Individual differences in the use of visual-perceptual information to guide weight transfer and bat movements in elite cricket batting

by

John Brenton (MSportsCoach)

This thesis is submitted in partial fulfilment of the requirements for the award of Research Masters with Training

Supervisor: Dr. Sean Müller

Co-Supervisors: Dr. Alasdair Dempsey; Assoc. Prof Corinne Read

School of Psychology and Exercise Science

Murdoch University

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STUDENT DECLARATION

I, John Brenton, do hereby declare that:

a) Except where due acknowledgement has been made, the work is that of the candidate alone;

b) The work has not been submitted previously, in whole or in part, to qualify for any other academic award;

c) The content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program;

d) Ethics procedures and guidelines have been followed.

Signed: Date:

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LIST OF ITEMS COMPLETED RELEVANT TO THE THESIS

MANUSCRIPT

Chapter 2

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Chapter 3

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PRESENTATION

Brenton, J. (2014, March). *Individual differences in timing of visual information pick-up for weight transfer and interception in expert cricket batting* [PowerPoint slides]. Confirmation of candidature presented to academics from Murdoch University.

ABSTRACT

Brenton, J., Müller, S., Dempsey, A.R., & Harbaugh, A. (2014). *Individual differences in expert visuomotor skill in cricket batting* [Abstract]. Abstract accepted for oral presentation at World Congress of Science and Medicine in Cricket, Sydney, March 2015.

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SUMMARY OF THE RESEARCH

Early pick-up of visual information is vital for success in high-speed striking sports such as cricket batting. Expert performers are more adept at utilising visual information to anticipate and guide motor skill action than lesser-skilled performers. Research in sport expertise has compared the capability to use visual information to guide motor skill action between groups of experts and groups of less skilled performers, whilst sport biomechanics has focused on motor skill execution. Little is known about individual differences within experts groups and the capability to use visual information to guide biomechanical action variables in striking skills. The purpose of this master's thesis was (a) to provide a critical review of literature in a position statement that would assist the implementation of perception-action coupled representative task experiments, and (b) advance existing sports science literature by combining sport expertise and sport biomechanics methodologies in an attempt to identify individual differences within an expert group of cricket batsmen. Eight expert cricket batsmen from the Western Australian Cricket Association High Performance Squad were tested on their capability to utilise early visual information to guide the timing of weight transfer (kinetics) and bat movement (kinematics) in an in-situ temporal occlusion batting task. Comparisons revealed there were some significant differences between batsmen for measures of initiation of weight transfer, initiation of bat downswing and duration of bat downswing. There was, however, no significant difference between batsmen in the completion of weight transfer measure. After comparing quality of interception, no significant difference was found between batsmen, indicating different movement patterns may be used to achieve the same outcome, a concept known as motor equivalence. These findings have extended both theoretical and applied knowledge of understanding expertise in striking sports, which may be useful for other sports.

Structure of the Thesis

This thesis is structured as follows: (a) chapter one presents a general introduction to the topic of expert striking skill in perception-action coupled contexts as it relates to the disciplines of sport expertise and sport biomechanics, (b) chapter two presents a position paper that first, briefly describes the methodologies used in expert perception-action coupled striking sport research and second, presents methodological considerations for furthering knowledge on expert striking skill in perception-action coupled experimental tasks, (c) chapter three outlines the experimental research conducted which is presented in manuscript format in preparation for journal submission and (d) chapter four describes conclusions and suggestions resulting from the experimental work carried out within the thesis. Literature sources that have been cited in the thesis follow at the completion of chapter four. Writing and referencing of the thesis has adhered to the accepted structure in the field of Motor Learning and Control, that being The Publication Manual of the American Psychological Association (6th Edition) (American Psychological Association [APA], 2010**.** Due to the foregoing structure of the thesis there is unavoidable repetition.

CHAPTER 1

Introduction

Research focus is growing in sports science of how knowledge and methodologies from disciplines of sport expertise and sport biomechanics can provide a more comprehensive understanding of the linkage between visual-perception and action (known as perceptual-motor behaviour or perception-action coupling) in striking skills such as batting in cricket (Buttifield, Ball, & MacMahon, 2009). Sport expertise is the study of athletes with a high skill level that have a vast number of years of experience in a specific sport, in comparison to less-skilled individuals (Müller & Abernethy, 2012). These comparisons can allow determination of what factor(s) differentiate and limit expertise such as the capability to pick-up visual information to guide action. The study of biomechanics in sport can involve two levels of analysis: (i) kinematics, known as the quantification of motion during motor skill execution and (ii) kinetics, which describes the forces that guide motor execution (Hamill & Knutzen, 2009). Clearly, during sport performance perception and action are linked, therefore, combining sport expertise and sport biomechanics methodologies appears logical to further knowledge of how expert players in striking sports use visual-perceptual information to guide biomechanical variables of action.

Expert striking skills provide fascinating exemplars to understand perceptual control of action variables because of the little time that these players have to precisely execute their skills. Expert batsmen, like experts from other striking sports, provide the impression of having "all the time in the world" despite performing their skill under several challenging constraints (Abernethy, 1981). For example, time constraints that occur in game situations due to bowlers in cricket delivering the ball at high velocity (above 140 kph), have a significant impact on the successful motor skill outcomes by performers (e.g., batsmen) in striking sports. The use of mid to late ball flight path in elite level completion to guide foot movements and efficient bat-ball interception is not solely sufficient to allow striking skills to be completed accurately. Land and McLeod (2000) found that when a batsman in cricket plays a shot such as the pull or the hook, the bat is swung horizontally in an arc at right angles to the trajectory of the approaching ball. The batsman must judge the spatial position of the ball to within ± 3 cm (limited by the bat's width) and its time of arrival to within ± 3 ms (limited by the time the ball takes to pass the effective percussion zone of the bat). When a batsman faces a fast bowler, the ball takes about 600 ms to reach the batsman, but the batsman's visual reaction time plus movement time can be 900 ms, so the batsman must select and time his footwork and bat movements based upon very early visual information in the bowler's delivery action (known as advance information) and early ball flight (Müller & Abernethy, 2012). In addition, it takes about 200 ms for even an expert batsman to adjust his shot on the basis of changes in the ball direction (McLeod, 1987). Therefore, striking sport skills rely heavily upon predictive (or anticipatory) visual control of motor skills.

