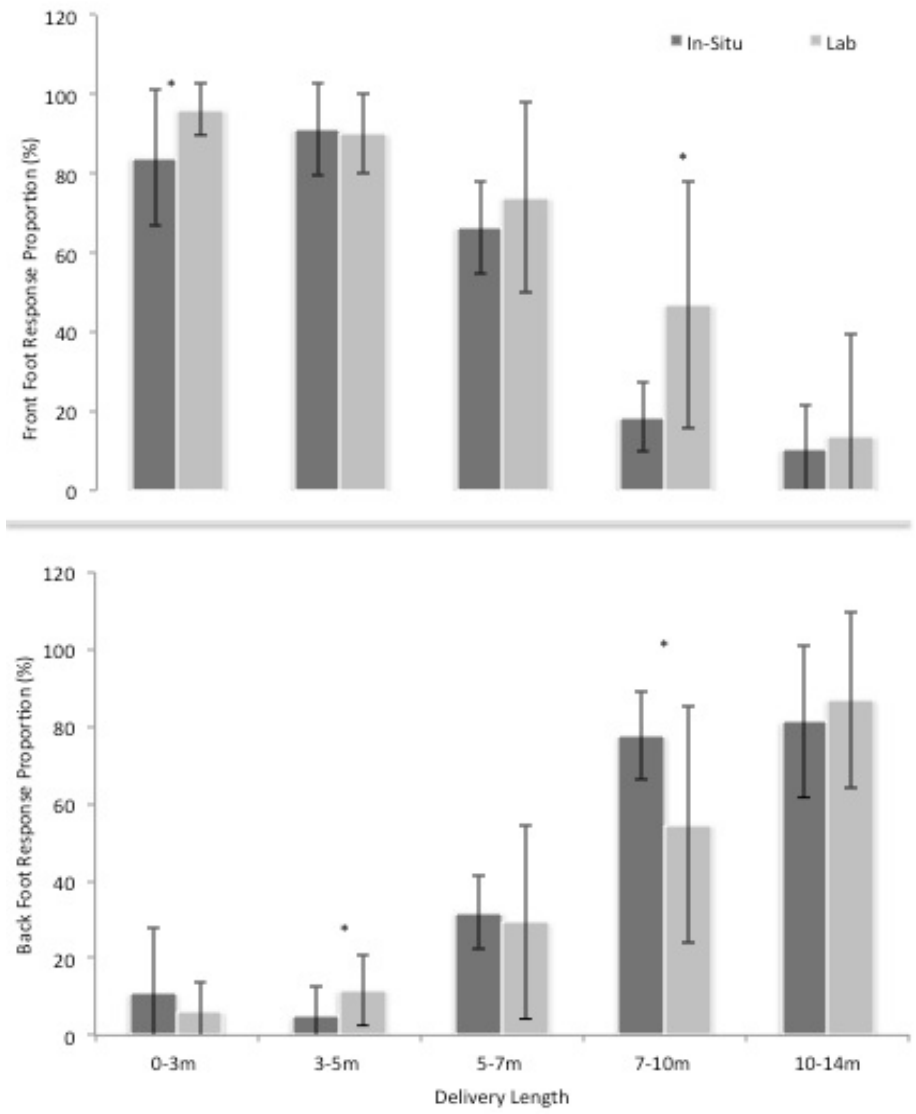


Figure 2.3 A comparison of the average front and back foot movement response proportions at very full (0-3m), full (3-5m), neutral (5-7m), short (7-10m) and very short (10-14m) length regions between *in-situ* and laboratory conditions. N.B. * $p < .05$. Error bars represent standard deviations of the mean.

2.4.1.3 Front foot movement magnitudes. A significant main effect for the size of front foot movements was shown for condition, $F(1,12) = 7.24$, $p < 0.05$, $\eta p^2 = .38$, with larger magnitudes of front foot movements being observed in the laboratory. A significant main effect of length, $F(4,48) = 169.33$, $p < 0.05$, $\eta p^2 = .93$, was due to significant differences between 3-5m ($M_{diff} = 0.36m$, $SD = 0.02$) and 5-7m ($M_{diff} = 0.15m$, $SD = 0.03$), between 5-7m and 7-10m ($M_{diff} = -0.08$, $SD = 0.04$) and between 7-10m and 10-14m ($M_{diff} = -0.42m$, $SD = 0.46$). A significant Condition x Length interaction $F(4,48) = 21.99$ $p < 0.05$, $\eta p^2 = .65$, resulted from differences between lab and *in-situ* in the 7-10m delivery length only.

2.4.1.4 Back foot movement magnitudes. No significant main effect for the size of back foot movements was shown for Condition ($F < 1$). However, there was a significant main effect of Length, $F(4,48) = 88.77$, $p < 0.05$, $\eta p^2 = .88$, with significant differences between 3-5m ($M_{diff} = 0.08m$, $SD = 0.00$) and 5-7m ($M_{diff} = -0.02m$, $SD = -0.01$), and between 5-7m and 7-10m ($M_{diff} = -0.22m$, $SD = -0.02$) and between 7-10m and 10-14m ($M_{diff} = -0.31m$, $SD = -0.03$). A significant Condition x Length interaction, ($F(4,48) = 4.47$ $p < 0.05$, $\eta p^2 = .272$), was due to significant differences between the conditions at the 3-5m and the 7-10m delivery lengths, with larger magnitudes of back foot movements in the laboratory at the 3-5m length and smaller magnitudes of movements in the laboratory being observed at the 7-10m length.

2.4.1.5 Foot movement correlations. A strong level of agreement was identified for front foot, $r(12) = .95$ $p < .05$ and back foot, $r(12) = .88$ $p < .05$, movement magnitudes

between *in-situ* and laboratory protocols. Therefore, changes in foot movements *in situ* were strongly associated with changes in foot movements in the laboratory conditions.

2.4.1.6 PROBIT foot movement transitions. In general, the probabilities of front foot movements were reflective of the *in-situ* and laboratory tasks. Data from the PROBIT analysis of the front foot response proportions indicated that the 50% probability threshold for a forward movement being made *in situ* was at the 7m delivery length region whereas this was at the 8m delivery length region in the laboratory task (see Figure 2.4). The 95% and 5% probability thresholds were at the 1.5m and 11.5m delivery lengths for the *in-situ* task and 2.5m and 14m for the laboratory tasks respectively. PROBIT of the back foot response proportions revealed that the 50% probability threshold was reached at 5.5m for the *in-situ* task and 6.5m for the laboratory tasks (see Figure 2.5). The 95% and 5% probability was reached at the 11.5m and 0m respectively for the *in-situ* task and the 95% probability was reached at 14m for the laboratory task, but the 5% probability was not reached.

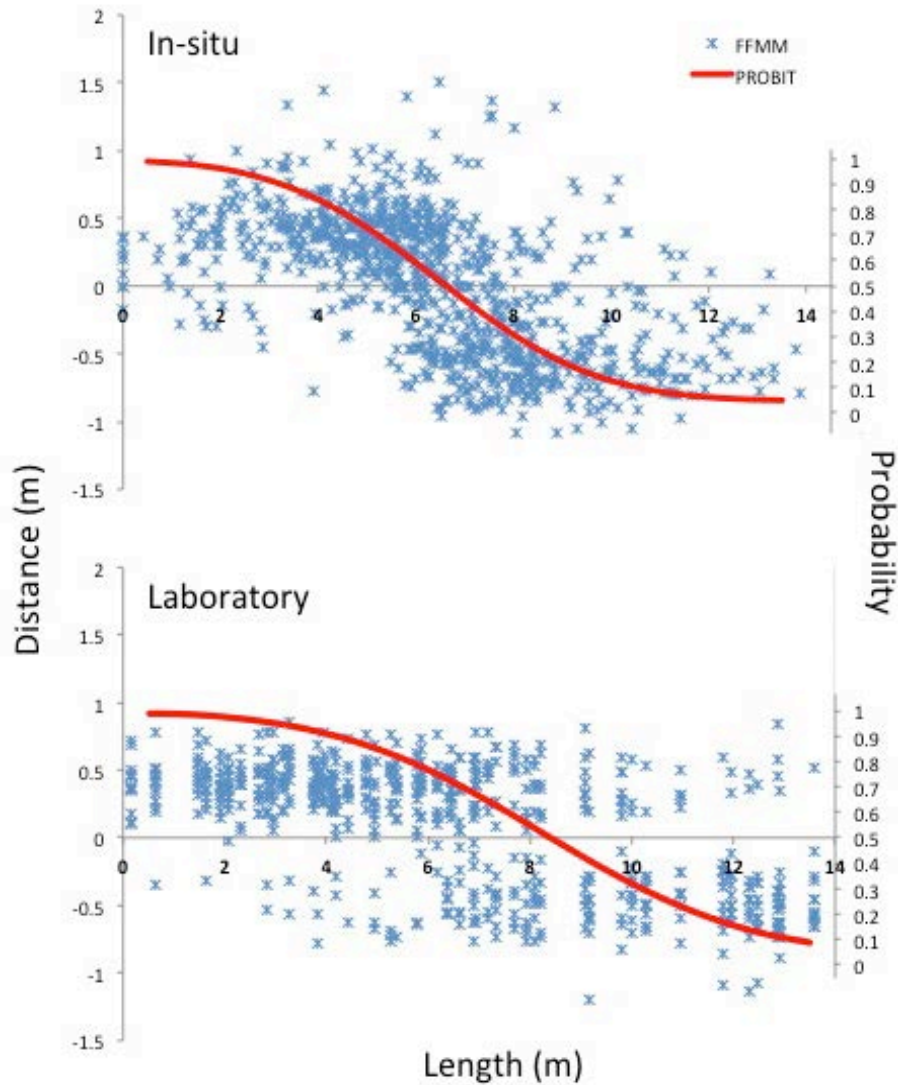


Figure 2.4 In-situ and laboratory front foot movement PROBIT analysis. The line of regression indicates the probability (%) of a forwards foot movement response across a range of delivery lengths. Blue markers indicate each foot movement direction and magnitudes (Distance, y axis) and delivery length (i.e., ball bounce point, Length x axis).

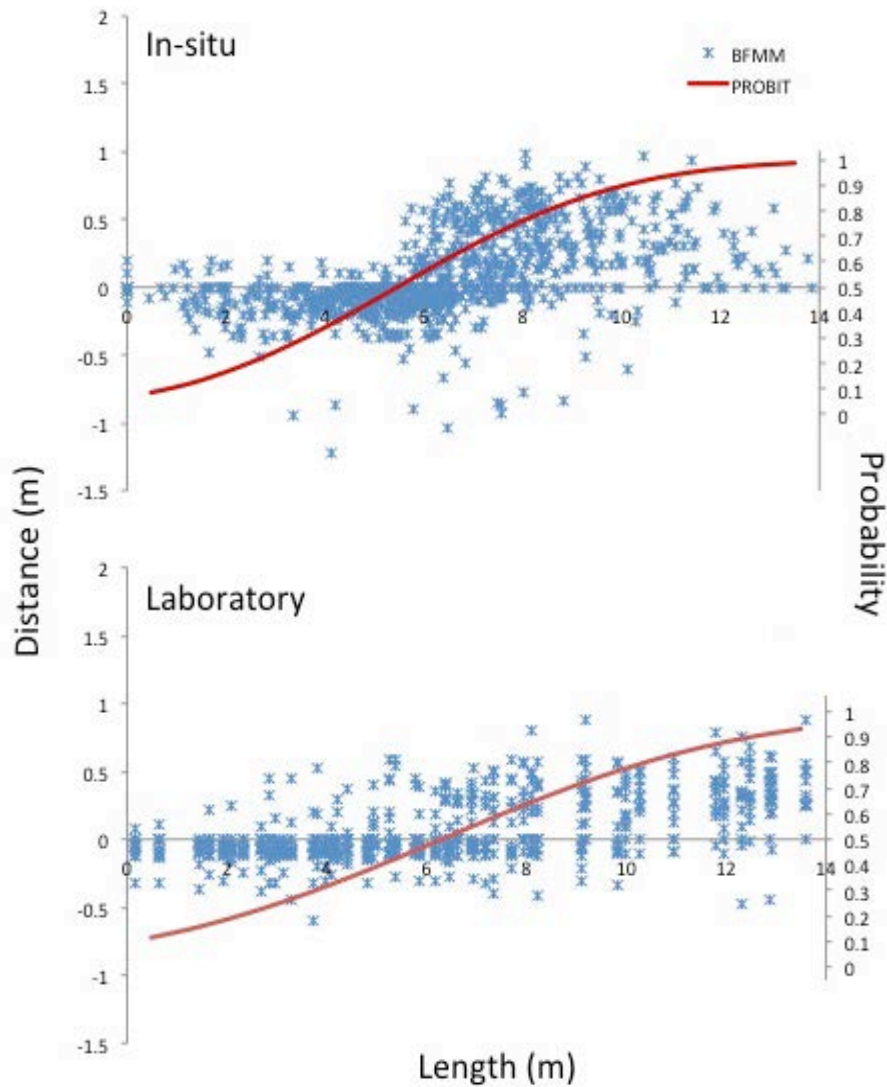


Figure 2.5 In-situ and laboratory back foot movement PROBIT analysis. The line of regression indicates the probability (%) of a backwards foot movement response across a range of delivery lengths. Blue markers indicate each foot movement direction and magnitudes (Distance, y axis) and delivery length (i.e., ball bounce point, Length x axis).

2.4.2 RELIABILITY

2.4.2.1 Foot movement correlation. A strong level of agreement was identified in front foot, $r(12) = .99$ $p < .05$ and back foot, $r(12) = .99$ $p < .05$, movement magnitudes between test versus re-test protocols (see Figure 2.6).

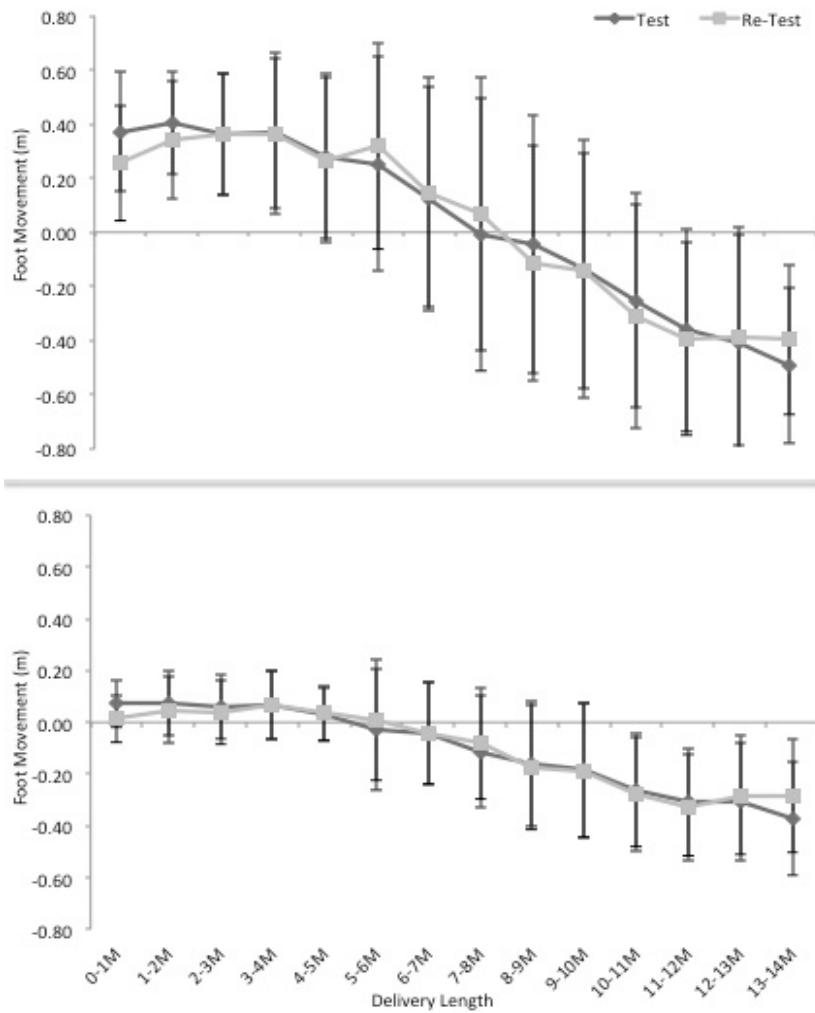


Figure 2.6 A comparison of the average front and back foot movement magnitudes over 1-metre length regions between test and re-test conditions. N.B. * $p < .05$. Error bars represent standard deviations of the mean.

2.4.2.2 Front foot movement. No significant main effect was found for test type, $F < 1$. Although there was a significant effect of length, $F(4,48) = 76.09$, $p < 0.05$, $\eta p^2 = .76$, there was no test type x length interaction ($F < 1$).

2.4.2.3 Back foot movement. Again there was no significant effect of test type, $F < 1$. or a test type x length interaction ($F < 1$). A significant main effect of length was shown, $F(4,48) = 50.71$, $p < 0.05$, $\eta p^2 = .68$.

2.4.3 BETWEEN- AND WITHIN-PARTICIPANT VARIABILITY

In order to show the pattern of variability in front foot movement magnitudes under laboratory and *in-situ* across delivery lengths and between individuals, between- and within-participant variability values have been displayed in Table 2.1. Overall, between-participant variability was relatively low, although there were some exceptions (e.g., participant 2, 7 (in situ) and 8 (Laboratory) showed generally higher overall SDs). Between-participant variability as a function of delivery length was higher and may be reflective of forward-backward transition points being located at different delivery lengths across for some participants. Variability was generally lower in the laboratory task than the in situ task and it increased at delivery lengths landing near 7-8m from the stumps.

Table 2.1 Between and within-participant front foot movement magnitude standard deviations (m) for the 13 skilled batsmen in the two conditions (*In-situ*, Laboratory) across the five delivery lengths categories.

Length	0-3m		3-5m		5-7m		7-10m		10-14m		Mean	
	Situ	Lab	Situ	Lab	Situ	Lab	Situ	Lab	Situ	Lab	Situ	Lab
Participant 1	0.10	0.10	0.27	0.15	0.42	0.17	0.45	0.34	0.34	0.06	0.32	0.16
2	0.48	0.18	0.42	0.19	0.37	0.08	0.45	0.40	0.41	0.13	0.43	0.19
3	0.28	0.25	0.23	0.14	0.56	0.09	0.34	0.30	0.21	0.46	0.32	0.25
4	0.26	0.06	0.20	0.37	0.45	0.43	0.34	0.10	0.35	0.11	0.32	0.22
5	0.12	0.33	0.53	0.36	0.55	0.39	0.29	0.48	0.33	0.34	0.36	0.38
6	0.27	0.27	0.21	0.07	0.46	0.35	0.62	0.46	0.30	0.06	0.37	0.24
7	0.26	0.08	0.27	0.08	0.59	0.08	0.52	0.09	0.46	0.28	0.42	0.12
8	0.26	0.09	0.21	0.59	0.42	0.72	0.45	0.62	0.05	0.13	0.28	0.43
9	0.35	0.13	0.08	0.35	0.34	0.48	0.56	0.42	0.28	0.50	0.32	0.38
10	0.30	0.13	0.24	0.32	0.28	0.45	0.45	0.27	0.58	0.35	0.37	0.30
11	0.32	0.05	0.20	0.12	0.49	0.24	0.53	0.21	0.36	0.08	0.38	0.14
12	0.58	0.07	0.25	0.11	0.35	0.09	0.37	0.37	0.17	0.34	0.34	0.20
13	0.21	0.08	0.32	0.37	0.34	0.41	0.33	0.54	0.33	0.32	0.31	0.34
Mean	0.29	0.14	0.26	0.25	0.43	0.31	0.44	0.35	0.32	0.24	0.35	0.26

2.4.4 CONSTRUCT VALIDITY COMPARING NOVICE AND SKILLED PARTICIPANTS

2.4.4.1 Front foot response proportion. There was a significant effect of skill, $F(1,23) = 14.14, p < 0.05, \eta p^2 = .38$ and length, $F(1,23) = 17.50, p < 0.05, \eta p^2 = .43$. A significant Skill x Length interaction effect, $F(1,23) = 19.73, p < 0.05, \eta p^2 = .46$, showed significant differences between skill groups at 0-1m, 7-8m, 8-9m, 9-10m, 10-11m, 11-12m, 12-13m and 13-14m delivery length conditions. Novices had higher percentages of front foot movements than skilled performers across these lengths.

2.4.4.2 Back foot response proportion. Again a significant skill effect, $F(1,23) = 20.51, p < 0.05, \eta p^2 = .47$ and length effect, $F(13,299) = 19.18, p < 0.05, \eta p^2 = .45$, were shown. A Skill x Length interaction, $F(13,299) = 19.74, p < 0.05, \eta p^2 = .46$, was due to significant differences between groups at 6-7m, 7-8m, 8-9m, 9-10m, 10-11m, 11-12m, 12-13m and the 13-14m delivery length conditions. As would be expected based on the front foot differences, skilled performers had higher percentages of back foot movement proportions than novices at these lengths.