Sport expertise studies indicate that highly skilled athletes possess the ability to perceive visual information from an opponent's movement pattern and use that information to anticipate subsequent events such as the type of tennis serve or ball type in cricket (Müller, Abernethy, & Farrow, 2006; Shim, Carlton, Chow, & Chae, 2005). In addition, highly skilled players use early ball flight information to anticipate and execute interceptive skills such as striking a cricket ball (Müller et al., 2009) . Research undertaken in this area has focussed on the comparison between experts and less skilled participants, that is, expert versus novice, intermediate versus novice and near-expert versus expert, with many researchers finding that experts have superior anticipatory and interceptive abilities compared to less skilled players (e.g., Abernethy & Russell, 1987; Farrow & Abernethy, 2003; Müller & Abernethy, 2006; Rosalie & Müller, 2013). Alternatively, sport biomechanics studies have reported that motor execution variables such as weight transfer and bat kinematics are varied based upon ball velocity in striking sports such as baseball batting (Fortenbaugh, Fleisig, Onar-Thomas, & Asfour, 2011; Katsumata, 2007). The results from these studies have been critical to researchers in developing an understanding of the skills adopted by expert performers to continually succeed under the constraints encountered at elite levels of competition.

There is a lack of studies that have combined measures of perception (e.g., visual anticipation) to biomechanical measures of action in striking sports. For example, studies such as Müller et al. (2009) have identified a linkage between perception and action, that is, the use of visual-perceptual information to guide lower body foot movements and bat-ball interception, but their measures did not include any biomechanical action variables such as timing of weight transfer that is important to striking skill. Furthermore, little is known about perceptual–motor skill differences between individuals within expert groups. Dicks, Davids, and Button (2010) examined individual differences for a visual anticipation task where experienced association football goalkeepers attempted to intercept penalty kicks with the results showing variation in response time across players. More research on the differences between individuals within expert or highly skilled groups could help to answer questions in relation to why some expert performers display higher, more consistent levels of motor skill goal achievement than others within the same group.

The research question of the experimental work in this Masters project was to combine methodologies from sport expertise and sport biomechanics to gather information about individual differences in the pick-up of visual information to time weight transfer and bat movements within a group of expert cricket batsmen. The information gathered will assist in advancing the literature within the gaps identified earlier in the disciplines of research (Buttifield et al., 2009; Portus & Farrow, 2011), as well as theoretical models of sport expertise (Müller & Abernethy, 2012) and practical application to players and coaches.

CHAPTER 2

Abstract

This position paper discusses some key methodological issues related to conducting complex whole body in-situ perception-action coupled studies involving striking sport skills. The methodological issues that are discussed include the use of opponents (actors), presentation of stimulus information, trial numbers for participants, participant group sample sizes, small-scale comparisons across expertise and individual differences, the use of object projection machines versus live opponents, as well as timing and accuracy measures. The position argued in each of the foregoing methodological issues is formulated from the theoretical framework of representative task design, where experimental design needs to reflect (and accommodate) the key constraints of the natural performance setting that the researcher intends relevant findings to be generalised. Collectively, the position presented and argued in this paper is that researchers and editors of journals should consider that the higher degree of experimental control that can be maintained for video-based perception studies simply is not possible for highly complex whole body perception-action coupled studies. It is hoped that this paper will create the opportunity to make in-situ studies more accepted and frequent than currently exists in the sport expertise literature.

Keywords: striking sports, perception-action coupling, methodology, representative task design.

Position Statement: Methodological Considerations for Investigating Expert Striking Skill in Perception-Action Coupled In-Situ Settings

In order to understand how the exceptional perceptual-motor skills of expert striking sport players differ from less skilled players, researchers have focused their investigations upon topics that can be grouped into anticipation and coordination for object interception. The focus of this paper is perceptual-motor anticipation, that is, the use of visual information to predict a future event and execute a motor response within in-situ tasks. In-situ refers to experimental tasks that are conducted in contexts or settings such as a laboratory or a tennis court or cricket pitch where a performer competes against an opponent to strike a ball. The visual information that guides perceptual-motor anticipation can include information occurring prior to object flight (i.e., pre-ball release, known as advance information), as well as sections of object flight, both of which may be used to predict the future location of a fast moving object such as a ball or shuttle cock, and then guide the striking action (interception) (Müller & Abernethy, 2012). Coordination refers to the striking skill movement pattern(s) that is used to intercept a fast moving object within in-situ tasks (Pinder, Davids, & Renshaw, 2012). A growing body of literature has used perception-action coupled experimental tasks and collectively this literature has indicated that to be able to efficiently strike a fast moving object such as a baseball or cricket ball, the capability to anticipate, as well as coordinate and adapt multi-limb body segments is critical for expert striking skill (Pinder, Renshaw, & Davids, 2009).

The purpose of this position statement is to (a) briefly describe the methodologies used in expert perception-action coupled striking sport research and the status of what is known about expert striking skill as reviews exist elsewhere (e.g., Müller & Abernethy, 2012) and (b) present methodological considerations for furthering knowledge on expert striking skill in perception-action coupled experimental tasks.

Methodologies and what is known about expert striking skill

Different methodologies have been used to understand expert striking skill in perception-action coupled experimental tasks. Some of the main methodologies include chronometric analysis, temporal occlusion, blur, eye movement recording, manipulation of the striking implement and weight transfer. These methods have been used either separately or in combination to investigate coordination and anticipation.