2.4.4.3 Front foot movement magnitudes. Again, there were skill, $F(1,23) = 6.78, p < 0.05, \eta p^2 = .35$ and length, $F(13,299) = 27.14, p < 0.05, \eta p^2 = .54$ effects (see Figure 2.7). There was also a significant Skill x Length interaction, $F(13,299) = 27.46, p < 0.05, \eta p^2 = .54$, with significant differences between the groups at 6-7m, 7-8m, 8-9m,

9-10m, 10-11m, 11-12m, 12-13m and 13-14m delivery length conditions. Novices had larger front foot movement magnitudes than the skilled performers.

2.4.4.4 Back foot movement magnitudes. There was a skill, $F(1,23) = 14.29$, $p < 0.05$, $\eta p^2 = .38$, length, $F(13,299) = 16.40$, $p < 0.05$, $\eta p^2 = .42$, and a Skill x Length interaction, $F(13,299) = 15.72$ $p < 0.05$, $\eta p^2 = .41$. The latter effect was due to significant differences between the groups at 6-7m, 7-8m, 8-9m, 9-10m, 10-11m, 11-12m, 12-13m and the 13-14m delivery length conditions (see Figure 2.7). Skilled performers had larger back foot movement magnitudes compared with novices.

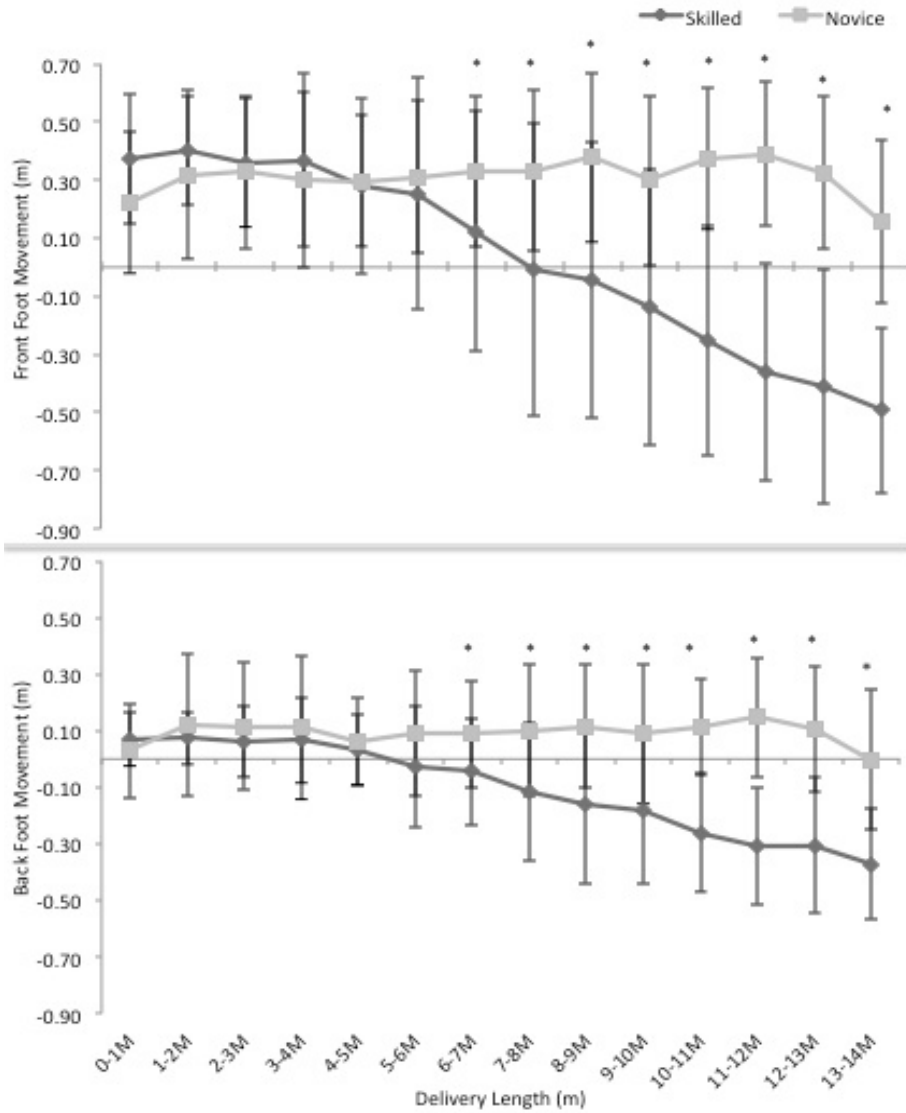


Figure 2.7 A comparison of the average front and back foot movement magnitudes over 1-metre length regions between skilled and novice participants. N.B. * $p < .05$. Error bars represent standard deviations of the mean.

2.5 DISCUSSION

The aim of this study was to examine an emergent behaviour from cricket batting *in situ* to evaluate the representative design of a laboratory-based cricket batting task. Skilled batsmen's foot movements were recorded as an indicator of their decision-making behaviour about delivery length. By comparing the pattern of foot movement behaviour across delivery lengths the degree of fidelity between *in-situ* and laboratory task was evaluated. PROBIT was used to model these data.

In-situ, there was a high probability of a forwards front foot movement to deliveries that landed 0-7m from the base of the batters' stumps. At 7-8 m, no dominant foot movement response was evident. A low probability of a forwards front foot response was shown for delivery ranges between 8-14m from the stumps. As would be expected, this pattern was reversed in the back foot movements *in situ*. These findings support the notion of a meta-stable region of foot movements (Pinder *et al.*, 2012). Additionally, these findings broaden empirical research by modeling cricket batsmen's decision making behaviours (Araujo *et al.*, 2006), thus allowing a prediction of the likelihood of behaviours being observed across a range of delivery lengths, and locate the presence of an unstable region of performance.

In order to establish the level of representative design of a laboratory task, the adaptive behaviours of laboratory and *in-situ* movements were compared. It was expected that a high degree of fidelity would be found if the pattern of foot movements identified *in situ* were consistent with that of the representative laboratory task. The data shows significant intra-class correlations between *in-situ* and laboratory for front and back foot

movement magnitudes. Also, similar PROBIT foot movement models emerged for both these conditions, indicating that a general pattern was maintained between these conditions. However, PROBIT analyses showed the 50% probability reached *in situ* was 1m different in delivery length than the laboratory-based task. ANOVA data also revealed significant differences between *in-situ* and laboratory conditions at the 0-3m and 7-10m regions for both front foot and back foot movement response proportions between *in-situ* and laboratory conditions. Specifically, it was observed that less forward movements in response to deliveries that landed 0-3m away from the batsman *in situ*, compared to laboratory.

Collectively, these findings suggest that batsmen are subjected to some degree of information degeneracy in the laboratory task (Davids, 2008). Whilst it is difficult to be certain why this was the case, there can be speculation on two possibilities. Because the similar sigmoid curve patterns of responses were observed, the same informational variables may have been used across *in-situ* and laboratory task conditions. However, because there was a translational shift in the 50% probability, a mis-calibration of the informational variables could have occurred, this may have resulted from the misalignment of the visual stimulus when presented in the laboratory task. To some degree, there was also a stretching and squashing of the sigmoid curve in the laboratory task condition, showing that response probabilities were not as high (or low) for the laboratory task and as such less consistent. Again, this suggests that batsmen may not have been able to as easily attend to or glean the important informational variables present in *in-situ* batting, potentially as a function of degraded depth cues present in the 2D stimulus used in the lab. However, the presence of the same general pattern of

response suggests that informational variables required for the purpose of moving forwards and backwards to the delivery were present or, at least, that other informational variables co-varied in a similar way to those variables found *in situ*.

In response to the question, “what is representative enough?” one should note that this general pattern of movement may or may not be considered representative when evaluating the naturally occurring cricket batting performance (i.e., in a match-like situation). Accordingly, the tests examined in this paper can be considered to be representative for investigating decision-making behaviour about length perception (Araujo *et al.*, 2006). Therefore, for a task to be representative it does not necessitate replication of the entire naturally occurring phenomena *in situ* (in this case cricket batting behaviour). In addition, researchers should substantiate claims of task representativeness (or lack of) with data. Furthermore, this may require the identification of complex trends in data. For example, here, more importance is placed on the pattern of movements across the transition point rather than there being a specific transition point when evaluating differences between *in situ* and laboratory conditions.

Significant differences between the conditions occur most frequently at the 7 - 10m length region. From a dynamical systems theory (DST) perspective, this length corresponds to a meta-stable region of performance (Pinder *et al.*, 2012). According to DST, increased variability is indicative of movements around bifurcation point, where no stable attractor is present to ‘hold’ a movement pattern for example. Therefore, any differences in the transition point around this region of variability are not considered as important as the overall pattern of the movement across this transition point. For instance, different transition points will be found for different playing surfaces and

different bowlers. However, the theoretical notion of a bifurcation point around movement transitions raises some interesting questions about how this point might change as a consequence of perceptual motor skill learning. For example, would the size of the region of instability be reduced as a perceptual motor skill improves? Is this a universal feature of perceptual motor skill? These questions could be addressed in future research using the PROBIT analysis in a longitudinal study of skill learning. Potentially this might provide an objective metric by which skilled performance could be compared between and across task domains.

This study also aimed to identify the reliability of the laboratory-based task, and examine if the task was able to discriminate between skilled and novice batsmen. Between the test and re-test, strong, positive correlations were shown and no significant differences. These results highlight that participants responded in a consistent way to the video-based stimuli across a range of delivery lengths in the laboratory task. Significant differences between skilled versus novice front and back foot movements across 7-14m delivery lengths were observed. Therefore, the laboratory task could discriminate between skilled and novice actions across a range of delivery lengths. Participants in the skilled group seemed to be able to extract task-specific information for their foot movements, with a systematic change in movement direction as delivery length changed. Novices however, did not change their movements in response to the changes in delivery length. There was a large forward bias in the novices' movements to delivery lengths. The observed front forward foot bias response may be due to the fact novice participants have no task-specific knowledge to inform the appropriate movement for goal achievement (Renshaw *et al.*, 2007).

In conclusion, the findings of this study underline the need to develop movement models of performance in sporting environments to understand fully the representativeness of tasks designed. Providing evidence on this allows experimenters to make data driven assessments of the degree to which their tests are externally valid whilst maintaining experimental control. With this in mind, these findings echo the conclusions made by Starkes *et al.* (1995) that the methodology and findings of the current study might lead researchers away from using unrepresentative dichotomous tasks with high levels of control, and towards a balanced approach that allows for more accurate generalization to natural environments, whilst maintaining a level of experimental control.

CHAPTER 3:

ANALYSIS OF ADAPTIVE BEHAVIOIURS IN CRICKET BATTING: THE EFFECT OF SKILL LEVEL, ACTION SPECIFICITY, AND TEMPORAL OCCLUSION ON PERFORMANCE

3.1 ABSTRACT

This aim of this study is to investigate the effects of manipulating the level of task representation on subsequent adaptive movement behaviours across delivery lengths (0 – 14m) by uncoupling movement responses and/or perceptual information. Skilled and novice performers carried out a cricket batting decision-making test consisting of four separate test blocks that were presenting in a counter balanced order; Coupled Un-occluded (perception – action representative), Coupled Occluded (representative action), Uncoupled Un-occluded (representative perception), and Uncoupled Occluded (unrepresentative). Analyses found a significant four-way interaction between the aforementioned variables, with skilled performance improving as a function of task representativeness, with high levels of performance under fully coupled conditions, which reverted to novice like performance under un-coupled conditions. These findings demonstrate that the demands of fast paced sporting tasks are interrelated with any changes in task representation provoking changes in adaptive movement behaviours. The implications of these findings are discussed in relation to previous perceptual cognitive studies. In future, researchers must take into consideration that there is no single

approach to studying perceptual cognitive skill in sport accurately. Instead, multi-disciplinary approaches are required to identify how task specific demands interact and are affected by manipulations in order to understand performance better.

Key Words: Expertise, Sport, Interceptive, Action, Perception, Anticipation.

3.2 INTRODUCTION

In the study of expertise, Ericsson & Smith (1991) originally proposed a three-stage approach, which captured expert performance *in situ* and developed representative tasks to identify the underlying mechanisms of expertise, and study its acquisition. This approach has been using in parts for much of the current evidence based perceptual – cognitive research to date. However, Davids *et al.*, (2005) suggest that the traditional study of motor behaviour may have been biased due to a perceived dichotomy between experimental rigor, which the expert performance approach affords, and external validity. Others have also argued that experimental designs which are not truly representative of performance environments (Pinder *et al.*, 2011b) and have failed to preserve the functional couplings between perception and action (Van Der Kamp *et al.*, 2008) limit current theory & understanding of perceptual – cognitive expertise; for example, experimental designs that have altered the representativeness of tasks by controlling task specific information. This study aims to examine the effects of manipulations in response mode, skill level, and occlusion condition have on decision making performance about delivery length with the aim of understanding how controlling the level of task representation effects subsequent adaptive behaviours.

Due to advances in technology and the introduction of theoretical paradigms (representative task designs, Brunswik, 1956, and dynamical systems theory) for the study of movement behaviours, some researchers believe representative tasks should be recognized and considered as part of a continuum when studying motor behaviour (Davids *et al.*, 2005). Similarly, when proposing a new framework for the study of motor

behaviour in sports, representative learning design, Pinder *et al.*, (2011b) suggest that practitioners should examine the degree of fidelity (see Stoffregen *et al.*, 2003) which exists between the experimental task and the performance setting when developing representative tasks in order to overcome some of the aforementioned methodological limitations.

Previous laboratory-based studies into anticipation in cricket batting have predominantly used the occlusion paradigm, which offers experimental control (Davids, 2008) and administrative convenience (Mann *et al.*, 2010). These have been able to identify significant differences in a range of perceptual cognitive skills between expert and novice populations. Sport specific experience (Renshaw & Fairweather, 2000), general practice hours (Weissensteiner *et al.*, 2008), and structured practice hours (Ford, Lowe, McRobert, & Williams, 2010) have all been identified as contributing factors to developing perceptual - cognitive skill in cricket batting, supporting the theory of deliberate practice (Ericsson *et al.*, 1993). Specifically, there has been interest in the contribution of pre-delivery kinematics of body segments to enable the anticipation of delivery deviation and length characteristics. Muller *et al.*, (2006) identified significant differences between high- and low-skilled batsmen when predicting spin direction due to spatial occlusion of the bowling hand. In both spin and pace conditions, they found no significant differences between skill levels when occluding the bowling arm, non-bowling arm, torso, lower body, and projected release point at ball release. Some have argued that information can be extracted from other body regions in order to anticipate the intended direction of an action (e.g. Huys *et al.*, 2008). However, it could be the case that the use of dichotomous, non-action specific responses, which are not representative

of the intended environment to be studied result in the lack of differences in these tests (e.g. Williams & Ericsson, 2005).

Mann *et al.*, (2010) studied the effect of differing response modes *in-situ* between skilled and novice cricket batsmen. The researchers analyzed the differences between verbal, foot movement, shadow batting and total batting responses to off-side or leg-side deliveries. These responses reflect different types of perception – action coupling of natural cricket batting. Results showed that skilled, but not novice anticipation performance increased with actions that more closely represented the cricket-batting task. Responses containing the least representative movements were accompanied with the biggest relative differences in anticipation performance when compared to a verbal response. Subsequent increases in specificity further improved anticipation performance, with results showing that full body movement using a bat induced greater anticipation than with no bat. Mann *et al.*, (2010) suggest that allowing a participant to respond by making a bat-ball contact increases the sensitivity of the method to differentiate between skilled and novice performers, highlighting the importance of using experimental procedures that accurately reflect the task demands of the natural performance environment. Pinder *et al.*, (2011a) addressed concerns about the manipulation of informational constraints and effects on subsequent movement organization. Pinder *et al.*, (2011a) analyzed cricket batters actions under *in-situ*, bowling machine, and life sized video conditions. The results showed that each distinct set of task constraints led to significant variations in patterns of movement control. Specifically, when responding to a life-sized video, batsmen were able to use information from the bowler's action, enabling reliability of initial behavioral responses consistent with the task of batting *in-situ*. Pinder

et al., (2011a) also reiterate that current popular experimental task designs may be limiting research progress, and that experimenters should attempt to design experimental tasks that are representative of specific performance contexts. These cricket specific findings are in coherence with Dicks *et al.*, (2010), who analysed the gaze behaviours of football goalkeepers under video and *in situ* conditions and various response conditions. Dicks *et al.*, (2010) found that gaze and movement behaviours function differently depending on the experimental task constraints which the goal keepers are exposed to.

As cited by Davids *et al.*, (2005), recent advances in technology and experimental protocols have made it possible for researchers to analyse adaptive behaviours in sporting environments. Chapter 2 of this thesis analysed cricket batsmen's foot movement patterns *in situ* in order to infer decision-making intentionality. The study aimed to examine a point at which foot movement patterns changed from one direction to the other whilst responding to a range of delivery lengths, Analyses identified patterns of movement characterized by a transition from a front foot dominant movement response to 'full' (0-6m) delivery lengths, into a back foot dominant movement response to 'short' (8-14m) delivery lengths. These findings are similar to those reported by Pinder *et al.* (2011a) who examined length perception of junior cricket batsmen *in situ* across pre-determined delivery lengths, demonstrating that at a delivery length of 7.5m, batsmen were forced into a region of performance where rich and varied patterns of functional movement behaviours emerged. These findings highlight the applied value of studying a movement system across a range of performance variables under representative settings. However, whilst protocols that are 'high' in representativeness are believed to offer greater

generalizability of results to the intended environment, not enough is currently understood about the trade-off between external validity and experimental control.

In a recent study, Chapter 2 measured the fidelity of a representative laboratory based protocol compared to *in-situ*. The findings suggested that there is degree of fidelity between the two environments, with the representative laboratory task allowing cricket batsmen to make naturalistic movements in response to varied delivery lengths. This novel approach minimizes the need to compromise experimental control, allowing researchers to make data driven assessments of the degree to which their tests are externally valid whilst maintaining experimental control. This study employs the same methodological approach used in Chapter 2 to examine the effects of frequently used methodological interventions in the literature; response mode, skill level, and occlusion condition on anticipatory performance, with the aim of understanding how manipulating the level of task representation effects subsequent adaptive behaviours. Based on previous research, it was expected that; 1) Improvements in skilled performance as a function of coupled response modes would be present (Mann *et al.*, 2010, Dicks *et al.*, 2010), 2) Differences between skilled and novice performance across conditions (Ford *et al.*, 2010), and 3) Decreased in skilled but not novice performance under occluded conditions (Muller *et al.*, 2006). In summary, we expect to see the greatest difference in performance between skilled and novice performers where the demands of the task are most representative to those observed *in situ*.

3.3 METHODS

3.3.1 PARTICIPANTS

Thirteen skilled right-handed male cricket batsmen (age: 23.2 ± 3.8 years), with 11.5 ± 2.3 years playing experience, and twelve right-handed male cricket novices (age: 25.3 ± 3.2 years) participated in the study. Inclusion criteria for the skilled participants were that they had at least eight years of club level playing experience and were playing at a regional, first division level for the past two years (in the UK). Novice participants were included if they had no competitive cricketing experience. Two right-arm bowlers (age: 21.6 ± 1.7 years) with 8.7 ± 1.5 years playing experience with similar conventional bowling actions and physical attributes (Bowler 1, average height of release: 2.09 ± 0.06 m; average bowling speed: 32.63 ± 0.78 m.s⁻¹. Bowler 2, average height of release: 2.11 ± 0.04 m; average bowling speed: 32.93 ± 0.43 m.s⁻¹) were recruited to create the laboratory test conditions. Participants provided informed consent prior to testing and ethical clearance was received from the local institutional ethics and governance committee.

3.3.2 VIDEO PRODUCTION AND TEST CONSTRUCTION

The two medium – fast bowlers were instructed to bowl from the popping crease (located 18.90m from the bowling crease at the batsman's end) towards the stumps and land the ball at five ranges of delivery lengths from the batsman's stumps, identified

by a previous movement analysis (Chapter 2). These consisted of a) “Very Full” (0-3m), b) “Full” (3-5m), c) “Neutral” (5-7m), d) “Short” (7-10m), and e) “Very Short” (10-14m) delivery lengths. Twelve deliveries were bowled towards each length category to create an adequate sample for test tape construction. The representative video footage of the bowlers was filmed (Sony Handycam HDR-TD10E, Tokyo, Japan) from the batter’s preparatory position on the batting crease and at a height of 1.76m. This camera was positioned, zoomed, and focused to replicate a batsman’s natural viewing perspective. Another high definition video camera (Canon LEGERIA HF R46, Tokyo, Japan) was positioned parallel to the pitch to record the ball flight characteristics of the bowlers’ deliveries (see Figure 3.1 for camera set up). Delivery length was measured from the point of ball bounce to the base of the stumps at the batter’s end. Calibration was attained using horizontal and vertical references of known distance. Bowler’s deliveries were selected for inclusion based on meeting the specified length criteria. The footage was then edited into 50 single deliveries (5 deliveries x 5 delivery lengths x 2 bowlers), used to construct randomized un-occluded and occluded tests.