Coordination. Chronometric analysis has been used to measure timing of movements and coordination in striking skills (e.g., initiation of bat downswing) relative to events such as ball release or racquet-ball contact, as well as sections of object flight or ball bounce. Studies using this approach have reported that major league baseball batters timed their step to coincide with the pitcher's ball release, whilst step duration was adjusted based upon the speed of the pitch (i.e., longer step duration for a slower pitch), but bat swing duration remained constant across different pitch speeds (Hubbard & Seng, 1954). Other studies have reported that highly skilled cricket batsmen and squash players initiated their definitive lower body movement (body positioning) based upon advance information, with ball flight information used to guide the striking implement (bat or racquet) downswing (Abernethy, 1984; Howarth, Walsh, Abernethy, & Snyder, 1984). Lesser skilled players, however, relied on ball flight information to guide both body positioning and bat downswing (Abernethy, 1984; Howarth et al., 1984). These studies indicate that experts initiate lower body movements based upon advance information and bat movements based upon early ball flight, with the duration of lower body movement, but not bat downswing, regulated to match object velocity.

More recently, Weissensteiner, Abernethy, and Farrow (2011) using a bowling machine and a full bat width condition reported that highly-skilled cricket batsmen completed their front-foot stride significantly earlier relative to bat-ball contact compared to less-skilled batters. Highly skilled batsmen also initiated bat downswing soon after completion of the front-foot stride, whilst less-skilled batsmen initiated bat downswing well before completion of the front-foot stride. In contrast, some studies report bat downswing is initiated before front-foot stabilisation when competing against an opponent (e.g., Gibson & Adams, 1989). Although Weissensteiner et al. (2011) study was focused upon front-foot strokes, Pinder et al. (2012) using a group of junior cricket batsmen measured timing of foot and bat movements, as well as accuracy of foot movements and quality of interception relative to balls that landed in a range closer (full length) and further away (short length) from the batsman. Pinder et al. (2012) reported that there was greater variability in timing of foot and bat movements, as well as correct foot movements and quality of interception when the ball landed in the middle region, than when the ball landed closer and further from the batsman. Collectively, the foregoing studies indicate that the striking movement pattern can be considerably different between expert and less skilled performers or when an opponent is present or not, with greater variability relative to key events such as ball landing position.

Anticipation. Occlusion glasses have been used to temporally occlude a performer's vision in-situ, which allows researchers to examine perceptual-motor anticipation (Müller & Abernethy, 2012). Studies using this approach have reported that experts, but not novices, were able to make verbal and motor predictions of tennis serve direction at greater than chance levels (above 50 percent) based upon advance information, but overall, prediction was superior with a motor response based upon ball flight information (Farrow & Abernethy, 2003). Mann, Abernethy, and Farrow (2010a), however, reported that skilled and novice cricket batsmen could not predict direction of a bowled ball above chance level using a verbal response when only advance information was provided, but prediction was above chance level for skilled players, but not novices, with motor responses. These findings indicate that perception-action coupled in-situ responses allow for maximal functioning of anticipatory skill.

Other temporal occlusion in-situ studies have tried to understand how advance and ball flight information are used to guide component phases in expert striking skills. Müller and Abernethy (2006) reported that when facing slower velocity bowlers, highly skilled cricket batsmen, but not lesser skilled players, relied upon early ball flight to guide foot movements in preparation for interception, with early ball flight information used to guide interception, as well as ball bounce and late ball flight to fine-tune interception. When facing faster velocity bowlers, highly skilled batsmen, but not lesser skilled batsmen, were capable of using advance information to guide definitive foot movements to above chance level (Müller et al., 2009). Again, highly skilled batsmen were superior at using early ball flight for positioning the bat for interception, as well as ball bounce and late ball flight to fine-tune interception (Müller et al., 2009). These studies indicate that as object velocity increases gross body movements are guided by earlier (advance) information and fine movements are guided by ball flight information.

Blurring of vision using contact lenses has been used to alter the degree of visual acuity and determine its influence upon expert anticipation and interception. Mann, Abernethy, and Farrow (2010b) reported that the highest blur condition was required until expert interception declined significantly below habitual vision when skilled batsmen attempted to strike balls delivered by a bowling machine. The authors also reported that a substantial degree of blur was required to cause a decline in expert interception when facing a live bowler that delivered balls faster than a ball projection machine. This study indicates that expert striking skills are likely controlled by visual information and pathways that predominate in the visual control of action, which do not rely upon high visual clarity such as the dorsal visual stream (e.g., see Goodale, Milner, Jakobson, & Carey, 1991). Therefore, in-situ studies that maintain complete perception-action coupling are vital to progress understanding of expert striking skills.

To specifically probe the eye movement pattern and spatial precision of expert striking skill, researchers have measured eye movements as well as manipulated the striking implement. Studies by Land and McLeod (2000) and Mann, Spratford, and Abernethy (2013) have reported that it is not possible to pursuit track a fast moving cricket ball, but rather an anticipatory saccade is made to predict the future landing position of the ball. Thereafter, an additional saccade was made by elite cricket batsmen, but not club level batsmen, to near the future bat-ball interception location (Mann et al., 2013). These findings provide an indication of the anticipatory capability of experts to move their eyes to key locations, which once stationary the eyes may be better positioned to use visual information to guide interception, although fixation location does not equate to information extraction (Abernethy, 1990). Manipulation of the width of the striking implement (bat) has provided an indication of the spatial precision that experts are able to cope with before there is deterioration in striking skill goal achievement. Weissensteiner et al. (2011) used different bat widths and found that expert cricket batsmen were superior to less skilled players at striking balls delivered from a bowling machine to targets with a half width bat. This provides an indication of the spatial precision that experts are capable of dealing with to maintain accuracy of interception. It is likely that this high degree of spatial precision for interception is based upon the capability to anticipate and adapt coordination patterns as discussed earlier.

The studies discussed thus far have focused upon perceptual-motor components related to expert striking skills. Sport biomechanics researchers have also attempted to understand expert interception, but their focus has been purely on motor execution. For example, Katsumata (2007) used a chronometric analysis to investigate weight transfer and bat movements in college level baseball batters facing a pitching machine. The author reported that the timing of the step, weight transfer and bat downswing were all linked to pitch velocity. Similarly, Fortenbaugh et al. (2011) investigated weight transfer in double-A baseball batters who faced a coach throwing pitches from half the distance to the mound. They also found that weight transfer was linked to pitch velocity. Biomechanical variables such as weight transfer (kinetics) are critical to expert striking skills because timing initiation and completion of this gross component of the striking skill that involves lower body movement is vital to ensure that there is sufficient time for completion of the fine motor upper body movements. Fortenbaugh et al. (2011) call for investigation linking visual-perception to motor execution (e.g., weight transfer). Accordingly, Müller, Lalović, Dempsey, Rosalie, and Harbaugh (in press) combined visual-perception through in-situ occlusion with action variables of timing of weight transfer and bat movements in baseball batting. They reported that a Major League Baseball (MLB) batter completed weight transfer earlier, than Australian Baseball League batters, with bat downswing of the MLB batter earlier than some ABL batters, with no difference in bat downswing duration. They state that the methodology provides a means to explore individual differences in visual control of action in future experiments.

The foregoing discussion provided a brief overview of the status in the in-situ literature of what is known about expert striking skill and was not meant to be exhaustive. This paper now turns to the important discussion of how experimental methodology should be designed in order to further understand expert striking skill in perception-action coupled in-situ tasks, which also has relevance to several other sports. The following discussion is structured into key points and draws upon some of the methodologies of the studies discussed above and others in the literature.

Methodological considerations for future in-situ research

The following discussion points outline key issues that would be valuable for researchers to consider when planning in-situ perception-action coupled research. The theoretical framework used to justify the points argued that follow is representative task design. Representative task design refers to (a) the structure of the experimental task so that some or all of the critical visual-perceptual information from the game situation is maintained, so that the performer has opportunity to couple action to perception in order to execute the motor skill, and (b) the capability of the performer to coordinate their action in a pattern that is like what occurs in a game situation . Whilst these are two key features of representative task design, there are other intricate features that also need to be considered as part of this theoretical framework in order to ensure greater likelihood of generalisation of finding from the experimental task to the game situation. Accordingly, the key issues discussed below provide guidelines as researchers strive to design representative perceptual-action coupled experimental tasks that can be generalised to striking skill performance in match (or game) situations. It is important to point out here that the representative design of the experimental task can be structured so as to generalise (a) to the interaction between a performer and an opponent in a match situation, (b) to contextual information that may contribute to competition between the performer and opponent, (c) psychomotor factors of anxiety, concentration, and/or pressure that may exist between the performer and the opponent during competition, and (d) physiological factors such as fatigue that may affect perceptual-motor competition between the performer and opponent. Here, the focus of the discussion is primarily to the interaction between the performer and opponent as mentioned above (a).

Consistent presentation of the same opponent to all participants

This methodological feature refers to consistent presentation of both advance and object flight information in terms of the same opponent(s) that are faced by the performer(s). The purpose is to ensure that the stimulus (opponent) is constant across participants so that comparisons can be made on dependent measures across groups or individual participants. This degree of experimental control can cause a variety of logistical difficulties that may impede an in-situ experiment, because opponent fatigue or potential injury can limit the number of performers tested in any one session and across multiple sessions, as well as the number of data trials per participant that are collected (Müller et al., in press). In addition, within some sports such as baseball, pitchers will only throw a certain number of pitches and depending upon whether they are the starting pitcher in a particular game, they are unlikely to pitch for several days after the game (see Müller et al., in press). It needs to be considered, however, whether in the actual game setting of striking sports, experts and less skilled players face multiple opponents. It then needs to be considered whether stimulus presentation in truly representative of the game situation. In a real game situation performers have to adapt to variations in stimulus presentation between opponents in order to anticipate and coordinate their action to succeed in achieving the skill goal. Therefore, as long as the temporal constraints of object velocity can be kept within a range across all participants (or factored into a covariate analysis of the dependent variables), then different opponents can be used across different participants to manage logistical difficulties and fatigue, as well as the ethical responsibility of the researcher to minimise injury to the opponent. This use of multiple opponents will help ensure that in-situ studies become more the norm than the exception.

Evidence of the use of different opponents across different participants is lacking in the literature because it is regarded as a limitation or confounding variable. There are indications in the literature of the limitations that logistical difficulties can present to completion of an in-situ experiment (Mann, Abernethy, & Farrow, 2010c). The contingency in case of opponent unavailability, injury or fatigue is to replace the opponent with another available opponent (Mann, Abernethy, et al., 2010c). Whilst some researchers may criticise this approach as a limitation, in fact, it is a more than reasonable strategy to minimise loss of data from a possible on-going experiment or to be able to plan and complete an experiment in situations where there are restrictions upon use of consistent opponents across all participants (e.g., pitch count restriction on a pitcher in baseball)(Müller et al., in press). To further justify use of multiple opponents or replacement opponents, the literature on temporal and spatial occlusion video simulation indicate that opponents present anticipatory cues in the upper limb nearing the point where an object such as a ball is released or thrown or near the point of racquet-ball contact (e.g., see Loffing & Hagemann, 2014; Müller et al., 2006). In addition, quantification of expert anticipation skill of expert athletes has been conducted using multiple opponents under international match conditions (Triolet, Benguigui, Le Runigo, & Williams, 2013). Therefore, researchers should be encouraged to use multiple opponents in order to make in-situ studies more representative of the game context as well as achievable.

Familiarity of the opponent to the performer

In a related manner to the previous discussion point, familiarity of the opponent refers to the performer(s) not having competed or practiced against the opponent(s). It is believed that opponent familiarity may confound the dependent measure, as the performer may have prior knowledge of the opponent and thereby may be able to anticipate and coordinate their actions in a much easier manner than when having to compete against an opponent who is unfamiliar. Studies that focus their research question upon the expert or near-expert (professional) performer end of the expertise continuum, however, will need to match the performer to suitably skilled opponents, hence, both the performer and opponent will need to be selected from the same skill or expertise level. Therefore, it is highly unlikely that the performer and opponent would have not competed against each other under game situations or practiced against each other (unless it is like baseball where pitchers do not pitch to batters on the same team). Even skilled club level performers may have competed or practiced against skilled opponents sampled from the same geographical region such as the same state.