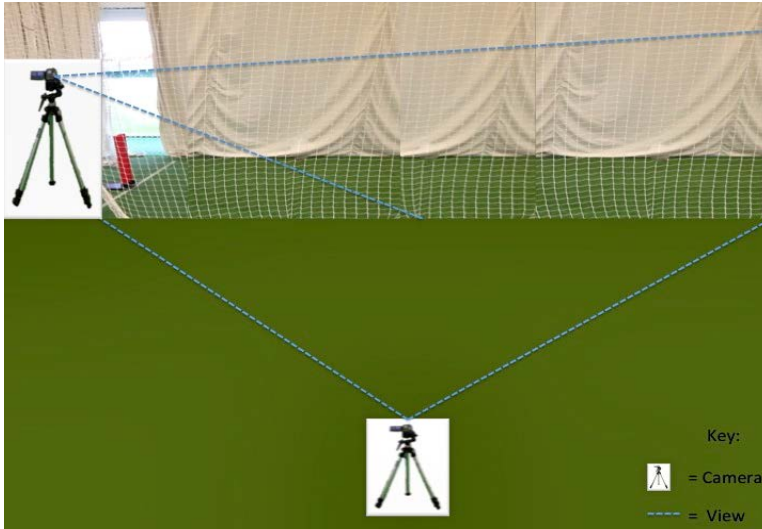


Figure 3.1 A schematic showing the positioning of cameras used to record the bowling kinematics and delivery length data.

3.3.3 PROCEDURE

Skilled and novice participants completed four separate test blocks; Coupled Un-occluded (perception – action representative), Coupled Occluded (representative action), Uncoupled Un-occluded (representative perception), and Uncoupled Occluded (unrepresentative). These were developed by manipulating either the occlusion condition and, or the action specificity condition. The test block order was counter balanced to control for potential learning effects, and each test was carried out independently after a specified rest period to control for any potential mental and physical fatigue effects. An initial familiarization protocol was administered before each test condition to allow batsmen to adapt to each setting, before completing the subsequent test.

3.3.3.1 Coupled Un-occluded Test (representative perception – action).

Experimenters constructed a simulation environment to replicate cricket batting decision making task demands (Chapter 2). This test block required participants to make representative full body movements in order to make bat –ball contact. Un-occluded deliveries were shown in full, starting from the beginning of the bowler’s run up, and finishing at the end of the bowler’s follow through. Two high definition video cameras were positioned to record the batsman’s movement kinematics. In each of the camera’s fields of vision, a distance calibration marker was set to a standardized distance to allow for digitization.

3.3.3.2 Coupled Occluded Test (representative action). This test block required participants to make representative full body movements in response to occluded deliveries with the intention of making “anticipated” bat –ball contact. Occluded deliveries were occluded to impede vision at the moment of ball release, presenting only pre-delivery bowling kinematics. The same camera set up and calibration protocols were adhered to.

3.3.3.3 Uncoupled Unoccluded Test (representative perception). This test block required participants to respond to the video simulation using a two-choice key press method, either selecting the forwards key to indicate a front foot movement, or the backwards key to indicate a back foot movement. Unoccluded deliveries were shown in full, starting from the beginning of the bowlers run up, and finishing at the end of the bowlers follow through.

3.3.3.4 *Uncoupled Occluded Test (unrepresentative)*. This test block required participants to respond to the video simulation using a two-choice key press method, either selecting the forwards key to indicate a front foot movement, or the backwards key to indicate a back foot movement. Occluded deliveries were edited to impede vision at the moment of ball release, presenting only pre-delivery bowling kinematics.

3.3.4 DATA COLLECTION

3.3.4.1 *Coupled Tests*. A high definition video camera was used to record batsman's foot movement kinematics in the laboratory. This footage was then calibrated for distance using Silicon Coach Pro 7 software (Dunedin, New Zealand). Once calibrated, each front and back foot movement distance was individually measured.

3.3.4.2 *Uncoupled Tests*. DMDX visual reaction timing software was used to present the video and record the key press responses to each corresponding delivery. These responses were automatically output into a notepad document detailing the intention and timing of each key press.

3.3.5 MEASURES

3.3.5.1 *Foot movement response proportion*. Foot movement response proportions were calculated for front foot and back foot separately as well as forwards

and backwards movements. For each foot and foot movement direction, the number of movements made within each delivery length region was calculated as a percentage of the total number of deliveries landing in that 1m region. This allowed the experimenters to identify typical responses across the delivery length bandwidths.

3.3.6 DATA ANALYSIS

A four-way repeated measures ANOVA, Group (2) x Response mode (2) x Occlusion (2) x Delivery length (5) was used to test the effects of different response modes, under varied occlusion conditions, on front foot movement response proportions between skilled and novice performers across different delivery lengths. The assumptions of ANOVA were tested for sphericity and where violations were found, Greenhouse Geiser adjusted measures were used. Significant effects of ANOVA were followed up using Bonferroni corrected independent and dependent samples t-tests. Effect sizes were reported as Partial eta-squared (ηp^2) values.

3.4 RESULTS

3.4.1 FRONT FOOT RESPONSE PROPORTIONS

There was a significant main effect of response mode used, $F(1,19) = 22.15$, $p < 0.01$, $\eta p^2 = .538$ and delivery length bowled, $F(4,76) = 35.87$, $p < 0.01$, $\eta p^2 = .564$ on the response proportions made by the participants. There was a nonsignificant main effect of group, $F(1,12) = 1.75$, $p > 0.05$, $\eta p^2 = .086$, and occlusion condition, $F(1,12) = 1.25$, $p > 0.05$, $\eta p^2 = .061$, on the response proportions made by participants. However, there was a significant 4-way interaction effect of Group x Response Mode x Occlusion condition x Delivery length, $F(4,76) = 6.61$, $p < 0.01$, $\eta p^2 = .258$, on the response proportions made by participants. These interactions are displayed in Figure 3.2. Bonferroni pairwise comparisons showed greater front foot movement response proportions under coupled compared to un-coupled conditions ($M_{diff} = 17.67\%$, $SD = 3.75$). Follow up tests also showed that skilled, but not novice front foot movement response proportions transition from high percentages to low percentages across full to short delivery lengths (0-3m vs. 3-5m $M_{diff} = .84\%$, $SD = 1.99$, 3-5m vs. 5-7m $M_{diff} = 17.77\%*$, $SD = 2.56$, 5-7m vs. 7-10m $M_{diff} = 1.51\%$, $SD = 3.76$, 7-10m vs. 10-14m $M_{diff} = 7.43%*$, $SD = 1.88$), highlighting the skill based difference lies with the need to adapt movement behaviour in response to a change in task demands. Table 3.1 contains a summary of lower level interactional effects that have not been reported in the text.

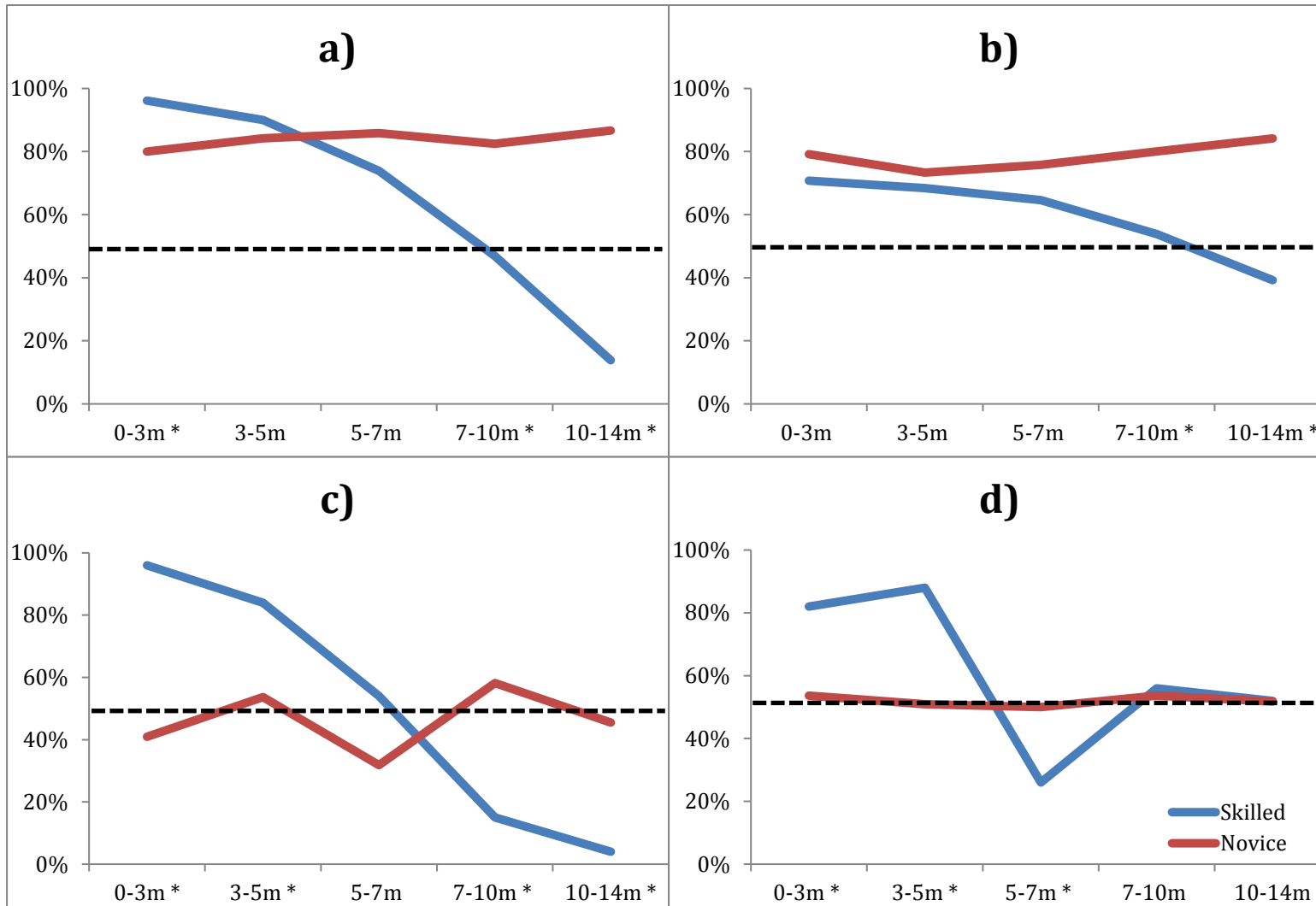


Figure 3.2 A comparison of skilled versus novice front foot movement response proportions across a) Coupled Unoccluded, b) Coupled Occluded, c) Uncoupled Unoccluded, and d) Uncoupled Occluded N.B. * indicates significant differences between skilled versus novice performance ($p < .05$), Dotted line indicates chance level response proportion

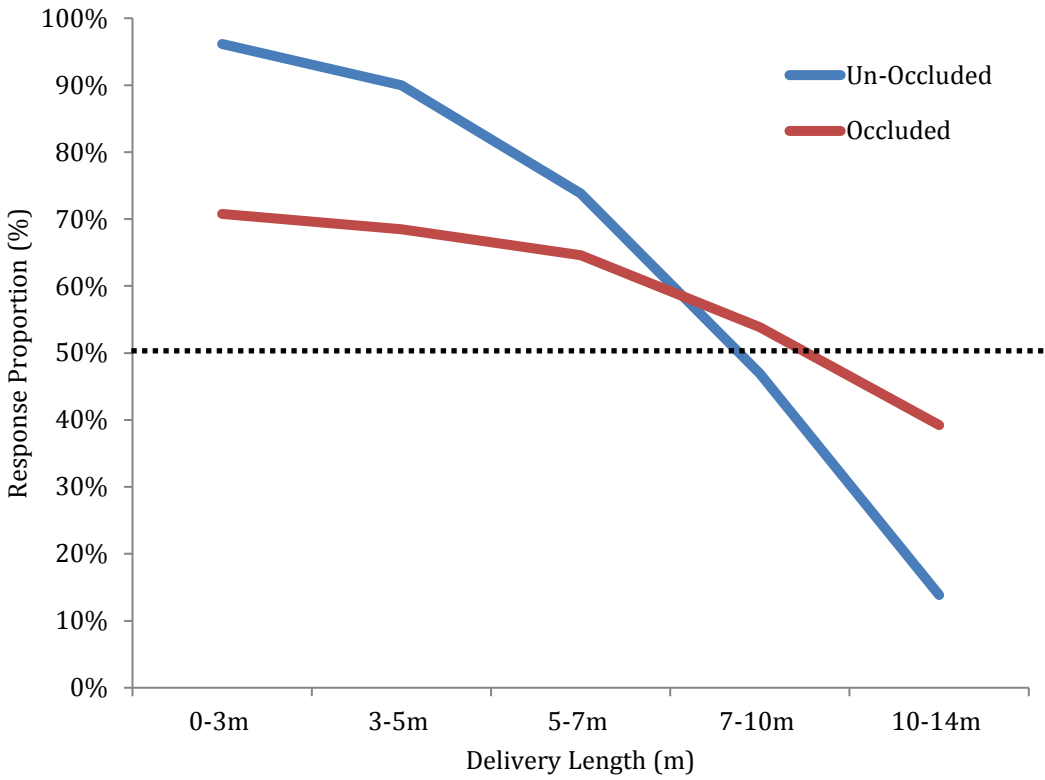


Figure 3.3 A comparison of skilled front foot movement proportions under un-occluded versus occluded conditions across delivery lengths. N.B. Dotted line indicates chance level response proportion.

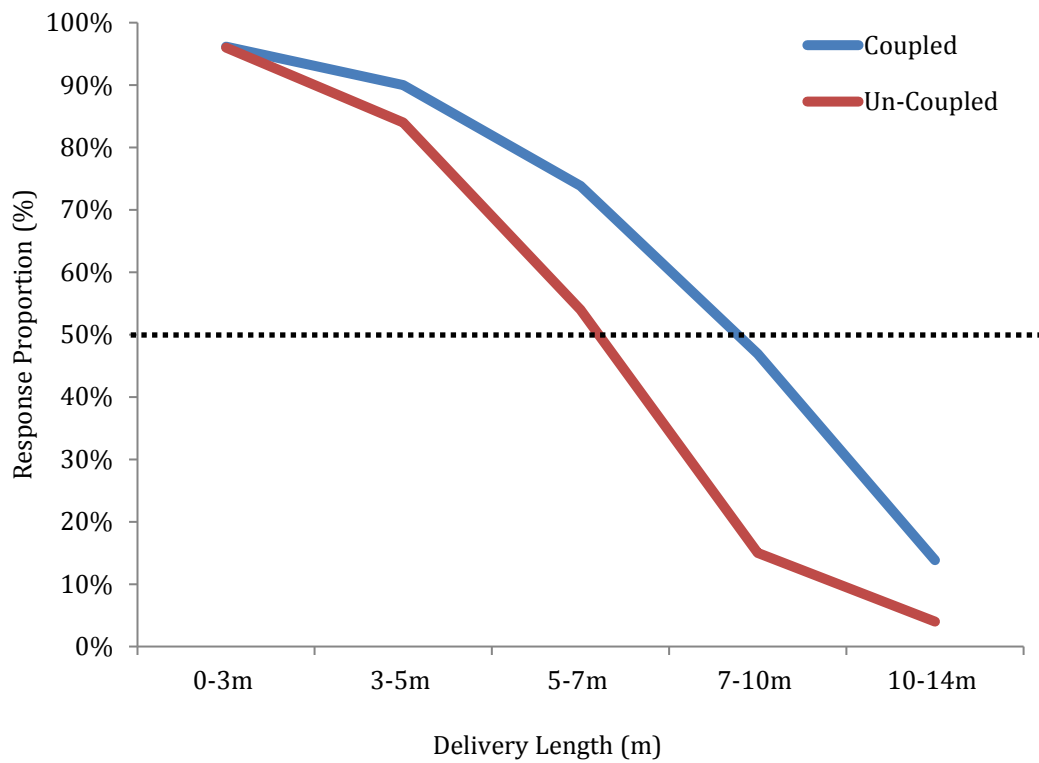


Figure 3.4 A comparison of skilled front foot movement response proportions between coupled versus un-coupled conditions across delivery lengths. N.B. Dotted line indicates chance level response proportion.

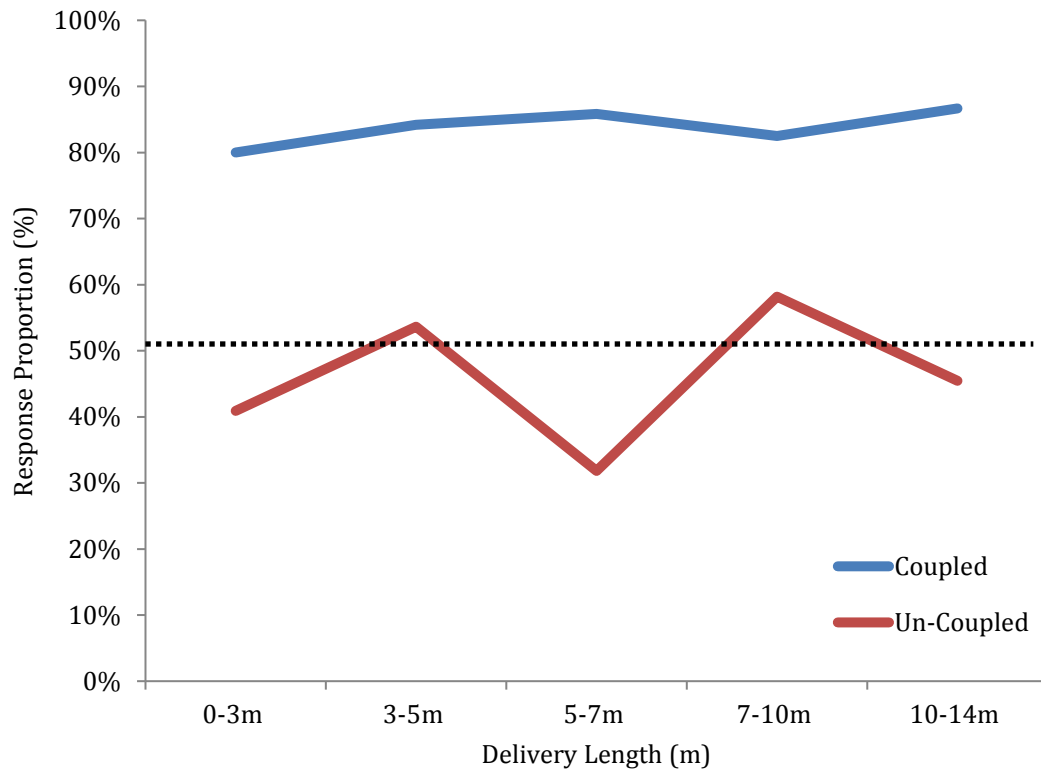


Figure 3.5 A comparison of novice front foot response proportions between coupled versus novice un-coupled conditions across delivery lengths. N.B. Dotted line indicates chance level response proportion.

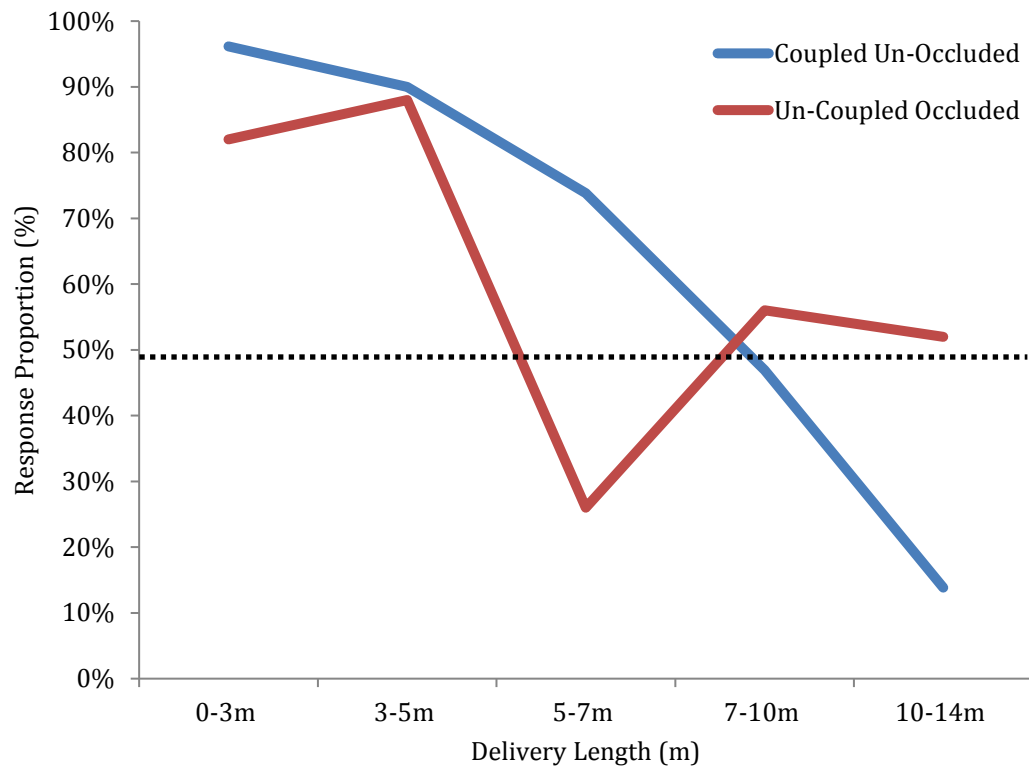


Figure 3.6 A comparison of skilled front foot movement proportions between coupled un-occluded versus un-coupled occluded conditions across delivery lengths. N.B. Dotted line indicates chance level response proportion.

3.4.2 BACK FOOT RESPONSE PROPORTIONS

There was a significant main effect of response mode used $F(1,19) = 26.31, p < 0.01, \eta p^2 = .581$, and delivery length bowled, $F(4,76) = 38.91, p < 0.01, \eta p^2 = .672$ on the response proportions made by the participants. There was a nonsignificant main effect of group, $F(1,12) = 2.72, p > 0.05, \eta p^2 = .125$, and occlusion condition, $F(1,12) = 2.96, p > 0.05, \eta p^2 = .135$, on the response proportions made by participants. However, there was a significant 4-way interaction effect of Group x Response Mode x Occlusion condition x Delivery length, $F(4,76) = 7.40, p < 0.01, \eta p^2 = .280$, on the response proportions made by participants. These interactions are displayed in figure 3.7. Bonferroni pairwise comparisons showed greater back foot movement response proportions under un-coupled compared to coupled conditions ($M_{diff} = 19.62\%, SD = 3.82$). Greenhouse Geisser post hoc tests also showed that front foot movement response proportions transition from low percentages to high percentages across full to short delivery lengths (0-3m vs. 3-5m $M_{diff} = 1.77\%, SD = 1.94$, 3-5m vs. 5-7m $M_{diff} = 18.84\%*$, $SD = 2.88$, 5-7m vs. 7-10m $M_{diff} = 0.45\%, SD = 4.01$, 7-10m vs. 10-14m $M_{diff} = 8.02\%*$, $SD = 1.86$), highlighting the need to adapt movement behaviour in response to a change in task demands. Table 3.1 contains a summary of lower level interactional effects that have not been reported in the text.

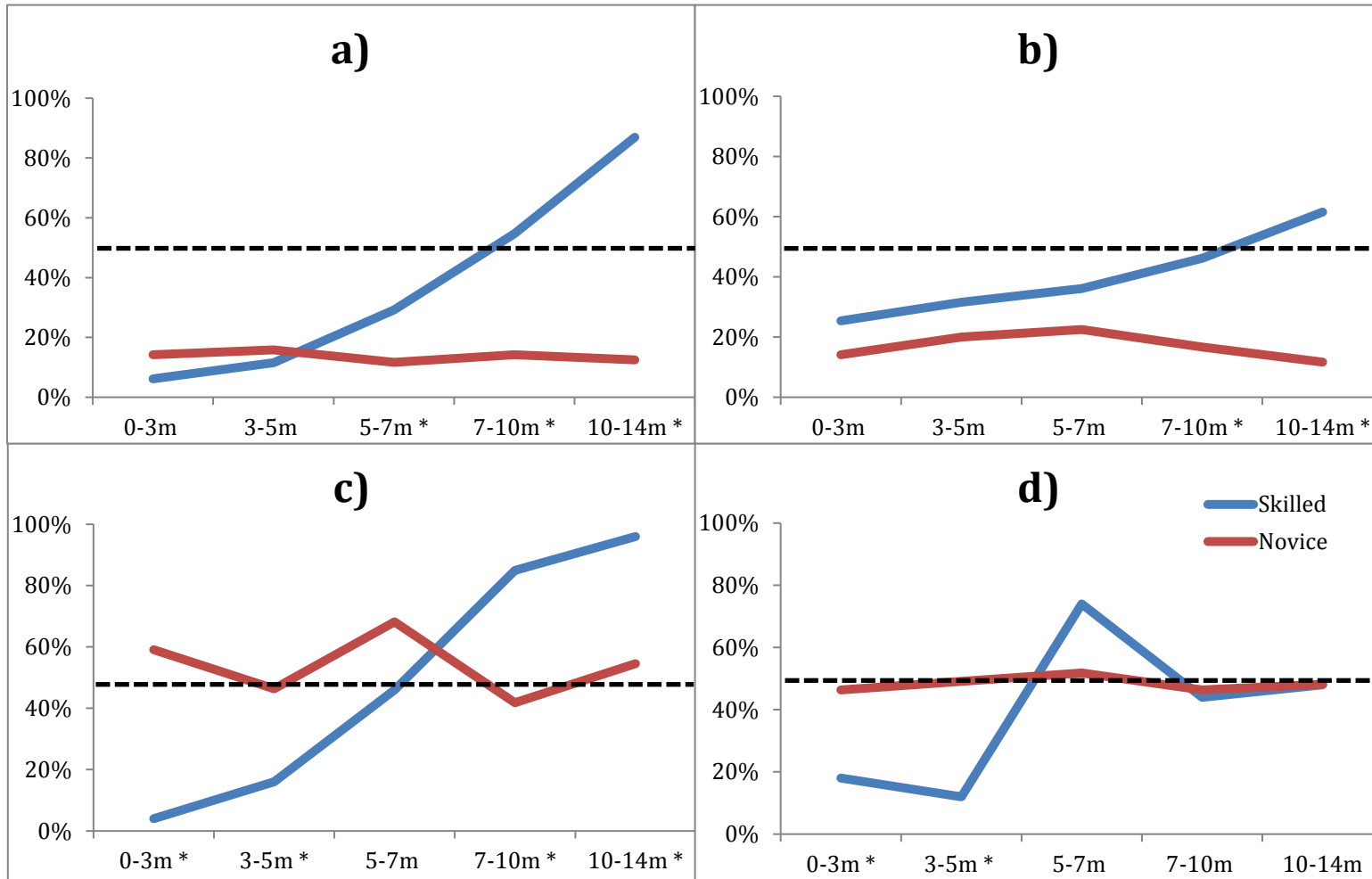


Figure 3.7 A comparison of skilled versus novice back foot movement response proportions across a) Coupled Unoccluded, b) Coupled Occluded, c) Uncoupled Unoccluded, and d) Uncoupled Occluded. N.B. * indicates significant differences between skilled versus novice performance ($p < .05$). Dotted line indicates chance level response proportion.

Table 3.1 Front & Back lower level ANOVA interactional effects.

Interaction	Foot	F	DOF	Sig.	η^2
Response Mode * Group	Front	11.75	(1/19)	.003	0.382
	Back	15.21	(1/19)	.001	0.445
Occlusion * Group	Front	1.24	(1/19)	.279	0.061
	Back	1.24	(1/19)	.279	0.061
Length * Group	Front	43.68	(4/76)	.000	0.697
	Back	43.23	(4/76)	.000	0.695
Response Mode * Occlusion	Front	16.62	(1/19)	.001	0.467
	Back	10.59	(1/19)	.004	0.358
Response Mode * Length	Front	3.97	(4/76)	.025	0.173
	Back	3.36	(4/76)	.039	0.150
Occlusion * Length	Front	10.82	(4/76)	.000	0.363
	Back	11.36	(4/76)	.000	0.374
Response Mode*Occlusion*Group	Front	0.00	(1/19)	1.000	0.000
	Back	0.03	(1/19)	.854	0.002
Response Mode * Length *Group	Front	2.00	(4/76)	.103	0.095
	Back	1.96	(4/76)	.108	0.094
Occlusion*Length*Group	Front	13.47	(4/76)	.000	0.415
	Back	13.14	(4/76)	.000	0.409
Response Mode*Occlusion *Length	Front	0.63	(4/76)	.585	0.032
	Back	0.51	(4/76)	.725	0.026

3.5 DISCUSSION

This study aimed to investigate the interaction between skill level, action specificity, temporal occlusion, and delivery length on cricket batting, primarily, to study if and how cricket batsmen's decision-making behaviours adapted across varying levels of task representation. The experimenters analysed skilled and novice cricket batting performance using a validated representative task design (Chapter 2) across four varied levels of perception and action representativeness; perception – action representative, perception representative, action representative, and un-representative conditions. Analyses revealed a significant interaction between response mode, occlusion condition, delivery length and skill level, illustrating that the aforementioned variables cannot be considered separately, as any manipulation of any of these variables will subsequently affect cricket-batting decision-making behaviour. The research in this chapter reinforces the aforementioned concerns of researchers in the field who suggest that the traditional study of motor behaviour may have been biased (Davids *et al.*, 2005) by experimental designs which are not truly representative of performance environments (Pinder *et al.*, 2011) and have failed to preserve the functional couplings between perception and action (Van Der Kamp *et al.*, 2008). Furthermore, these findings endorse the need for researchers to develop representative task designs, which maintain high levels of fidelity to *in-situ* conditions under controlled conditions to best investigate perceptuo-motor skills. The inferences of this finding for previous laboratory studies, which have previously manipulated one or more of the interrelated variables, are explored further in this discussion.

Under fully representative task conditions, the data shows that skilled performers are able to identify delivery length cues effectively from the representative environment and adapt their

movement response according to the length of delivery bowled. Whilst previous research has shown skilled batsmen are able to adapt their movement response *in-situ* (Pinder *et al.*, 2012) and under representative laboratory conditions (Chapter 2), no research has been carried out into the skill-based differences of performers under representative conditions across a full range of task constraints (delivery lengths). Intriguingly, novice performers adopt a predominately front foot movement response regardless of the length of delivery; typically novices would display chance level behaviour under dichotomous conditions (Muller *et al.*, 2006). This response suggests that novices are unable to recognize the need to adapt their movement patterns in response to varied delivery lengths, either due to an inability to distinguish between differing length cues which are present in the bowler's action and ball flight (Muller & Abernethy, 2006), and, or they do not possess the appropriate task specific movement patterns required for back foot movement shots. By contrast, skilled performers who have developed a vast range of task specific knowledge over years of deliberate practice (Ford *et al.*, 2010) are able to identify relevant informational cues (Muller *et al.*, 2006) and execute the most appropriate movement response to varied delivery lengths. This finding suggests that the difference between skilled and novice performance is the ability to identify and respond effectively to a change in task demands from full (0-5m) to short pitched deliveries (>7m), this difference between skill levels is anecdotally reported frequently by cricket coaches (Woolmer, Noakes, & Moffett, 2008). Researchers have previously identified and labelled this area where a change in decision-making is required to maintain successful task performance as the bifurcation point or decision-making threshold (Pinder *et al.*, 2012, and Chapter 2). Ultimately, skilled performers are able to identify the need for adaptive movement behaviour in response to task demands, whilst novices are unable to identify the need to adapt.

Beyond the construct of previous experiences, and task specific movement patterns, it is still intriguing that the novice group produced a dominant front foot movement response across task constraints, one may have expected novices to produce no foot movement at all, or alternatively, completely erratic and varied foot movements if this was the case. Nonetheless, it is important to take into consideration that these observed differences between novice and skilled performers may have been different if the task was performed *in situ*. Yes, skilled performers were still able to identify the ‘need’ to change their movement response from front foot movement to back foot movement accordingly, but it may be their experience of the *in situ* environment that affords this. Ethics notwithstanding, it is expected that novices would produce a significantly different pattern of behaviours if they were subjected to the *in situ* constraints of the task, specifically, the presence and subsequent threat of a hard, fast moving object would likely see highly variable and un-characteristic foot movements.

Under representative action conditions, the findings show that skilled batsmen are still able to identify delivery length cues from occluded pre-release information to alter their subsequent movement responses. Nonetheless, a decreased range of front foot movements across delivery lengths was identified, starting at a lower response proportion (Occluded = 71% versus Un-occluded = 96% at 0-3m delivery lengths) and finishing at a higher response proportion (Occluded = 39% versus Un-occluded = 14% at 10-14m delivery lengths) compared to un-occluded conditions, shown in figure 3.3. This tapered response may be due to the occlusion of confirmatory ball flight information, which is used to predict ball bounce location (Mann, Spratford, & Abernethy, 2013) and scale subsequent movement responses (Land & McLeod, 2000, and Pinder *et al.*, 2011a). Skilled batsmen also reached the decision-making threshold (50%) at a noticeably shorter delivery length under occluded conditions (Occluded = 7-10m,

versus Un-occluded = >7-10m), further highlighting the importance of confirmatory ball flight to supplement decision-making. Due to the aforementioned nature of the task, novice batsmen demonstrated the same generic response regardless of the occlusion condition. These findings confirm that skilled performers are still able to maintain an expert performance advantage over novice batsman (Muller *et al.*, 2006), but the occlusion of ball flight has a noticeable impact on the scaling of their movement response and decision-making precision.

Under representative perception conditions, skilled batsmen are able to inform similar decision-making behaviour compared to the representative action condition. The data show that batsmen have a similar range of response proportions (Coupled = 96% - 14%, Un-Coupled = 96% - 4%), however, the point at which each condition reaches the decision-making threshold is slightly different, with un-coupled reaching the decision-making threshold earlier than the coupled response. This can be seen in figure 3.4. These findings are incongruent with Mann *et al.*, (2010) who showed that increases in perception – action coupling increases skilled batting performance respectively. They also found that increased levels of perception-action coupling advance the capability of a methodology to differentiate between skilled and novice performers *in situ*. Although a significant difference was found between skilled and novice performance under coupled and uncoupled conditions, these findings show that skilled performance was similar across both coupled and un-coupled conditions – not exemplifying the expert performance advantage. Alternatively, what did differ was the response of the novice performers, who under uncoupled dichotomous conditions displayed chance level response proportions, which ranged from 58% to 32% across delivery lengths in contrast to 87% - 80% under coupled conditions, shown in figure 3.5. Seemingly, the dichotomous task provoked a change in novice decision-making behavior, as the addition of another possible response (other than predominant

front foot movement), and the decreased complexity of the response mode provided the novices with increased affordances to act.

These findings reinforce the earlier suggestion that caution should be taken when implementing and interpreting representative task designs to study skill-based differences in performance. Whilst we have seen uncharacteristic novice behaviours emerge under representative task constraints, we have equally witnessed a difference in expected skilled behaviours (see Mann et al., 2010) under un-coupled conditions. To offer one explanation, under un-coupled conditions, skilled performers are not required by the task to make an on-line response to the experimental stimuli, rather a key press response. Whilst instructed to make the judgment as you would *in situ*, the participants may have viewed the stimuli for the duration (post expected bat – ball contact), allowing for a prospective response that alters the intended nature of the task (van der Kamp, 2003). It can be argued that it is valuable to expose novices to the full constraints of the task at hand in order to get representative differences in skill, however as seen in this chapter, tasks which best reflect the participant population's true skill levels are shown to be most representative of their true ability (chance level decision making behaviour). Which ever is preferred, this study demonstrates that it is important to understand and take into consideration the effect of manipulating task constraints on both skilled and novice performance respectively.

Finally, under unrepresentative conditions, a noteworthy change in skilled behaviour is observed. Skilled performers demonstrate a similar transition in decision making behaviour as seen in previous conditions, however, across short length deliveries their response proportions revert to novice like chance levels (see figure 3.6). This pattern of behaviour is equivalent to that observed for novices under the fully representative condition, whereby they are unable to

identify the task specific cues in order to inform decision-making. This demonstrates that when skilled performers are required to respond under un-coupled occluded conditions they become unable to utilize the same pre delivery cues that they previously used to respond correctly under coupled occluded conditions. These findings imply that when skilled batsmen are not able to produce a naturalistic response, they are less able to draw upon their task specific knowledge bases to make informed decisions (Williams, Davids, & Williams, 1999). Farrow and Abernethy (2003) found that skilled tennis players are able to maintain superior prediction accuracy under uncoupled response conditions, but only under occluded conditions. The findings of this study are not dissimilar, as skilled batsmen are still able to identify when to move forwards, however, once they are subjected to deliveries past the decision making threshold, they lose their expert performance advantage over novice batsmen, who maintain their chance level response proportions.

In summary, the present study aimed to build on the findings of Mann et al., (2010) by identifying the interactions between skill level, response mode, and temporal occlusion and their effect on cricket batting performance. This study primarily advances previous research findings (Mann et al., 2010) by using superior methods that measure the scale of the movement response (foot movement magnitudes) in reaction to a wide but also defined range of task constraints (0m – 14m delivery lengths) in order to model emergent behaviours, e.g. skilled batsmen moved 0.4m forwards to a delivery pitched 3.5m away from the stumps. This is in contrast to previous studies (Mann et al, 2010), which have used very narrow (off vs. on side, dichotomous) and un-specified task constraints (we do not know the magnitude of the direction in which the ball was away from the stumps), making it difficult to distinguish between the informational differences of each stimuli presented. This absence of measurement means that the participants in the study may

have been subjected to more or less difficult stimuli that were not controlled for, depending on how far the ball was travelling away from the stumps. For example, if a delivery were travelling 0.3m vs. 0.1m to the batsman's left hand side it would be easier to distinguish. The advances present in this study allow for the complete analysis of emergent actions and decisions that occur throughout the task (0m – 14m) and provide detailed information of the differences between tasks and populations. As a result, this novel investigation was able to demonstrate that the aforementioned variables are interrelated and sensitive to manipulation; by altering either the response mode and or the occlusion conditions resulted in alterations in the performance of both novice and skilled participants. These results have implications on previous studies that have used dichotomous un-representative response modes and the occlusion paradigm to research perceptuo – motor skills in sports to differentiate between skill levels. Whilst validated representative task designs that match the constraints imposed on experts are needed to study the characteristics of expert performance, exposing novices to these constraints may not be appropriate. For example, the delivery speeds which experts are exposed to may prevent novices from performing the task at hand. As seen in this study, representative task designs are able to capture skilled behaviour best, eliciting the need for adaptive behaviours across task demands; however, they do not seem to be able to reflect naturally observed novice behaviours. In contrast, un-representative task designs are able to reflect typical novice behaviours (at or around chance levels), however, they subsequently lessen the expert performance advantage by muting skilled performers task specific knowledge bases and recall systems. Evidently, the balance of eliciting expert performance and maintaining true novice behaviour is an extremely difficult paradigm. Future research needs to take into consideration that there is no single approach to studying

expert and novice performance; rather a multi disciplinary or factorial approach is required to understand the complex interactions that are present fully.

CHAPTER 4:

UNCOUPLING PERCEPTION AND ACTION: CAN SIMULATION – BASED TRAINING AID ‘REPRESENT’ *IN SITU* TASK DEMANDS?

4.1 ABSTRACT:

In a bid to assess the representativeness of simulation-based training paradigms, this study compares the fidelity of cricket batsman’s responses across three different conditions, live (real action & ball flight), simulated (simulated action & real ball flight), and bowling machine (no action & real ball flight). Under each condition, nine highly skilled batsmen faced a randomized sixty-ball protocol consisting of a balanced number of delivery lengths (short, medium, and full). Batsmen’s foot movement response proportions were used to measure decision-making, whilst foot movement magnitudes, movement initiation and duration times were also recorded. Lastly, subjective ratings of shot selections and executions were recorded to compare performance outcomes across the tasks. The findings show that there was a high degree of fidelity between the live and bowling machine conditions, whilst there was a low degree of fidelity between live and simulated conditions. These findings highlight the fact that simulated tasks must not be assumed to be representative, reinforcing the need for validation of task designs before use in experimental and applied settings.

Key Words: Simulation, Representative Design, Fidelity

4.2 INTRODUCTION:

After continual debate into the limitations of previous methodologies that have been used to study perceptual-cognitive skills in sport (see Davids *et al.*, 2005), there has been a shift towards the use of simulation-based paradigms (e.g. medicine, Greenleaf, 2007, military, Howard, 2008, and aviation, Gheorghiu, 2013), in order to advance current practice. Vignais, Kulpa, Brault, Presse, & Bideau, (2015) state that simulation – based paradigms allow researchers to control and modify the visual information presented, ensuring reproducibility and standardization of protocols more carefully. Equally, simulation – based paradigms allow participants to actively explore task constraints and utilize specific information to guide responses (Araujo, Davids, & Serpa, 2005; Bideau, Kulpa, Vignais, Brault, & Multon, 2010). Although simulation-based paradigms have been considered advantageous, concerns have still been raised over the representativeness of and subsequent skill transfer between simulation-based paradigms and *in situ*.

In their review paper, Van der Kamp *et al.*, (2008) contend that protocols, which do not couple perception with subsequent action, do not represent *in situ* processing. Whilst it has been widely adopted for its experimental control (Mann *et al.*, 2008), Van Der Kamp *et al.*, (2008) argue that the occlusion paradigm investigates perceptual – cognitive skills in isolation by assuming that a single perceptual presentation or process supports anticipation skill, ignoring the contribution of and interdependence between other perceptual and cognitive processes, limiting the current understanding of perceptual – cognitive skills that contribute to sporting performance. In their two – visual system framework, Van Der Kamp *et al.*, (2008) suggest that there are two interacting visual systems which contribute towards successful perceptual – cognitive skill execution; Ventral, which is responsible for perceptual processing and Dorsal, which is

responsible for action processing. Van Der Kamp *et al.*, (2008) endorse the use of a two-visual system model for the study of perceptual – cognitive skills, asking researchers to reconsider the way visual anticipation is investigated by studying the contributions of, and interaction between the two-visual systems. For example, an approach that includes the measurement of both components of visual anticipation (affordance perception and movement control), whilst manipulating task specific information, would allow researchers to identify if manipulations in ventral information subsequently affect dorsal movement control (Van Der Kamp *et al.*, 2008).