There are a number of examples in the literature where researchers have gone to great effort to ensure that opponents have not competed against or practice with the performers (e.g., Bootsma & van Wieringen, 1990). There are also other examples in the literature where performers and opponents are recruited from the same team or squad ensuring that it is highly unlikely that some of the performers have not practiced or competed against the opponents under match situations (e.g., Müller & Abernethy, 2006; Müller et al., 2009). It is our contention that this type of familiarity should not be viewed as confounding variable, because familiarity with the opponent certainly does not result in scores on the dependent variable (i.e., foot movement accuracy and 'good bat-ball contacts in cricket batting) that are a ceiling effect (Müller & Abernethy, 2006). Accordingly, familiar opponents can still challenge the anticipation and coordination skills of performers within an experimental setting, with familiarity between performer and opponent representative of actual match situations across the skill continuum. Therefore, the use of familiar opponents should be encouraged within in-situ experimental tasks to ensure suitably skilled opponents can be selected as competitors for the sample performers.

Degree of control over presentation of opponent and object information

Degree of control over stimulus presentation refers to experimental constraints such as the velocity of the object to be intercepted and its spatial location for interception (e.g., landing position of the object and its flight characteristics). In a similar manner to familiarity, the purpose of tightly controlling the constraints of the performance environment is to ensure consistent presentation of perceptual information across participants that may be used to guide motor responses. The assumption is that researcher may then be sure of the external validity of comparisons made on a dependent variable(s) across groups or individual participants. Again, variation in stimulus presentation does exist in the natural game situation to which generalisation is made from the experimental task. It follows then that representative experimental tasks cannot avoid variability in the presentation of the stimulus information as human motor performance in terms of example performers (Bootsma & van Wieringen, 1990) and example opponents (Phillips, Portus, Davids, & Renshaw, 2012) have been reported to include functional variability. Accordingly, the perceptual information presented by the opponent will inherently include a degree of variability to which the performer attempts to couple action with a degree of variability. In a related manner, it is argued in the literature that the capability to adapt coordination patterns to different perceptual-motor constraints, as well as the capability to achieve the same motor skill outcome using different coordination patterns (known as biological degeneracy or motor equivalence) is critical to high-speed dynamic striking sports (Pinder et al., 2012). Consequently, imposing strict experimental control on the variability of the perceptual information presented by the opponent(s) or the requirements for the motor response by the participants within the setting of a representative task design has the potential to challenge the external validity of the findings.

Existing research typically applies a set of guidelines for acceptable stimuli to control to a degree the variability in stimulus information presented to participants. In relation to object landing position, for example, studies in cricket batting indicate that short length balls landed approximately 4m from the batsman (Müller & Abernethy, 2006), whilst in table tennis, balls landed within a 25 x 25 cm target 30 cm from the edge of the table tennis table (Bootsma & van Wieringen, 1990). In relation to object flight characteristics, there are no guidelines for aspects such as swing or curve of the object, other than what may be assumed that the object flight characteristics were presented with an opportunity to strike the object (Müller et al., 2009). The difficulty in setting strict guidelines for object flight characteristics is because depending upon the expertise of the opponent(s) used within in-situ studies, accuracy in achieving the eventual target location of the object (that is likely linked to object flight characteristics) can vary considerably (Phillips et al., 2012). In terms of object velocity, studies have presented this temporal constraint within ranges across participants, for example, on average 45 kph in tennis (Williams, Ward, Knowles, & Smeeton, 2002) and 90 to 110 kph in cricket (Mann, Abernethy, et al., 2010b). Therefore, it seems reasonable for future in-situ research to set ranges for the temporal constraint of velocity and spatial constraint of object location, which are both goal related. The movement pattern or flight characteristics used to achieve these goals, however, may involve considerable variability, although, variability of certain opponent kinematics has been reported to be within 5-20ms (Mann, Abernethy, Farrow, Davis, & Spratford, 2010).

Sample size and expert striking skill research

Historically, the purpose of expert perceptual-action coupled striking skill research has been to understand factors that differentiate the expert or highly skilled athlete from the less skilled in successful achievement of the relevant motor skill goal (Müller & Abernethy, 2012). A variety of classification terms such as ‘expert’ and ‘skilled’ have been used to refer to athletes from different parts of the skill continuum. For example, ‘expert’ has been used to refer to athletes of national and state (or provincial) level(Farrow & Abernethy, 2003), whilst ‘highly skilled’ has also been used to refer to athletes of state (or provincial) level (Müller et al., 2009) with ‘skilled’ used to refer to athletes of elite club level (Mann, Abernethy, et al., 2010a). The closer towards the expert end of the skill continuum that the researcher requires to select a sample of participants, it is highly likely that the population of participants available to sample will decrease. On face value this can present the impression that the sample is small or low and not worthy of making a contribution to the scientific literature. Representative sampling of participants so that they include a proportion of the population of ‘experts’ or ‘highly skilled’ athletes is critical and related to representative task design discussed earlier (Pinder et al., 2011). More recently, researchers are beginning to investigate individual differences within highly skilled performers (Müller et al., in press) and individual differences within expert performers. Accordingly, if the attempt is to differentiate the upper limit of expert striking skill, then selection from a small group of experts is unavoidable. Therefore, small sample sizes should be encouraged as they are representative of the population.

Sample sizes of those athletes categorised as either ‘expert’ or ‘highly skilled’ and ‘skilled’ vary from six to eight (Farrow & Abernethy, 2003; Müller et al., 2009) to between seven to twelve (Mann, Abernethy, et al., 2010a, 2010c), respectively. Other studies that use different terminology for classifying participants with high skill level have used samples of one (Land & McLeod, 2000), two (Mann et al., 2013), five (Bootsma & van Wieringen, 1990), seven (van Soest et al., 2010) and ten (Triolet et al., 2013) participants. It is important to consider the population from which these samples were drawn. For example, within a state or provincial cricket team there are six highly skilled batsmen that may participate as regular members in a team of eleven, with perhaps four to five others that form the squad of batsmen, totalling a population pool of appropriately ten highly skilled batsmen. When this sample size is considered in terms of the accessible population it indicates more appropriately the accurate representation and value of the sampled ‘highly skilled’ or ‘expert’ group. Furthermore, taking into consideration that in-situ data collection can be time consuming (e.g., approximately 2 hours per participant) in comparison to video simulation methods (e.g., 20 minutes), as well as that highly skilled or expert athletes are unlikely to return for repeat sessions, the foregoing samples are highly relevant and valuable. Also, geographical location may limit the population size. Therefore, researchers should justify their sample sizes relative to the population they were drawn from, which can be used to defend the validity of their sample.