Panchuk, Davids, Sakadjian, MacMahon, and Parrington (2013), have provided empirical support of this model whilst manipulating advanced visual information during a one hand catching task. Panchuk *et al.*, (2013) found that catching performance was constrained by the absence of advanced perceptual information from the throwers actions; however, there were no observed differences when advanced perceptual information was present. Stone, Panchuk, Davids, North, and Maynard (2014) found similar results in another ball catching experiment, where under integrated video and ball projection conditions participants catching performance was more successful, with earlier and more persistent ball tracking, larger maximum grip aperture emerging earlier with a slower maximum velocity compared with ball projection only conditions. These results demonstrate that accurate interception requires integration of advanced visual information from both movement kinematics and from subsequent ball flight trajectories. Most recently, Stone, Maynard, North, Panchuk, and Davids (2015), used a novel method that manipulated the synchronisation between advance visual information and its relationship with subsequent ball flight. Interestingly, the researchers found there to be decrements in catching performance when footage of slower throws was paired with faster ball projection speeds. This key finding highlights the importance of coupling advanced visual information and ball flight to

regulate emergent movements. With this in mind, this chapter aims to identify if a simulation-based paradigm, which aims to couple perception and action is able to represent *in situ* task constraints and maintain naturalistic behaviors.

In order to assess and preserve the functionality and action fidelity of methodologies used by researchers and practitioners, Pinder *et al.*, (2011b) proposed the representative learning design framework, which supports the design of dynamic interventions that consider interacting constraints on movement behaviours. Pinder *et al.*, (2011b), explained that functionality would ensure that the degree of success of a performers actions are controlled for, and compared between learning contexts, and secondly, performers were able to achieve specific goals by basing actions in learning contexts on comparable information that exists in the performance environment. These principles closely echo those of the two-visual system (Van Der Kamp *et al.*, 2008), stressing the importance of coupling perceptual information with movement responses. The concept of action fidelity (Stoffregen *et al.*, 2003), has been adopted by researchers to measure the degree of association between task performances, specifically, the level of fidelity of a task can be established through the detailed analyses of movement kinematics and co-ordination between conditions to infer representativeness (Chapter 2).

Renshaw *et al.*, (2007) were the first to investigate the representativeness of cricket batsmen's movement kinematics under bowling machine versus 'real' bowling conditions. The researchers observed significant changes in co-ordination and timing between these conditions. For example, initiation of the batsman's backswing was later and downswing was faster against a bowler compared to the bowling machine. These findings are in support of those found by Shim, Carlton, Chow, and Chae (2005), who demonstrated that tennis players responded later to balls that were projected by a machine compared to a live hitter. Pinder *et al.*, (2011a) investigated co-

ordination and timing further by studying the movement organization of cricket batsmen under 'live', bowling machine, and life-size video conditions. Results showed that each distinct set of task constraints led to significant variations in the patterns of movement control; under bowling machine conditions, removal of advanced information from a bowler's action caused significantly delayed responses, reduced peak bat swing velocities and reduced ball contact qualities, whilst under video conditions, batsmen were able to use pre-delivery information, enabling fidelity of initial behavioral responses consistent with the live condition. Most recently, fidelity of a representative laboratory based protocol was measured and compared to *in-situ* (Chapter 2). Cricket batsmen's foot movement kinematics in response to a range of delivery lengths under *in-situ* and representative laboratory-based (life-size video projection & coupled movement) conditions were measured. Findings showed that there was a degree of fidelity between the two environments, with the representative laboratory task allowing cricket batsmen to make naturalistic movements in response to varied delivery lengths. These findings are a demonstration of how, when combined, Pinder et al.'s (2011b) representative learning design framework, and Stoffregen et al.'s (2003) concept of action fidelity are able to provide researchers and practitioners with a measure of how the studied task reflects the context to which it is intended to generalize.

In a simulation specific study, Vignais *et al.*, (2015) studied the performances of handball goalkeepers between video and simulated paradigms, whilst responding under coupled and uncoupled conditions. Analyses found that goalkeepers were more effective, more accurate, and started to intercept earlier under simulated conditions. Superior performance under coupled simulated conditions versus uncoupled video conditions was also reported, reinforcing the importance of preserving the link between perception and action to maintaining expert task

performance (Van Der Kamp *et al.*, 2008). These results show that well designed, simulated environments can provoke expert performance better than traditional video methods, especially when participants are allowed to engage in coupled action specific responses. However, there is a wealth of simulated task environments, which do not couple perception and action responses (e.g. Howard, 2008), neglecting the interrelated contributions of the two – visual system theory (Van Der Kamp *et al.*, 2008). In addition, little is known about the effects of time latencies and reductions in display fidelities, which have been reported under simulated conditions (Vignais *et al.*, 2015; Miles, Pop, Watt, Lawrence, & John, 2012). These influences may perturb perception and action, potentially impairing performance and causing negative efficacy of training (Li, Patoglu, & O'Malley, 2009). To ensure validity and reliability it is essential that data driven assessments of the degree to which simulated tasks are representative be made (Chapter 2).

In a bid to assess the representativeness of simulation-based paradigms, this study uses Pinder *et al's* (2011b) representative learning design as a framework to compare the action fidelity of batsman's movement responses across three different visual information conditions, live (real action & ball flight), simulated (simulated action & real ball flight), and bowling machine (no action & real ball flight). These task conditions allow for the investigation of Van der Kamp *et al's* (2008) hypothesized two - visual systems framework, primarily, identifying the contribution of ventral (perceptual) based information sources (pre-delivery kinematics) through the gradual uncoupling of visual cues. With this framework in mind, it would be expected that a gradual decrease in fidelity of performance with uncoupling would be present. Due to the presence of pre-delivery information (Pinder *et al.*, 2011a) it would be expected that the simulation-based paradigm would provoke naturalistic behaviours similar to those observed *in situ*, and better than those observed under the bowling machine task. In order to measure the

level of representativeness between tasks, batsmen's adaptive behaviours across delivery bounce heights were compared. Batsmen's foot movement response proportions were recorded as a behavioral expression of a participant's decision-making intent (Araujo *et al.*, 2006); foot movement magnitudes, initiation and duration times, and subjective ratings of shot execution and selections were also recorded to describe the correspondent execution of motor skills. A high degree of fidelity would be established if batsmen's behaviours identified *in situ* were replicated under the simulated action real ball flight or no action real ball flight experimental tasks (Chapter 2).

4.3 METHOD:

4.3.1 PARTICIPANTS:

Nine highly skilled junior male cricket batters (age: 17.5 ± 3.8 years), with 7.9 ± 2.33 years playing experience and two right-arm medium-fast bowlers (age: 18.6 ± 1.2 years) with 8.34 ± 1.32 years playing experience with similar conventional bowling actions and physical attributes (average height of release: 2.19 ± 0.10 m; average bowling speed: 35.53 ± 0.65 m.s⁻¹) were recruited to take part in this study. All participants were members of a county cricket academy program and regularly competed in regional first division and county age group competitions in the UK. Each participant engaged in at least four structured and two unstructured cricket specific activities per week. Participants provided informed consent prior to testing and ethical clearance was received from the local institutional ethics and governance committee.

4.3.2 DESIGN AND PROCEDURE:

In order to identify fidelity of cricket batting performance, cricket batsmen's adaptive movement behaviours were analysed under live, bowling machine, and simulated tasks, in relation to delivery bounce heights. In order to control for variations in inter-individual anthropometrics and their subsequent effect on responses, batsman's responses in relation to delivery bounce heights rather than delivery lengths were measured to enable deliveries to be scaled to batsman's height.

4.3.2.1 Live Task – Experimental Task Constraints Identification: The live condition was completed first as an indicator of batsmen’s *in situ* adaptive movement behaviours (Araujo *et al.*, 2006, & see Chapter 2) across a range of delivery characteristics (lengths, bounce heights & speeds). Two medium – fast bowlers were instructed to bowl a thirty-ball protocol at each batsman, randomised by delivery length. Analyses revealed that in order to represent the live bowling condition, the simulation-based paradigms should deliver the ball at speeds of 35.53 m.s^{-1} ($\pm 0.65 \text{ m.s}^{-1}$) and at a release height of 2.19m ($\pm 0.10\text{m}$) across a range of delivery lengths.

4.3.2.2 Simulated Task Construction: In order to simulate the task constraints present in the live condition, the same two medium – fast bowlers were instructed to bowl (located 18.90m from the bowling crease at the batsman’s end) towards three delivery length regions from the batsman’s stumps. Each delivery region targeted specific length thresholds that provoke different bounce heights. These consisted of a) “Full” ($0\text{-}6\text{m}$), b) “Neutral” ($6\text{-}8\text{m}$) and c) “Short” ($8\text{-}14\text{m}$) delivery lengths. The simulated video footage of the bowlers was filmed (Sony Handycam HDR-TD10E, Tokyo, Japan) from the batter’s preparatory position on the batting crease and at a height of 1.76m . The camera was positioned, zoomed, and focused to replicate a batsman’s natural viewing perspective. Another high definition video camera (Canon LEGERIA HF R46, Tokyo, Japan) was positioned parallel to the pitch to record ball flight characteristics of the bowlers’ deliveries, see Figure 4.1 for camera set up. Delivery length was measured from the point of ball bounce to the base of the stumps at the batter’s end. Calibration was attained using horizontal and vertical references of a known distance. Bowler’s deliveries were selected for inclusion based on meeting the specified length criteria, following a middle stump to off side line, whilst displaying no noticeable characteristics (e.g. background information), to prevent a

learning effect. The footage was then edited into 12 single deliveries (2 deliveries x 3 delivery lengths x 2 bowlers), and programmed into a ProBatter® cricket simulator (ProBatter Sports, Milford, CT), which pairs the video of the bowlers kinematics with its corresponding ball flight characteristics (see Figure 4.2).

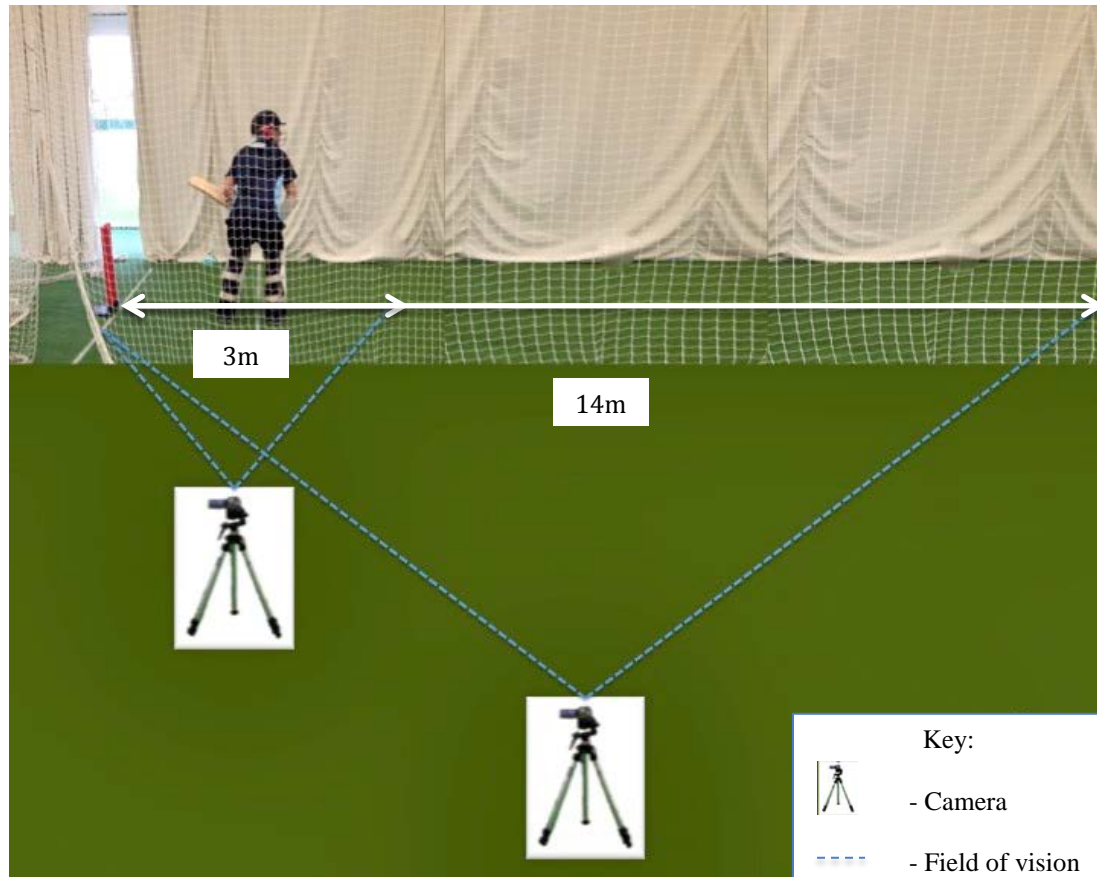


Figure 4.1 A schematic showing the positioning of cameras used to record the *in-situ*, bowling machine, and ProBatter movement analysis.



Figure 4.2 A demonstration of the fully simulated experimental task, which pairs life sized two-dimensional video with corresponding ball flight characteristics.

4.3.3 EXPERIMENTAL TASKS

The following experimental tasks were not counter-balanced. The decision to do so was purely logistical, as the researchers only had limited access to the simulated task facilities as well as the skilled participants that were used in this study.

4.3.3.1 Live Task. Testing took place in a specialized indoor cricket training facility on a pitch that was set up according to the International Cricket Council (ICC) pitch regulations. Prior to an analysis, a sport specific warm-up and a 12-ball (6 deliveries per bowler) familiarization protocol were carried out. Batsmen were instructed to play naturally whilst keeping (i.e., protecting) their wicket; they were set a standard medium – fast pace field setting scenario in attempt to replicate on-field constraints. The bowlers were instructed to bowl a randomized sixty-ball protocol consisting of a balanced number of full, medium, and short-pitched deliveries. The protocol consisted of 10 blocks of 6 trials, alternating blocks between bowlers (60 deliveries total, 30 deliveries per bowler).

4.3.3.2 Bowling Machine Task. Testing took place on the same indoor training pitch to control for variation in ball bounce. Prior to an analysis, the same sport specific warm-up and a 12-ball familiarization protocol were carried out. Batsmen were given the exact same playing instructions and set the same field positions, as in the live condition. The experimenters used a BOLA Professional Bowling Machine® (Bristol, UK), which was set up to replicate the delivery speeds and release height of the live condition. The machine was controlled by an ECB level 3 qualified coach who was instructed to follow a randomized sixty-ball protocol.

4.3.3.3 Simulated Task. The simulated system was set up on a pitch adhering to International Cricket Council (ICC) regulations. Prior to an analysis, the same sport specific warm-up and a 12-ball familiarization protocol were carried out. Batsmen were given the exact same playing instructions and set the same field positionings as in the live condition. The experimenters carried out the fully simulated condition using a ProBatter® bowling-machine (ProBatter Sports, Milford, CT), which was set up to replicate the delivery speeds of the live condition, however, ball release height was fixed at a height of 2.18m. The simulator was pre-programmed with a pseudo randomized sixty-ball protocol in which the delivery length was varied between short, good and full. The protocol consisted of 10 blocks of 6 trials, allowing a short period of rest after each block to simulate a change of bowling.

4.3.4 DATA COLLECTION

Two high definition (1080p) video cameras (Canon LEGERIA HF R46, Tokyo, Japan, & Sony Handycam HDR-TD10E, Tokyo, Japan) were positioned parallel to the pitch (also displayed in Figure 4.2) to record the batsman's movement kinematics and corresponding delivery bounce heights; measured vertically as the distance from the point of bat-ball contact (or if the batsmen had missed the ball, the point at which the ball crossed the batting crease) down to the ground. Calibration was attained using horizontal and vertical references of known distances. Video footage was then calibrated for distance using Silicon Coach Pro 7 software (Dunedin,

New Zealand) to record measurements. Once calibrated, each front and back foot movement distance was measured in correspondence with delivery bounce height.

4.3.5 MEASURES

Each foot was fitted with a marker at the head of the talus. This anatomical marker was used to measure foot movement direction as an indicator of batsmen's decision-making behaviour about delivery length. Each measure was taken from the last frame before the foot had lifted off from the ground, until the first frame that the foot had been fully placed onto the ground. Inter- and intra-rater reliability were assessed on the same 100 trials. Strong correlations were found for both intra- ($r = .92$) and inter-rater ($r = .89$) reliability.

4.3.5.1 Foot movement response proportion. Foot movement response proportions were calculated for front foot and back foot separately as well as forwards and backwards movements. For each foot and foot movement direction, the number of movements made within that 1m-delivery length region was calculated as a percentage of the total number of deliveries landing in that 1m region. This allowed the experimenters to identify typical responses across the fourteen 1m regions.

4.3.5.2 Foot movement magnitude. Foot movement magnitude was defined as the forwards-backwards direction (+/-) and distance (m) that each foot moved during shot execution.

4.3.5.3 Movement Initiation. Defined as the moment in time, which a definitive cricket shot was initiated (after any pre-stroke routine trigger movements had been made) in relation to the ball release time point.

4.3.5.4 Movement Duration. Defined as the time taken from initiation of a definitive cricket shot to bat – ball contact (or estimated contact if no contact had been made i.e. the moment in time the bat and the ball passed in space).

4.3.5.5 Shot Selection. A subjective rating given by two ECB level 2 coaches as to the quality of shot selection made in relation to delivery bowled. The coaches were instructed to judge selection of the respective shot by its pertinence to the delivery bowled.

4.3.5.6 Shot Execution. A subjective rating given by two ECB level 2 coaches as to the quality of the bat – ball contact made. The coaches were given guidelines as to what constituted to a rating of 0, 5, and 10 in order to guide their ratings. A rating of 0 was to be awarded when no bat – ball contact had been made, 5 when bat – ball contact had been made, but the ball did not travel in the intended direction and trajectory of the batsman, and 10 when bat – ball contact was made and the ball travelled in both the intended direction and trajectory.

4.3.6 DATA ANALYSIS

The live, bowling machine, and simulated performance data were grouped by six delivery bounce height intervals (0.2 – 0.4m, 0.4 – 0.6m, 0.6m – 0.8m, 0.8m – 1.0m, 1.0m – 1.2m, &

1.2m – 1.4m). Intra-class correlation coefficient analyses were used to measure the degree of agreement between live, bowling machine, and simulated foot movement response proportions and magnitudes across delivery bounce height intervals. Furthermore, two-way, within-participant ANOVAs with task (live, BF, and simulated) and delivery bounce heights (0.2 – 0.4m, 0.4 – 0.6m, 0.6m – 0.8m, 0.8m – 1.0m, 1.0m – 1.2m, & 1.2m – 1.4m) were used to analyse participants' foot movement response proportions and magnitudes separately. The same analyses were carried out to investigate the effects of movement times, shot execution and selection across tasks and delivery bounce height intervals. Significant effects of ANOVA were followed up using Bonferroni corrected dependent samples t-tests. When assumptions of ANOVA were not met, then a non-parametric equivalent was used and followed up using a Wilcoxon signed ranks test. The data is presented as a mean and standard deviation, whilst effect sizes were reported as Partial eta-squared (ηp^2) values, using the following benchmarks to establish the size of the effect observed; small = 0.1, medium = 0.3, and large = 0.5 (Field, 2009).

4.4 RESULTS

4.4.1 FOOT MOVEMENT RESPONSE PROPORTIONS:

The effect of Condition was not significant, $F(1,3) = 0.29$, $p > 0.05$, $\eta p^2 = 0.04$. There was a significant main effect of Bounce height, $F(1,6) = 103.35$, $p < 0.01$, $\eta p^2 = 0.93$. However, this effect was superseded by a significant interaction effect of Bounce x Condition, $F(2,18) = 6.61$, $p < 0.01$, $\eta p^2 = 0.40$, on the response proportions made by participants. These interactions are displayed in Figure 4.3. Bonferroni corrected t-tests showed that response proportions were greater for the live and bowling machine tasks compared to the simulated task at 0.4m bounce height ($M_{diff} = 20.74\%$, $SD = 6.23$) and this effect was reversed at the 1.20m ($M_{diff} = 39.55\%$, $SD = 9.75$) bounce height. All other effects were not significant.