Trial numbers during complex whole body actions

The number of experimental trials that are experienced by each participant within a group(s) is an important methodological feature. Trial number can influence the variability of the mean score(s), reliability of the dependent measure and generalisation of the dependent variable to game settings. Too few experimental trials may increase the variability of the data set (standard deviation) and may not indicate to what degree the observed dependent measure is reproducible. Like sample size, it would seem intuitive that the larger the trial numbers the more likely the data set will be representative of expert skill performance in natural skill settings. Due to the varying contexts under which each subsequent striking skill performance is executed in the game setting it does not seem necessary that a large number of experimental trials or repeat trials of each level of the independent variable are necessary. Therefore, the number of experimental trials could depend upon the representative number of performances relative to the striking skill and the context of the game situation.

In the striking sport literature there is considerable variation is the number of trials used at the individual participant and group level. At the individual participant level trial number has ranged from seven (Bootsma & van Wieringen, 1990) and between five to seven (Land & McLeod, 2000) trials per participant, to three to six trials per condition (Mann et al., 2013) and seven trials for one highly skilled participant (Müller et al., in press). At the group level trial numbers have included 540 tennis ground strokes (n = 9 participants) with 270 trials in each condition , 288 cricket batting strokes (n = 12 participants) with 72 trials in each condition (Pinder et al., 2009) and 275 cricket batting trials for experts (n = 6) with a range of 16 to 65 trials across different occlusion condition (Müller et al., 2009). In evaluating the volume of trials required to maintain external validity, it is important to consider the type of perceptual-motor coupled task and the accessibility of the participants. For example, in Shim et al. (2005), 270 trials were presented under a projection machine condition, which incurs no fatigue or time in comparison to a live opponent(s). In Land and McLeod (2000) the use of five to seven trials for analysis for each participant may have been due to limited access to high skill level participants. Therefore, whilst every attempt should be made to maximise the number of trials in expert striking skill research, the nature of the task as well as accessibility to the performer and opponent will dictate to a degree the number of trials of data that may be collected.

Small-scale and individual differences in expertise

Several existing in-situ studies have used group designs to make comparisons between experts, highly skilled or skilled players to lesser skilled players. This group design approach has been used to make generalisations to a relevant broader population of athletes. Group designs, however, present an expert model that is different to a lesser skilled model. The understanding of how coordination and anticipation differ on smaller scales such as between groups of experts and near-experts, as well as within groups of experts, near-experts and lesser skilled players, is not well understood. Moreover, group designs are inherently limited because they portray individual solutions to the motor skill problem of interception as a collective movement pattern for an expert sample, which is then generalised as representative of striking skill for the expert population as a whole. This could mask the likelihood that multiple individualised movement patterns may exist within striking skill expertise to achieve the goal of successful interception. Individual differences is a key concept to prominent motor control theory such as dynamical systems and constraints theory that attempt to explain human motor skill performance and learning as an interaction between the individual, task and environment constraints (Newell, 1986). Therefore, it is vital to avoid misrepresenting the potential range of expert patterns of coordination and anticipation in striking skills by investigating small scale (expert versus near-expert), as well as individual differences.

There are no known studies that have examined expert (national) versus near-expert (state) differences in coordination or anticipation in striking sports, nor are there studies that have examined individual differences within a particular skill group in striking sports. Recently, Müller et al. (in press) reported that a batter with Major League Baseball experience completed weight transfer earlier, compared to five other batters who played at Australian Baseball League level, when their vision was occluded during ball flight. The major league batter's initiation of bat downswing was earlier than some of the other batters, but there was no difference in downswing duration across batters. In other sports, comparisons have been made between experts and near-experts, with experts but not near-experts capable of information pick-up from a static and dynamic opponent (Rosalie & Müller, 2013). In addition, individual differences in coordination behaviour have been reported in skilled soccer goal keepers, where some respond earlier and others later to save penalties (Dicks et al., 2010). To provide a more complete theoretical and empirical understanding of expertise in striking sports, clearly, small-scale and individual designs are necessary.

Use of ball projection machine versus live opponents

Due to the overemphasis on experimental control and logistical difficulties associated with recruiting opponents, existing in-situ studies have used a combination of object projection machines and live opponents. A key problem with traditional projection machines is that they do not present advance cues, which has been reported to be critical for anticipation in striking sports (see earlier discussion). Accordingly, it is not possible for performers to couple their striking movement pattern to both advance and ball flight information as occurs in natural game settings. Therefore, the representativeness of designs which utilise projection machines is questionable at best and non-existent at worst.

There are several studies in the literature that have reported differences in the coordination pattern of the performer when object projection machines are used in comparison to a live opponent. An early case study by Gibson and Adams (1989) reported that when batting against a bowling machine the batsman's backlift and foot movements were initiated earlier when compared to facing a bowler. More recently, Shim et al. (2005) reported that when highly skilled tennis players attempted to strike balls from a projection machine, their racquet initiation was significantly later than when attempting to strike balls delivered by a live opponent. In addition, Pinder et al. (2009) reported differences in timing of several components of cricket batting strokes in a group of young cricket batsmen, where their bat backlift, front foot movement and bat downswing were all significantly earlier when facing a bowling machine compared to a bowler. Furthermore, Weissensteiner et al. (2011) reported data from a study that utilised a bowling machine showing that the front-foot is stabilised prior to bat downswing initiation, whereas, studies into baseball (Müller et al., in press) and cricket (Stuelcken, Portus, & Mason, 2005) that have used a live stimulus report that weight transfer is not completed or the front-foot is not planted prior to bat downswing initiation, respectively. Probatter object projection machine, which provides video-based advance information, has been used as an alternative to live stimulus that overcomes the issues of experimental control of stimulus presentation and limitation to trial numbers imposed upon the opponent. Probatter, however, has its own limitations. For example, ball release occurs from a fixed location that is different to facing an opponent (bowler) in cricket (Portus & Farrow, 2011). Collectively, the foregoing evidence indicates that the coordination pattern of striking skills is altered when attempting to intercept an object from a projection machine compared to an object delivered by an opponent. Therefore, it is vital that future in-situ research finds appropriate ways (as mentioned) earlier to incorporate opponents into the representative experimental design.