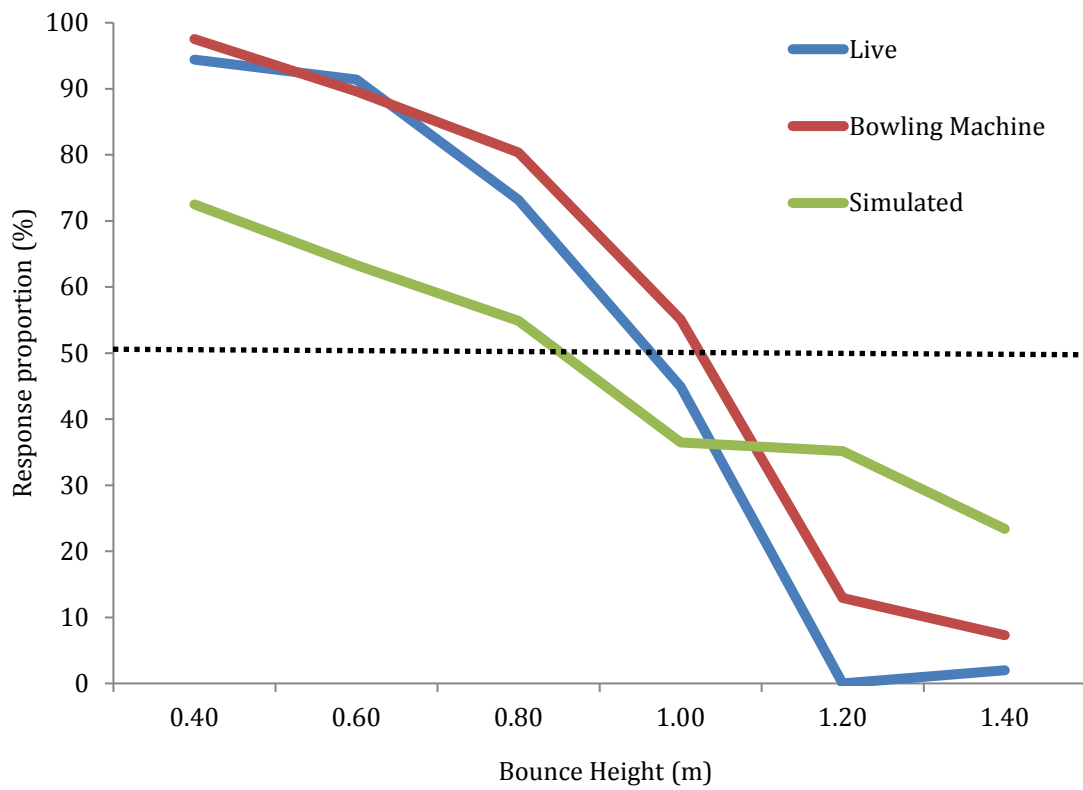


Figure 4.3 Batsmen's front foot movement response proportions across each delivery bounce height interval between tasks. The dotted line is used to indicate chance level behaviour (50%), and is reflective of a decision-making threshold.

4.4.2 FOOT MOVEMENT MAGNITUDES

There was a non-significant main effect of Task, $F(1,3) = 1.34, p > 0.05, \eta p^2 = 1.62$, on the movement magnitudes made by participants. There was a significant main effect of Bounce height, $F(1,6) = 116.07, p < 0.01, \eta p^2 = 0.94$. However, this effect was superseded by a significant interaction effect of Bounce x Task, $F(2,18) = 7.48, p < 0.01, \eta p^2 = 0.51$, on the movement magnitudes made by participants. This interaction is displayed in Figure 4.4. Bonferroni corrected t-tests showed significant differences between live and bowling machine tasks, finding smaller bowling machine foot movement magnitudes at the 1.20m ($M_{diff} = 0.14m, SD = 0.03$) and 1.40m ($M_{diff} = 0.14m, SD = 0.00$) intervals, whilst tests between live and simulated tasks showed greater live foot movement magnitudes at the 0.4m interval ($M_{diff} = 0.17m, SD = 0.04$) and smaller simulated foot movement magnitudes at the 1.20m ($M_{diff} = 0.18m, SD = 0.05$) and 1.40m ($M_{diff} = 0.19m, SD = 0.04$) intervals. All other effects were not significant.

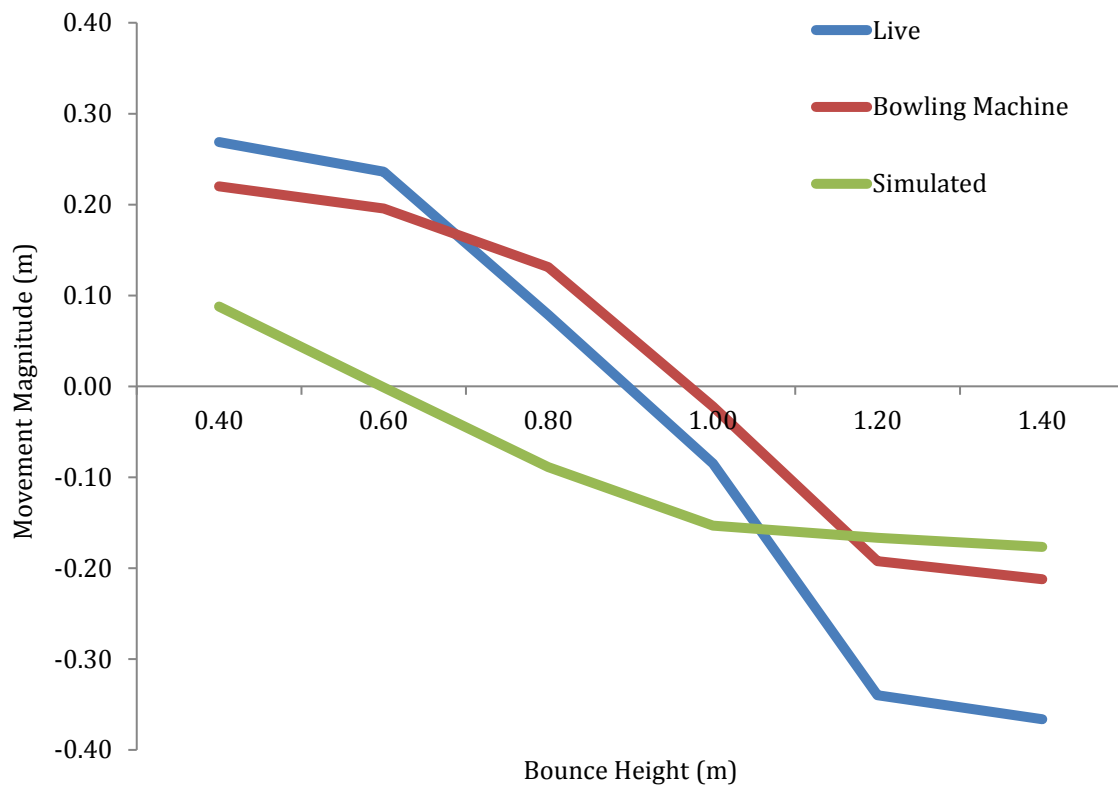


Figure 4.4 Batsmen's front foot movement magnitudes across each delivery bounce height interval between tasks. The solid line is used to indicate neutral movement magnitudes.

4.4.3 MOVEMENT INITIATION TIMES:

There were no significant difference between the live, bowling machine, or simulated tasks at the 0.4m ($\chi^2(2) = 0.75, p > 0.05$), 0.6m ($\chi^2(2) = 3.25, p > 0.05$), 0.8m ($\chi^2(2) = 2.50, p > 0.05$), 1.0m ($\chi^2(2) = 2.50, p > 0.05$) and 1.2m ($\chi^2(2) = 3.00, p > 0.05$) bounce heights. However, there was a significant difference between the live, bowling machine, or simulated tasks at the 1.4m ($\chi^2(2) = 7.75, p < 0.05$) bounce height. Wilcoxon signed ranks tests identified significant differences between bowling machine and simulated movement initiation times ($Z = -2.19, p = 0.02$) showing greater movement initiation times under the simulated task. Whilst no significant differences were found between live and simulated, and live and bowling machine tasks ($p > 0.05$).

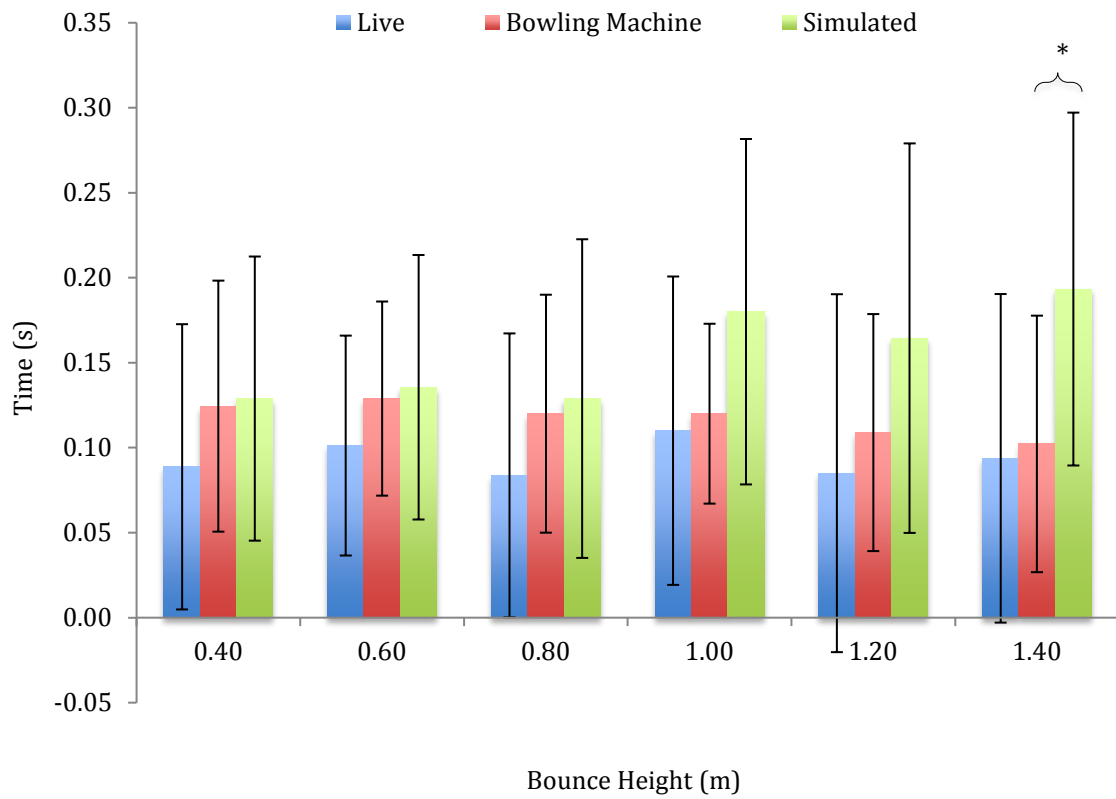


Figure 4.5 Batsmen's movement initiation timings across delivery bounce heights between tasks.
 N.B. * indicates significant differences between tasks ($p < .05$).

4.4.4 MOVEMENT DURATION TIMES:

There were no significant differences between the live, bowling machine, or simulated tasks at the 0.4m ($\chi^2(2) = 1.75, p > 0.05$), 0.6m ($\chi^2(2) = 4.75, p > 0.05$), 0.8m ($\chi^2(2) = 0.75, p > 0.05$), 1.0m ($\chi^2(2) = 3.25, p > 0.05$) and 1.2m ($\chi^2(2) = 3.00, p > 0.05$) bounce heights. However, there was a significant difference between the live, bowling machine, or simulated tasks at the 1.4m ($\chi^2(2) = 6.25, p < 0.05$) bounce height. Wilcoxon signed ranks tests identified significant differences between bowling machine and simulated movement initiation times ($Z = -2.19, p = 0.02$) showing shorter movement duration times in the simulated task. Whilst no significant differences were found between live and simulated, and live and bowling machine tasks.

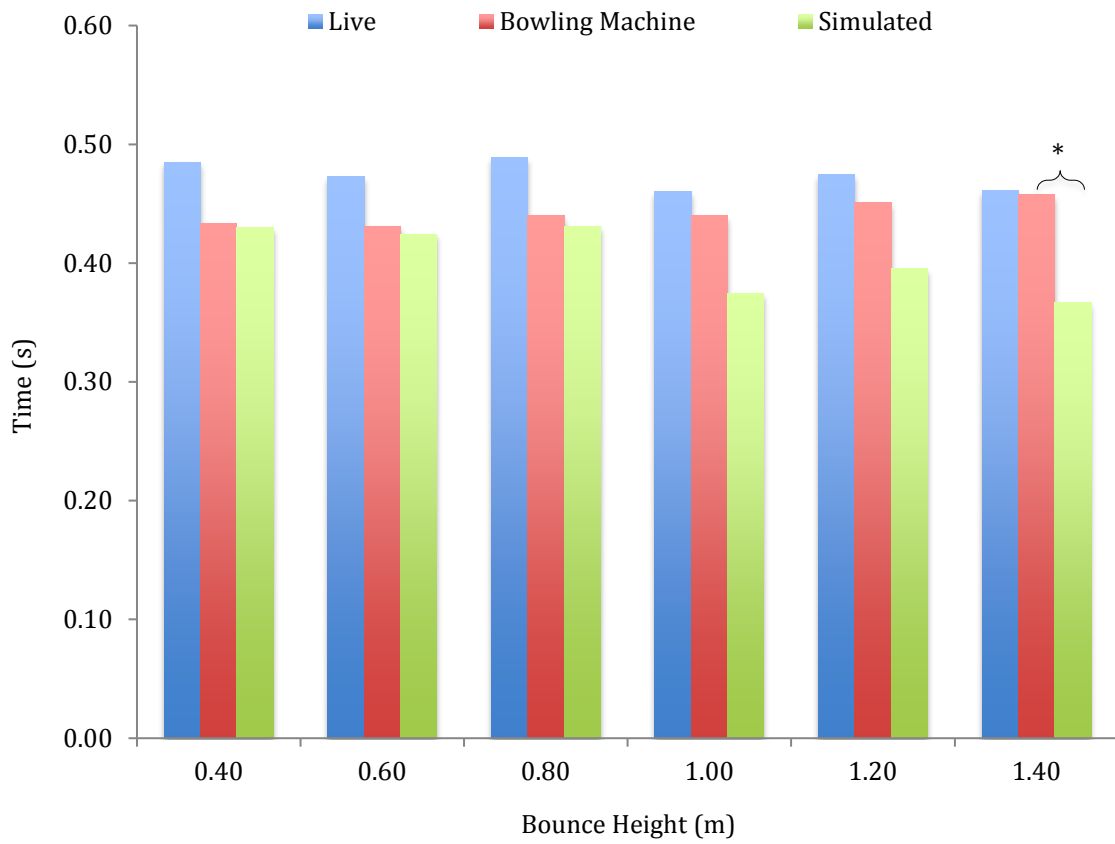


Figure 4.6 Batsmen's movement duration timings across delivery bounce heights between tasks.

N.B. * indicates significant differences between tasks ($p < .05$).

4.4.5 SHOT SELECTIONS:

There was a significant main effect of Task, $F(1,3) = 10.90, p < 0.01, \eta^2 = 0.60$, on the shot selections made by the participants, Bonferroni corrected t-tests revealed significant differences between bowling machine versus simulated tasks ($M_{diff} = 2.09, SD = .47$), with greater shot selection qualities being made under the bowling machine task. These interactions are displayed in Figure 4.7. There was a non-significant main effect of delivery bounce height, $F(1,6) = 0.35, p > 0.05, \eta^2 = 0.05$. There was also a non-significant interaction effect of Bounce x Task, $F(2,18) = 0.59, p > 0.05, \eta^2 = 0.07$, on the shot selections made by participants.

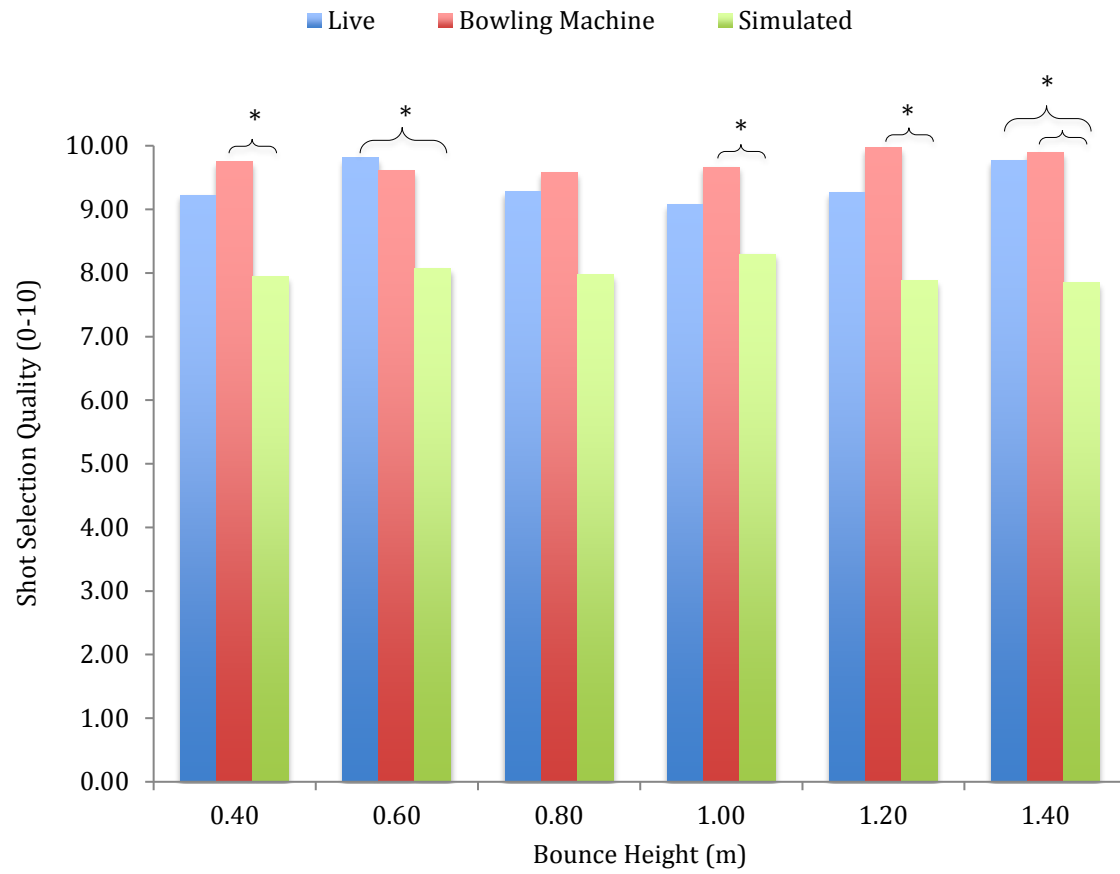


Figure 4.7 Batsmen's shot selection qualities across delivery bounce heights between tasks. N.B.

* indicates significant differences between tasks ($p < .05$)

4.4.6 SHOT EXECUTIONS:

There was a significant main effect of Task, $F(1,3) = 16.44$, $p < 0.01$, $\eta p^2 = 0.70$, on the shot executions made by the participants. Bonferroni t-tests revealed significant differences between live versus simulated tasks ($M_{diff} = 3.48$, $SD = .74$), with greater shot execution qualities under live conditions, and bowling machine versus simulated tasks ($M_{diff} = 2.45$, $SD = .58$), with greater shot execution qualities under the bowling machine task. There were non-significant main effects of Bounce height, $F(1,6) = 1.48$, $p > 0.05$, $\eta p^2 = 0.17$, on the shot executions made by the participants. There was also a non-significant interaction effect of Bounce x Task, $F(2,18) = 1.37$, $p > 0.05$, $\eta p^2 = 0.16$, on the shot selections made by participants. These interactions are displayed in Figure 4.8.

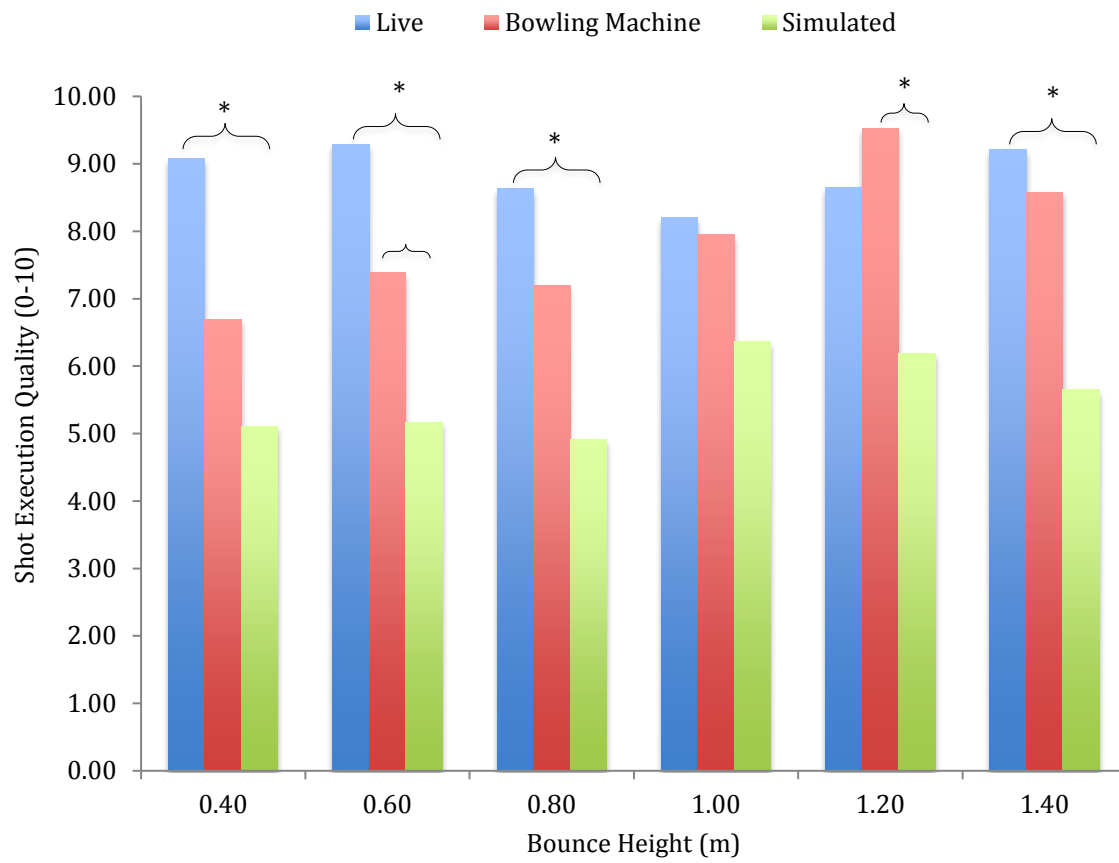


Figure 4.8 Batsmen's shot execution qualities across delivery bounce heights between tasks.

N.B. * indicates significant differences between tasks ($p < .05$)

4.5 DISCUSSION:

The primary aim of this study was to investigate the effect of graded uncoupling of ventral (perception) based information sources on decision-making skill and subsequent adaptive movement behaviours. In contrast to our predictions, the results showed that under the fully simulated task batsmen were unable to utilize the same level of information present *in-situ* to guide representative decision-making behavior. Additionally, it was found that bowling machines are able to provoke representative decision making behaviours better than the simulated task, with no significant differences compared to *in situ* across delivery bounce heights. Interestingly, these findings do not support those proposed by the two – visual system theoretical framework (Van Der Kamp *et al.*, 2008), and representative learning design (Pinder *et al.*, 2011b), and are in contrast to the findings of Panchuk *et al.*, (2013), and Stone *et al.*, (2014).

However, it is important to note three things, firstly, the cues that are presented by the simulator may not be veridical or representative. In this case, the degradation between *in situ* and two-dimensional video visual information may serve to evoke differences in perception and subsequent actions (Dhimi, Hertwig, & Hoffrage, 2004). Previous studies have shown there to be no effect of level of detail (Vignais, Bideau, Craig, Brault, Multon, Delamaeche, & Kulpa, 2009), or visual blur (Mann *et al.*, 2010 and Mann, Ho, De Souza, Watson, & Taylor, 2007) on task specific performance, whilst cricket specific studies have also been able to identify a high degree of fidelity of actions under life sized video tasks (Chapter 2 & Pinder *et al.*, 2011a). Whilst, there have been a select number of studies that have coupled life sized video display with real ball flight characteristics recently (Panchuk *et al.*, 2013, Stone *et al.*, 2014, & Stone *et al.*, 2015), they have experimented under considerably slower temporal constraints in comparison to

this study (50 – 60km/h versus 130km/h). With this in mind, it is a consideration that at these temporal constraints the integration of real ball flight characteristics with two-dimensional video displays may inhibit with the interdependent nature of the dual visual system, as previous studies have established fidelity under two dimensional video conditions alone (Chapter 2 & Pinder *et al.*, 2011a). Secondly, as suggested by Miles *et al.*, (2012) and identified by Stone *et al.*, (2015) there may be significant time latencies or a level of desynchronisation present which could affect perception – action coupling. Third, it should be noted that under the bowling machine task there are subtle cues that are available to batsmen (e.g. angle of ball projection machine & pre-delivery routine), which have been learned through previous experiences to counteract the removal of pre-delivery information and aid decision-making (Renshaw *et al.*, 2007). Comparatively, as the simulation task was a novel experience for participants irrespective of familiarization, it is highly likely that there was not an adequate habituation period to allow the participants to fully acclimatise to the simulated task constraints. In retrospect, this study would have benefitted from a longitudinal approach that would have enabled participants to be monitored over a period of time. This approach may have provided useful information as to how skilled participants habituate to new training methods, and if acclimatised, provided a more accurate assessment of task representativeness in comparison to *in situ*.

With these considerations in mind, it is important to understand how each set of task constraints effect subsequent adaptive movement behaviours. Results revealed a significant interaction effect of delivery bounce height and task on foot movement magnitudes. Specifically, under both bowling machine and simulated tasks batsmen were unable to scale their movement magnitudes fully to match those of *in situ*. These findings are in support of Renshaw *et al.*, (2007), who also found that batsmen adjust their shot specific movement responses under the

bowling machine task versus *in situ*, producing smaller step lengths as well as lower peak backswing heights. This demonstrates that although the decision-making behaviours of batsmen in the bowling machine task are not significantly different, their subsequent movement responses are. This finding reinforces the notion that the removal and or any manipulations in presentation of pre delivery kinematics, which contains advance cues as to where the ball is being delivered (Davids *et al.*, 2005), may interfere with the interdependent nature of the proposed two-visual system (see Panchuk *et al.*, 2013, & Stone *et al.*, 2014), restricting a batsman's ability to scale their movement responses fully, for example, simulated movement may evoke a scaling of the movement based on information from ventral processing stream as opposed to the dorsal stream thought to be used in the live condition (see Stone *et al.*, 2015).

In order to examine why batsmen were unable to produce fully scaled responses, their respective movement initiation and shot duration times were studied. The results revealed a significant interaction effect of delivery bounce height and task on foot movement times, with batsmen initiating their movements later under the simulated task compared to the bowling machine task, whilst no significant differences were observed between *in situ* and bowling machine tasks. Previously, Renshaw *et al.*, (2007) also found there to be no differences between skilled batsmen's *in-situ* and ball flight simulated movement initiation times, whilst Pinder *et al.*, (2011a) observed batsmen initiating movements earlier *in-situ*, and Gibson and Adams (1989) conversely saw batsmen initiating movements earlier under bowling machine conditions. Additionally, a significant interaction effect of delivery bounce height and task on foot movement duration times was also found, with batsmen producing shorter duration movements in the simulated task compared to the *in-situ* and bowling machine tasks, a novel measure which has not been reported in literature before. Together, these results provide insight as to why

batsmen produce smaller scale movements under fully simulated task conditions; initiating their movements later, resulting in less available time to execute a adequate movement in response to what is already a very time sensitive task (Weissensteiner *et al.*, 2008).

Lastly, the impact of scaled movements and increase in time constraints had on a batsman's qualitative shot selection and executions was assessed. The results revealed a significant main effect of task on shot selection, with batsmen selecting greater quality shots under the bowling machine task compared to the simulated task, whilst there were no significant differences between *in – situ* and simulated tasks. A significant main effect of Task on shot execution was also found, with batsmen executing greater quality shots under *in situ* and bowling machine tasks compared to simulated tasks, whilst there were no significant differences between the *in – situ* and bowling machine tasks. To the author's knowledge, there have been no previous investigations into the quality of subsequent shots under changing task constraints. In this instance, this study identified that any alteration in task constraints leads to differences in the selection and execution of skills. This finding is important for both research and applied practice, highlighting that in order to study or learn skills efficiently, engaging in tasks that are considered to be 'representative' may lead to alterations in the execution and subsequent outcome of the skill in question. A concern previously described by Miles *et al.*, (2012), who state that caution should be taken when using simulation to train motor skills, suggesting that there is a danger that a skills may be trained incorrectly resulting in a potential negative transfer to the performance environment.

In summary, the results suggest that under simulated task conditions, batsmen are unable to utilize the same level of information as *in situ*, resulting in responses which are initiated later, shorter in magnitude, less appropriate, and executed inferiorly to those observed *in situ*. Notably,

through integrating quantitative and qualitative descriptive statistics it has been demonstrated that it is not only important to identify the fidelity of decision making behaviours in question, but also their subsequent effect on motor control, thus allowing researchers and coaches to understand the impact of changes in task constraints have on performance fully. Whilst these findings are novel and insightful, further investigations are needed to clarify the presence and subsequent effects of time latencies on performance, possibly by manipulating the coupling or synchronisation of presented ball release and actual ball release as previously carried out by Stone et al., (2015). These investigations may provide insight into the interdependent functioning of dorsal and ventral streams and their subsequent contributions to perception and action under task constraints that are representative to the fast paced interceptive actions. As discussed earlier, further research needs to consider the possibility that simulated performance may improve as a function of practice. If so, what is the transfer of this learned behaviour to the performance environment, does it supplement or degrade decision-making performance?

CHAPTER 5: EPILOGUE

5.1 THESIS AIMS:

The principal aim throughout this thesis was to answer the question “what simulation environment is representative enough?” when using experimental task designs to study perceptual-cognitive skill in sport. In order to answer this question, Chapter 2 aimed to model the emergence of adaptive behaviours, and subsequent decision-making intentionality (Araujo *et al.*, 2006) under a broad range of task constraints *in situ*. A novel method for recording foot movement magnitudes was developed and provided a benchmark of naturally occurring behaviours required to make data driven assessments of task representativeness.

Once this model was evaluated, it was used in Study 2 to investigate the representativeness of a simulated laboratory task, which used life-sized displays and fully coupled action responses. In order to do so, the fidelity (Stoffregen *et al.*, 2003) of adaptive movement behaviours between *in situ* and representative conditions was assessed. This method of evaluation provided objective evidence on the degree of representativeness in a laboratory task, and a referent of its generalizability and transfer to *in situ* conditions. The level of test re-test reliability of perceptual cognitive skill tests was also identified, something that has not been reported in previous literature, as well as the construct validity of the representative task. These measures were all aimed at providing a comprehensive evaluation of the external and internal validities of the representative task in question; an important process for evaluating representative tasks to study perceptual – cognitive skill.

Previously, the use of dichotomous responses as well as occlusion paradigms has been critiqued (Van Der Kamp *et al.*, 2008). In order to understand the dynamics of representative

laboratory based tasks more fully, Chapter 3 aimed to describe how manipulations in the level of task representation affect subsequent adaptive behaviours; specifically, how changes in action representativeness and occlusion of task specific information affected both skilled and novice performance. These findings have provided knowledge on the most appropriate methodology to study this behaviour under controlled laboratory conditions accordingly.

Finally, the question “can simulation-based training aids ‘represent’ *in situ* task demands?” was asked. The work of Pinder *et al’s* (2011b) representative practice design framework provided a theoretical backdrop, again, with the aim of providing data driven assessments of the representativeness of representative practice tasks. Additionally, the experimental manipulation used allowed further investigation of Van Der Kamp *et al’s* (2008) qualitatively different processes engaged when occluded and non-occluded stimuli are used (Panchuk et al., 2013, Stone et al., 2014 & 2015). The findings of which will intend to advance the theoretical frameworks proposed by both Pinder *et al.*, (2011b) and Van Der Kamp *et al.* (2008), whilst informing applied practice.

5.2 PRINCIPAL FINDINGS:

In chapter 2, the emergent behaviours and subsequent decision making intentionality of skilled cricket batsman were modelled successfully across a broad range of delivery lengths *in situ*. PROBIT analysis identified a high probability of front foot movement responses to deliveries that landed 0-7 m from the base of the batters stumps, at 7-8m no dominant foot movement response was evident, and a low probability of front foot movement responses was shown at 8-14m from the stumps. This pattern was reversed for the back foot movement responses. Whilst these support the existing findings of Pinder *et al.*, (2012), who previously identified the presence of a meta-stable region of emergent behaviours in cricket, the results demonstrate for the first time that emergent behaviours can be modelled across a broad range of constraints *in situ* in order to measure decision-making intentionality (as suggested by Araujo *et al.*, 2006). The analysis method (PROBIT) used to measure and benchmark the probability of a response across a decision-making threshold advances previous literature in perceptual – cognitive skill in sport, allowing for the prediction of likely responses of participants across task constraints. Subsequently, using the front foot movement transitions modelled *in situ*, the representativeness of a simulated laboratory based task was analysed. The findings showed significant intra-class correlations between *in situ* and laboratory conditions for front and back foot movement magnitudes. Therefore, changes in foot movement magnitudes *in situ* were strongly associated with changes in foot movements under laboratory conditions. Also, a similar shape of probability curve was generated from PROBIT foot movement models for both of these conditions, indicating that a general pattern of response was maintained between conditions; potentially due to the same, or at least, co-varying informational variables required for forwards

– backwards movement decision making being present. Further to this, strong positive correlations were found between test and re-tests, with no significant differences found between trials, as well as significant skill based differences between skilled versus novice front and back foot movements across 7-14m delivery lengths. This study is the first of its kind, providing a pioneering objective approach to substantiating claims of task representativeness, test re-test reliability, and construct validity through modelling behavioural responses under different task constraints.

In chapter 3, the initial findings of Chapter 2 were furthered by detailing the dynamics of how manipulations in the level of task representation (coupled, uncoupled, occluded, & unoccluded) effect subsequent adaptive behaviours of skilled and novice participants. Analyses revealed that manipulations in response mode affect both skilled and novice performance, with skilled participants improving performance as a function of coupled responses. However, when the amount of information presented was occluded, skilled participants were still able to maintain task performance under coupled, but not uncoupled conditions. Whilst novices adopted a forward's movement response bias under coupled conditions and performed at chance levels under uncoupled conditions. It is important to note that novice behaviours were unaffected by the level of information presented to them under both coupled and uncoupled conditions. Although previous studies have been able to identify significant differences under varied response modes (Mann *et al.*, 2010), occlusion conditions (Muller *et al.*, 2006), delivery lengths (Pinder *et al.*, 2012), and skill levels (McRobert *et al.*, 2009) independently. The analyses carried out in Chapter 3 demonstrate the interrelated nature of the aforementioned variables, emphasising that they cannot be considered separately, as any manipulation of these variables will subsequently affect task performance. Other novel findings in this chapter include the first investigation into

the skill-based differences of adaptive movements under representative task constraints. The data showed that skilled batsmen were able to identify delivery length cues in order to adapt their movement response, from full (0-5m) pitched deliveries which predominately require a front foot movement response to short pitched deliveries (>7m) which require a back foot movement response, whilst novices adopted a predominate and persistent front foot movement response regardless of length. These findings propose that the difference between skilled and novice performance is the ability to identify the need for adaptive movements in response to changes in task demands, possibly as a result of their superior task specific knowledge bases (Ford *et al.*, 2010). Additionally, when novices are not required to make naturalistic responses, and are presented with a dichotomous key press response instead, they exhibit typical novice like chance level behaviours (32% - 58%) across the range of delivery lengths. However, whilst skilled batsmen are able to maintain the expert performance advantage under dichotomous key press conditions (in contrast to those found *in situ* by Mann *et al.*, 2010), when paired with the occlusion condition, they reverted to novice-like behaviours. These contrasting findings highlight the difficulty in designing representative tasks that are able to accurately represent specific populations, in order to make objective comparisons, as well as the environment in question. This dichotomy is difficult to balance, as the more representative the task, the greater the need for and use of task specific information to complete the task successfully becomes. These conditions facilitate expert performance, allowing them to execute their learned movement responses needed in order to succeed in the task, whilst novices become disadvantaged, as they do not possess the necessary task specific knowledge bases required to respond with movement. When task representation is limited, the opposite phenomenon is present; experts are stripped of their knowledge bases, reducing their performance level. However, when novices are able to

respond in a manner that does not require any task specific knowledge (e.g. key press tasks), they revert to novice like chance level behaviours.

In chapter 4, the coupling of life sized video displays with subsequent real ball flight characteristics was investigated in cricket batting for the first time. Analyses revealed an unexpected finding, that under fully simulated conditions (video projected bowler & coupled ball flight) batsmen were unable to utilise the same level of information present *in situ* to guide representative decision-making behaviours. Instead, batsmen were able to produce representative decision-making behaviours under bowling machine (ball flight only) conditions better than the fully simulated condition, with no significant differences compared to *in situ*. Furthermore, no differences in decision-making behaviours between *in situ* and bowling machine conditions were found, however, significant differences in their foot movement magnitudes were observed. The possible mechanisms for this, as well as the theoretical and practical implications of these findings are outlined respectively in this chapter.

5.3 THEORETICAL IMPLICATIONS:

When designing representative task designs in the study of perceptual – cognitive skills in sport, researchers have previously adopted Ericsson & Smith's (1991) expert performance approach. This three-step approach provided the first descriptive and inductive framework for the study of expertise in sport. However, this approach was subject to criticism, with some arguing that the current understanding of perceptual motor skill may have been compromised through experimental designs that are not representative of the performance contexts (Araujo *et al.*, 2006; Van Der Kamp *et al.*, 2008; Pinder *et al.*, 2011b). In a bid to address concerns, Pinder *et al.*, (2011b) re-visited the concept of representative design (Bunswik, 1956) in an attempt to provide a structure for assessing the functionality and action fidelity of experimental and learning designs in sport. Pinder *et al.*, (2011b) suggest that researcher's and practitioners should ensure coupling between perception and action is maintained to support functionality and fidelity of performance, referencing the importance of Stoffregen *et al's* (2003) theory of action fidelity, with the purpose of identifying whether a performer's responses remain the same in two or more contexts.

In an attempt to satisfy Pinder *et al's* (2011b) call for a theoretical framework for interpreting the functionality and action fidelity of representative tasks, figure 5.1 can be used as a way of assessing the transfer of perceptual, action, and performance fidelities between *in situ* and representative tasks. The model of this framework was guided by the findings in Chapter 4, which intended to investigate the gradual uncoupling of visual cues in practice environments using the theoretical framework proposed by Pinder *et al.*, (2011b), whilst exploring Van Der Kamp *et al's* (2008) hypothesised dual visual systems framework. In their paper, Pinder *et al.*,

(2011b, p.151) state that in order to attain representative learning design, “practitioners should design dynamic interventions that consider interacting constraints on movement behaviours, adequately sample informational variables from the specific performance environments, and ensure the functional coupling between perception and action processes.” Further to this, performers should be able to “achieve specific goals by basing actions in learning contexts on comparable information to that existing in the performance environment.” Whilst these guidelines are in keeping with the concept of representative design (Brunswik, 1956), the principal findings in chapter 4 suggest when adhered to; the framework does not guarantee task representativeness.

Chapter 4 studied the representativeness of a simulated cricket-bowling machine, which couples a life sized video display with correspondent real ball flight characteristics. This design allowed cricket batsmen to face corresponding 2-D video and live ball projection of a bowler whilst responding with full interceptive cricket batting strokes. However, the results in Chapter 4 showed that under these conditions, cricket batsmen were unable to produce representative behaviours. Whilst in this instance, one can only speculate that there may be several mechanisms that may have contributed to this finding. Previously, near life-sized video displays have been shown to enable fidelity of initial behavioral responses consistent with *in situ* (Pinder *et al.*, 2011a), the findings in Chapter 2 are in support of this, whilst those found in Chapter 4 are not. It could be possible that the methodology used by Pinder *et al.*, (2011a) and in Chapter 2 allowed cricket batsmen to use the same type of information (2D video display) throughout, whilst under simulated conditions, cricket batsmen were subjected to two different types of information; 2D video display for bowling kinematics, and live on-line information for ball flight characteristics. We propose that the synthesis of the two information types may have subsequently altered the

relationship between pre-delivery kinematics, which contains advanced cues as to where the ball is being delivered (Davids *et al.*, 2005), and subsequent confirmatory ball flight characteristics, impeding the interdependent nature of the dual visual system (Van Der Kamp *et al.*, 2008). These findings are in contrast to previous studies, which have observed naturalistic performance whilst coupling 2D visual information with live ball flight characteristics (Panchuk *et al.*, 2013, & Stone *et al.*, 2014). However, these previous studies have not compared performance to *in situ*, and have also subjected participants to relatively inferior temporal task constraints in comparison.

The findings of chapter 4 and the in-ability to provide a rationale backed up by data lead me to question, “How can researchers objectively measure the underlying mechanisms that contribute to task representativeness as a whole?” Previously it has been shown separately that performance is affected by the perceptible information presented to a performer (Muller *et al.*, 2006) as well as the opportunities for action provided (Mann *et al.*, 2010). Figure 5.1 necessitates that both components, as well as their interaction (perception-action coupling) should be measured in order to inform any differences which are observed in performance between environments. For example, in Chapters 2, 3 & 4 the measurement of actions in the form of foot movements was used to infer decision-making intentionality across a broad range of delivery lengths. These measures quantify the degree to which the movements observed across representative environments are reflective of those *in situ*. Figure 5.1 also proposes other ways in which fidelity can be analysed, including analysing the level of perceptual processing between environments. Although not conducted in this thesis, experimenters could employ process tracing measures such as those used by Mann *et al.*, (2013) to examine whether participants adopt the same perceptual retrieval and processing strategies. If conducted in Chapter 4, these

measures may have provided data to show if there was a misalignment in the perceptual component that caused the difference in task performance. If so, then that data could be used to identify what needs to be changed in order for the representative task to attain higher levels of fidelity. Finally, researchers should also measure task performance itself, for example the measurement of shot selection and execution seen in Chapter 4 of this thesis. Whilst simplistic, these measures can provide the most objective measure of whether a task is representative of *in situ* or not. If not, then researchers can then look to assess the fidelities of the other components and their interactions in order to identify what is responsible for the differences in performance. Although the use of representative learning design proposed by Pinder *et al.*, (2011b) provides useful guidelines, the assessment and reporting of task representativeness should be integrated when studying sporting performance in order to provide a referent for the level of representativeness of the task used to study the construct in question.