Timing and accuracy measures in understanding striking skill

To understand expert striking skill, the timing and sequencing of component phases of the striking skill have been measured relative to events such as object release, bounce or contact. This has been done in order to provide an indication of lower and upper body movement patterns of the interceptive action relative to perceptual information. In addition, existing studies have also measured outcome performance of component phases of striking skills such as accuracy of lower body positioning (e.g., foot movements in cricket) and success in terms of interception (e.g., quality of bat-ball contact). Outcome measures have been used in order to provide an indication of goal achievement relative to component phases of the striking skill and how this may vary across levels of expertise. Including both timing and sequence measures as well as outcome measure in one experiment that examines expert striking skill can provide a more complete understanding of the coordination patterns used by experts to achieve component phase goals. In addition, measuring the use of visual-perceptual information to time biomechanical variables such as kinematics and kinetics is vital to better understand how perception is tightly coupled to action during striking skills. The visual control of biomechanical variables is lacking in the striking sport literature, although recent research has provided a methodology and evidence for future work (Müller et al., in press).

Many of the studies discussed earlier in this paper, either focus in isolation on coordination by measuring timing variables (kinematics) (Pinder et al., 2009), or focus in isolation on accuracy measures such as achievement of component goals (Müller et al., 2009). What needs to be extended from these measures is how coordination measures such as timing variables of kinematics or kinetics vary from individual to individual in the achievement of outcome goals such as quality of interception (e.g., good, bad or no contact).

This may indicate whether multiple coordination patterns can be used to achieve a similar goal of interception (motor equivalence), as has been reported in other motor skill (Mattos, Latash, Park, Kuhl, & Scholz, 2011). Therefore, potential exists to manipulate the available perceptual information through in-situ techniques described earlier, and thereby, determine how pick-up of this perceptual information is linked to coordination and goal achievement measures in striking sports.

Summary

Research into expert striking skill has progressed from the primary focus on video-based simulation paradigms to more representative in-situ perception-action coupled paradigms. In-situ research has highlighted the importance of including the coupling of action to perceptual information in order to fully understand the capability of expert striking skills. The preponderance with experimental rigor (internal validity) such as the control of experimental variables and sample sizes that are large, which can be more realistically achieved through video-based experiments that are much more simpler and less time consuming, have the potential to stall future endeavours by researchers to conduct in-situ studies. Whilst it is not the view of this paper that experimental rigor should be discarded within in-situ studies, it should be recognised that the degree of experimental rigor that exists within a video-based experiment will clearly not be to the same degree that is possible in an in-situ study for the reasons outlined in this position statement. As long as some key variable(s) can be controlled within a range (or accommodated through relevant statistical analyses), then an in-situ experiment should be highly valued in terms of its contribution to the literature. This manner of thinking is required across collaborators, colleagues, journal reviewers and editors to ensure that complex whole body perception-action coupled studies are encouraged to become the norm rather than the exception, in order to progress understanding of expertise and skill learning in striking sports and sports in general.

CHAPTER 3

Abstract

In-situ sport expertise studies have mostly concentrated on visual-perception to guide simple measures of action or motor skill execution. The aim of this study was to examine the pick-up of early visual information to time weight transfer together with bat kinematics within a group of elite Western Australian Cricket Association (WACA) cricket batsmen using in-situ temporal occlusion. The batsmen faced bowlers of equivalent competition standard and attempted to make contact with deliveries, whilst their vision was either temporally occluded during ball flight or not occluded (control condition). Responses under the occlusion condition were analysed to quantify the pick-up of visual information to time biomechanical action variables, with results indicating that there was no significant difference between batsmen in the time of completion of weight transfer. There was evidence that the initiation of weight transfer, initiation of bat downswing and duration of bat downswing were significantly different between some of the expert batsmen. Comparison of quality of bat-ball interception, however, revealed no significant difference in the frequency of ‘all’ bat-ball contacts to ‘no’ bat-ball contacts between batsmen. These findings indicate that individual differences exist in the striking coordination pattern of elite batsmen, but that these different movement patterns may be used to achieve a similar outcome, a concept known as motor equivalence.

Keywords: temporal occlusion, visual anticipation, sports biomechanics, perception-action coupling, motor equivalence

Individual differences in the use of visual-perceptual information to guide weight transfer and bat movements in elite cricket batting

Several researchers in sports science have called for the integration of knowledge and methodologies from the disciplines of sport expertise and sport biomechanics in order to provide a more comprehensive understanding of the linkage between visual-perceptual information and action in expert striking skills such as batting in cricket, as well as other sports (Buttifield et al., 2009; Fortenbaugh et al., 2011; Müller & Abernethy, 2012; Portus & Farrow, 2011). Despite these stimulus papers, in an effort to understand expertise in high-speed striking sports, the concentration of research focus thus far has been firmly upon: (a) the investigation of visual skills such as anticipation and its linkage to simple measures of action from a sport expertise perspective or motor execution alone from a sport biomechanics perspective, and (b) the emphasis upon group designs, where an expert group is compared to a less skilled group or a single skilled group is studied. Better collaboration between sport expertise and sport biomechanics researchers may unravel traits of experts that were previously unknown.

The discipline of sport expertise is the study of athletes with a high skill level that have a vast number of years of experience in a specific sport, in comparison to less-skilled individuals (Müller & Abernethy, 2012). These comparisons can allow determination of what factor(s) differentiate and limit expertise such as the capability to pick-up visual information for anticipation. Perceptual-motor anticipation, which is relevant to this study, involves the capability of the performer to utilise available visual information to predict the future outcome of an event (e.g., position of a ball) and complete a motor response such as to strike a ball (Rosalie & Müller, 2013). Striking sport skills such as cricket batting rely heavily upon perceptual-motor anticipation due to the high temporal constraints of ball velocity that leave little time for the batsman to read the delivery and make effective interception (Müller & Abernethy, 2012).