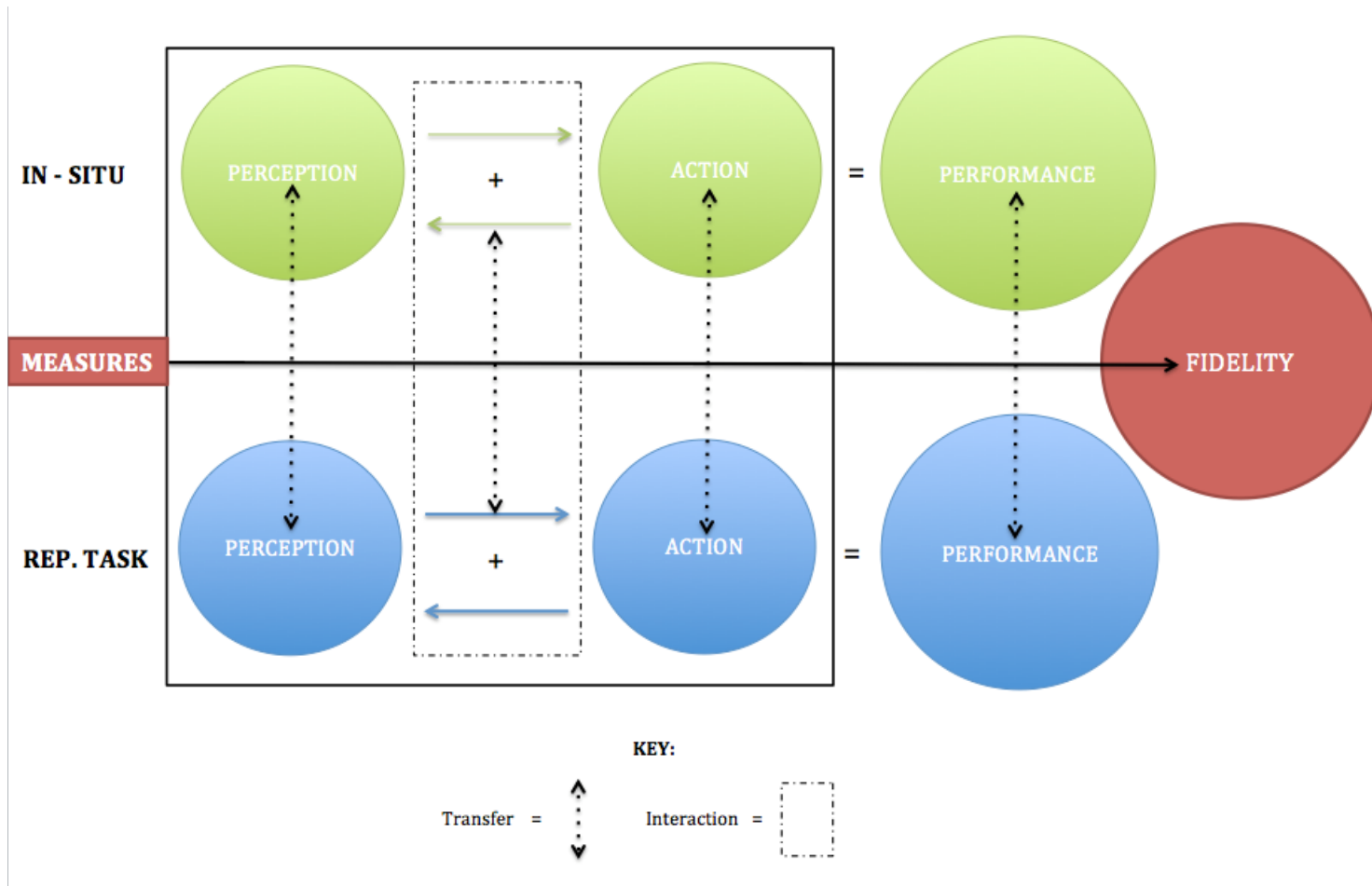


Figure 5.1 A proposed framework for the study of task representativeness between environments. To establish task fidelity, process-tracing measures are used to assess the transfer between perception, action, and performance characteristics from *in situ* into representative task designs. If the measures acquired are similar, then a high level of fidelity is observed. However, if the measures differ, the framework can be used to identify which characteristic of the representative task, or the interactions between them, is not veridical of *in situ*.

This framework could prove to be the first step in the much needed, but ambitious process of standardising protocols and measures for the study of perceptual-cognitive skill in sport. At present, there are numerous variations in the theoretical frameworks (Ericsson & Smith, 1991; Araujo *et al.*, 2006; Van Der Kamp *et al.*, 2008; Pinder *et al.*, 2011b), methodological approaches (laboratory, field based, and *in situ*) and process tracing measures employed; ultimately resulting in a domain which offers little consistency and interrelation among research groups. In order to advance current understanding, consideration of how protocols and measures can be standardised in order to provoke validity, reliability, interrelation and transfer. For example, Pinder *et al.*, (2009) previously studied the co-ordination of two front foot cricket batting shots under *in situ* and bowling machine conditions. In relation to the measures in this thesis the researchers did not sample a broad enough range of delivery lengths to be able to infer fidelity between conditions. Other previous works by Pinder *et al.*, (2012) have used anecdotal and pre-prescribed “regions” of performance when studying emergent behaviours, ignoring the naturally occurring transition of behaviours as seen in Chapter 2 of this thesis. In order to provide a comprehensive representation when inferring fidelity, PROBIT analysis was used across a broad range of task constraints (delivery lengths) to develop a model of adaptive behaviours in cricket batting. Whilst taking nothing away from either study, the methods used in this thesis for modelling and assessing the fidelity of emergent behaviours of sporting actions are superior, providing complete and objective assessments of the degree to which the laboratory based test maintained external validity and reliability.

PROBIT analysis could also be used to develop and standardise the measurement of decision-making skills in sporting contexts. Whilst previous research has typically measured and categorised decision-making skill in sports dichotomously, chapter 2 measured the task specific behaviours of cricket batsmen (front or back foot movements) as expressions of their decision making intentionality (Araujo *et al.*, 2006). As a result, PROBIT analysis was subsequently used to model decision-making probabilities to identify the specific delivery lengths that resulted in 95th, 50th, and 5th percentile probabilities of foot movements being made. These metrics provided data driven assessments of the exact lengths where dominant, neutral, and non-dominant foot movement responses are present; allowing for direct comparison between conditions (validity & transfer), test versus re-tests (reliability), and skill groups (validity). Whilst the reported metrics are most definitely a novel advancement in the study of decision-making skills in sports, there is potential for further development, discussed later in this chapter.

In addition to standardising measures used, attention also needs to be focused upon the methodological protocols that are employed in the study of perceptual-cognitive skills. As evidenced and discussed in Chapter 3 of this thesis, alterations in either the response mode and or the occlusion conditions resulted in changes in the performance of both novice and skilled participants. These findings highlight the sensitive and interrelated nature of representative task designs. For example, eliciting expert performance and maintaining true novice behaviour is an extremely difficult paradigm. The results showed that fully representative task designs were able to provoke skilled adaptive behaviours across task demands, but did not elicit typical (chance level) novice

behaviours, whilst by contrast, un-representative task designs, reflected typical novice behaviours, subsequently moderated the expert performance advantage. These findings stress that caution should be taken when using the expert – novice paradigm to study the characteristics of skilled behaviours in sport.

For example, if the focus of Chapter 3 was to be exclusively on front foot movement behaviours as seen in other experimental designs (Pinder *et al.*, 2009), there would not be any differences observed between skilled and novice decision-making behaviours under representative conditions. As discussed in Chapter 3, novices adopted a generic front foot movement response regardless of delivery length. Novices seemingly adopted this response due to the fact they do not possess any previous task specific knowledge base, which would allow them to identify the need for an alternative response. Subsequently, as physical ball flight characteristics and the need for interception were absent, novices did not receive any tangible feedback from their response. If ball flight and the need for interception were present, novices may have identified the need to adapt their response accordingly. Conversely, when novices were subjected to a dichotomous task, they reverted to typical chance level behaviours regardless of occlusion condition, whilst skilled batsmen were still able to maintain performance under un-occluded conditions. However, under occluded conditions skilled batsmen reverted to novice like decision-making behaviour. These differences in performance across experimental designs highlight the difficulty in comparing skilled versus novice populations to infer perceptual – cognitive skill.

In order to standardise the study of skill based differences, one could speculate that researchers should use only one of the following protocols which; i) study different

populations under representative environments, which facilitate the emergence of representative behaviours for a given population (e.g. slower delivery speeds for novices), or, ii) ethics notwithstanding, expose novices to the same task constraints as skilled participants in order to identify the naturalistic differences between populations, or finally, iii) sample a range of skilled performers who are at different levels of proficiency under naturalistic task constraints to identify the subtle, but different skill based differences that mediate performance. These findings imply that researchers need to not only consider the representativeness of the task relative to the environment, but also the representativeness of the population relative to the environment and or task as well.

5.4 PRACTICAL APPLICATIONS:

Due to the nature of this thesis, the theoretical and practical applications of its findings are closely mirrored. Today, sporting performance is considered to be a highly complex phenomenon, supported by a network of multidisciplinary support staff, whose job is to measure, track, develop, and enhance performance capacities. In order to do so, practitioners have developed a vast array of standardised measures and tests to assess the physiological capabilities of performers, however, little attention has been paid to developing similar measures and tests of perceptual – cognitive skills.

Although in its infancy, this direction of research demonstrates that novel ways of measuring and modelling the perceptual – cognitive aspects of skill are indeed possible. For example, by measuring the behavioural expression of a task specific action in order to infer and model decision-making intentionality. Previously, there have been no metrics to my knowledge of this being carried out in an applied setting. As shown in Figure 5.2, by using PROBIT analysis several metrics that can be used to describe decision-making performance; 1) Decision Making Threshold (DMT) – the point at which no dominant movement response is present, 2) 45-55% Gradient – describes the rate of transition from dominant to non - dominant movement response, & 3) 75% - 25% Range & Gradient – describes the range of indecision and rate of transition from dominant to non - dominant movement response. By using these methods, practitioners would be able to compare and contrast player's decision-making capabilities across a range of task constraints, developing performance tracking benchmarks, allowing for comparisons between skill levels, age ranges, and across different time points (pre to post training). This approach

would allow practitioners to make objective judgements on player's decision-making as well as their physiological capabilities, providing a more comprehensive evaluation of skilled performance

Further to the development of objective measures for perceptual – cognitive skills, establishing the fidelity and representativeness of practice tasks is imperative. As mentioned earlier, cricket is a highly constrained and physically demanding task with bowlers sometimes bowling deliveries in excess of 40.23ms^{-1} . For these reasons, it is common practice for workload limits on bowling to be imposed by governing bodies, leaving simulation as a practical alternative to facing real bowlers. However, in order for practitioners to be confident in the representative task practices transferring to performance, objective measures need to be provided. As referenced earlier, several studies to date have reported on the fidelity of both developing (Pinder *et al.*, 2009) and skilled (Pinder *et al.*, 2011a) cricket batsmen's movement responses under *in situ* versus bowling machine conditions. These studies may be used to inform practitioners as to how to employ representative practice designs best, if at all. These recent developments in the qualification of task fidelity are a step forward in the development and effective use of representative tasks for skill learning and training purposes.

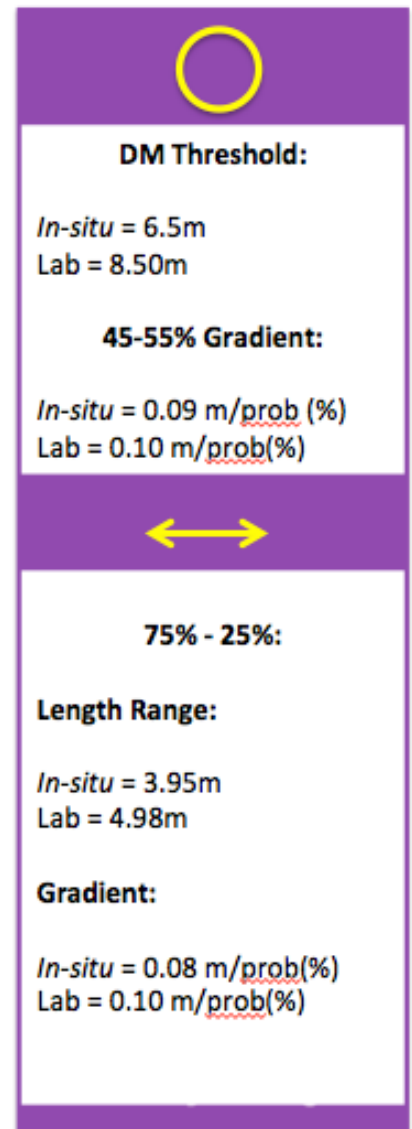
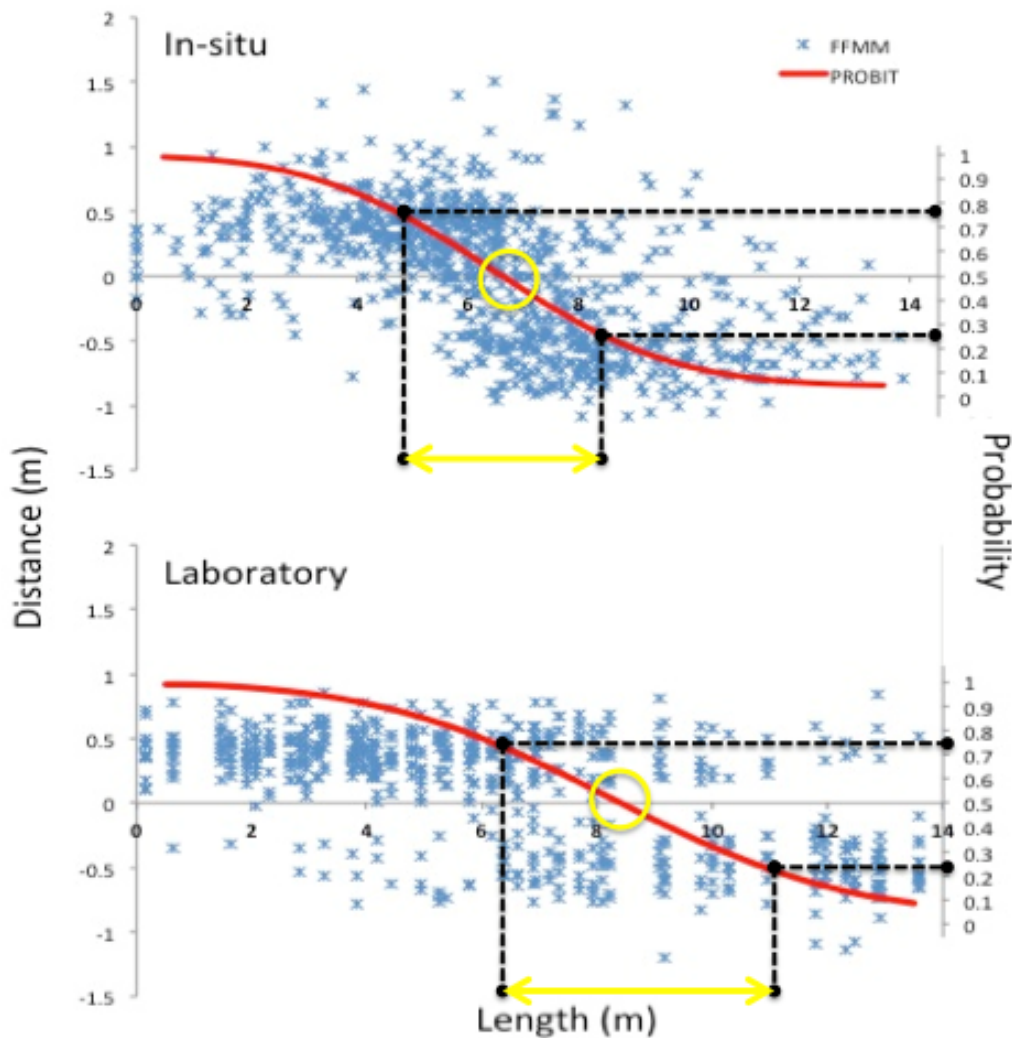


Figure 5.2 Examples of the perceptual – cognitive metrics that can be identified using PROBIT analysis between experimental conditions.

5.5 FUTURE RESEARCH DIRECTIONS:

The findings of this thesis have gone a long way to advancing the current methods used to model and assess the fidelity of representative tasks, however, it is important to acknowledge that further research is required in order to validate the use of modelling adaptive behaviours in sports. As suggested in Chapter 2, future research is needed to model performance in other sporting environments. Whilst this thesis has been able to effectively model cricket batting decision-making, future research needs to be able to demonstrate that the same principles can be applied across sporting contexts and domains. Future research may look to use Figure 5.1 as a referent for establishing fidelity of representative tasks. Using this framework in future research could be the first step towards standardising measures and protocols to enhance research inter-relatedness and cohesion as suggested earlier in this chapter.

Chapter 3 observed several differences in task performance between skilled and novice participants under a range of experimental task designs. In conclusion, it was found that task designs with high levels of fidelity enable skilled participant's to maintain decision making performance, whereas novices produced a bias response which was not reflective of chance level behaviours associated with novice decision making. Conversely, tasks with low levels of fidelity removed skilled participants performance advantage and enabled novices to respond at and around chance level under dichotomous conditions. These findings stress that consideration needs to be taken when using methodologies that compare populations of different skill levels to infer the characteristic's of skilled performance. Rather, experimenters should not only ask whether an experimental task is representative of the environment, but also the population to

which it is intended to generalise. Earlier in this chapter three separate methodologies are outlined that could be used in future research in order study population based differences.

Throughout this thesis, each study has primarily focused on measuring the behavioural expression of decision-making in order to infer decision-making intentionality. Whilst novel, the studies could have been improved by the use of further process tracing measures (eye movement recording) to identify the perceptual mechanisms responsible for decision-making performance. These measures would have been particularly useful to diagnose if different processing systems were responsible for the observed differences under live and simulated conditions in Chapter 4. Whilst it is accepted that an experiment cannot measure everything, the addition of these measures would have provided comprehensive analysis of the differences between live and representative tasks. Additionally, whilst the findings of this thesis have highlighted the importance of maintaining the interrelation between perception and action for successful task performance, it is important to acknowledge the potential complications when trying to study the dual visual systems framework (Van Der Kamp *et al.*, 2008). As evidenced in both chapter 3 and 4, any manipulation of task constraints ultimately results in changes in the subsequent adaptive behaviours produced. Therefore, trying to study the framework under simulated or representative constraints does not maintain the true interaction between perception and action. With this in mind, future research should consider manipulating information presentation at serial time under *in situ* conditions (see Stone *et al.*, 2015). When combined with the aforementioned perceptual cognitive process tracing measures (Dicks *et al.*, 2010), this approach may provide comprehensive insight into the perceptual-cognitive processes that contribute towards successful performance.

Finally, an important facet of representative practice design is the inference of transfer between representative tasks and *in situ*. The study of transfer will undoubtedly feature heavily in future research, as it is integral to the development and use of representative practice designs in research and applied settings. However, the findings in chapter 4 which are in contrast to the hypotheses, provoked questioning into the accumulation of practice hours across each of the conditions (bowling machine versus fully simulated), and whether those subsequently affected task performance and in turn fidelity. As reported earlier, batsmen are able to use subtle information to inform decision making under bowling machine conditions. However, there is no research to date that investigates how and if these are developed as a function of practice, or are they naturally occurring? Ultimately, future research is needed to ascertain whether practice under representative task constraints result in skill learning and if so, are these advances in skills transferred into *in situ*?

5.6 CONCLUSIONS:

To conclude, I would like to revisit the question “what is representative enough?” The findings of this thesis have advanced understanding of task representativeness by proposing methods and frameworks that can be used to assess representativeness, as well as identifying the characteristics of what makes tasks representative. This thesis has shown us that it is not “what is representative enough?” which is important, but rather, “how representative is it?” With this in mind, it is imperative that representativeness of a task should be measured in relation to a benchmarked model of naturally occurring performance *in situ*; researchers should infer fidelity with regards to the aspect of performance in question (e.g. decision-making), not the total skill. If, as demonstrated in chapter 3, there is data driven evidence that couples changes in adaptive behaviours *in situ* with those in the representative task, researchers can be confident fidelity between environments exists; the subsequent degree of which (low, medium, high) can be defined by additional evidences (PROBIT metrics) that identify how closely the changes in performance are matched between conditions across task constraints. If embraced fully, these guidelines will help enable the study of perceptual – cognitive skill to hold greater external validity, whilst maintaining experimental controls, a task that has so far eluded researchers in the past.

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