Previous sport expertise studies indicate that highly skilled athletes possess a superior capability to less skilled players to perceive visual information from an opponent's movement pattern prior to object flight (known as advance information) and parts of ball flight to anticipate subsequent events such as the type of tennis serve (e.g., Shim et al., 2005). In relation to cricket batting, temporal occlusion in-situ studies have reported that highly skilled cricket batsmen, but not less skilled players, use advance information to anticipate ball length (or ball landing position) and position their body for interception, as well as use early ball flight information to anticipate and intercept (strike) a delivered ball (Müller et al., 2009). Other studies by Hubbard and Seng (1954) that used a chronometric analysis (timing and sequencing of motor execution relative to key events in an opponent's movement pattern) indicate that major league baseball batters facing pitchers initiated their stride in the batting motion at the moment the pitcher released the ball, signifying the batters utilised early visual information to influence lower body positioning. Bat downswing was commenced before the step was concluded with the length of time of the downswing remaining uniform (Hubbard & Seng, 1954). Initiation of bat downswing prior to completion of the front-foot stride has also been reported in cricket batting (Stuelcken et al., 2005). Recently, Weissensteiner et al. (2011) used a bowling machine and reported that expert cricket batsmen initiated and completed their front-foot movement earlier than less skilled players. They also reported that bat downswing of experts was initiated after front-foot plant, whilst bat downswing of less skilled players was initiated before front-foot plant. Therefore, experts are capable of using earlier visual information to guide action, but the coordination of action can vary dependent upon whether an opponent is present or not.

Studies such as Müller et al. (2009) have identified a linkage between visual-perceptual information and simple measures of action, but these types of studies do not provide evidence of the use of early visual information to time biomechanical variables such as weight transfer that are linked to foot movements (e.g., to make forward and backward foot movements) to position the body for bat-ball interception in cricket batting. In their review of the sport expertise literature, Müller and Abernethy (2012) present a model of expertise, which outlines that early visual information (advance and/or early ball flight) is linked to lower body movements (e.g., foot movements), whilst other visual-perceptual information (ball flight) is linked to upper body movements (e.g., interception) in striking sports. The authors also mention that the inclusion of biomechanical measures in sport expertise research may provide a better understanding of how experts exploit the linkage between visual-perception and action. To this, evidence indicates that experimental conditions that do not replicate the specific perception-action coupling of the natural task may limit the extent to which expert perceptual-motor anticipation can be demonstrated and consequently may provide an inaccurate insight into the nature of expert performance (Farrow & Abernethy, 2003; Mann, Abernethy, et al., 2010a). Therefore, there is a need for combining methodologies and further investigation of expert striking skill within in-situ tasks (see also Chapter 2).

Sport biomechanics studies into striking sport skills have focused upon methods that measure motor execution. For example, Katsumata (2007) tested college baseball batters when batting against a pitching machine whilst standing on force plates, which were used to record their weight transfer as they made an effort to hit pitches. Findings indicated that the batters were able to identify differences in pitch velocities, as variations in the timing of weight transfer and stride pattern were identified, particularly in relation to the identification of slower pitches. Another example study, Fortenbaugh et al. (2011) supported these findings when they found that double-A Minor League baseball batters showed variations in the timing of weight transfer dependent upon the velocity of the pitch. What is missing from these biomechanical studies is the systematic manipulation of visual-perceptual information so as to determine the linkage between important visual skills of anticipation to guide biomechanical variables of action such as weight transfer in perception-action coupled skill settings.

Recently, Müller et al. (in press) conducted some preliminary research using in-situ temporal occlusion (perception) with measures of weight transfer and bat movements (action variables). Baseball batters faced pitchers and attempted to intercept pitched balls whilst their vision was occluded during mid ball flight. In relation to swings at pitches, they reported that a Major League Baseball (MLB) batter completed his weight transfer significantly earlier than a group of five Australian Baseball League (ABL) batters, with initiation of bat downswing of the MLB batter earlier than some ABL batters, but there was no difference in duration of bat downswing. The MLB batter also attained a higher percentage of successful hits than the ABL batters. In baseball batting, at least, it appears that early visual information is used to time earlier weight transfer and to some degree earlier bat downswing initiation. Further research is required to expand upon these preliminary findings.

In addition to the focus upon perception or measures of motor execution, there has also been a focus upon group designs to understand expertise in sport. Research undertaken in sport expertise to understand visual information to guide action has predominantly focussed either on comparisons between expert and less skilled groups, that is, expert versus novice groups, intermediate versus novice groups and near-expert versus expert groups. The findings indicate that expert groups have superior anticipatory and interceptive abilities compared to less skilled groups in perception-action coupled tasks (e.g., Farrow & Abernethy, 2003; Müller & Abernethy, 2006). In sport biomechanics it is commonplace to study a single skill group rather than make comparisons between expert and less skilled groups (e.g., see Fortenbaugh et al., 2011). Group designs assume the findings indicate that one model of anticipation or coordination exists for an expert cohort that is different to that of a group of less skilled players. It may well be, however, that different coordination patterns are used by individual expert players to forge linkages between perception and action to achieve the skill goal, but these patterns may be masked by group designs. Addressing this question requires investigation at the individual participant level of analysis.

Little is known about the perceptual–motor skill differences between individuals within expert or skilled groups. This is surprising as theoretically there are in existence prominent motor control theories that argue for a focused analysis at the level of the individual. Newell’s (1986) constraints theory identified the importance of understanding motor control, learning and development from the individual’s capacity to functionally interact with key constraints, both task and environmental, in order to exploit them to successfully achieve the motor skill goal. Newell’s theory forms a key component for dynamical and ecological system theory, which discusses the performer (individual), environment and action linkages are the most effective in the understanding of motor behaviour, not the performer or the environment studied in isolation or necessarily in groups (Araújo, Davids, & Passos, 2007). It is argued that constant communication between the performer (individual) and the environment provides the most important information about motor skill performance and learning (Araújo et al., 2007). Factors including perceptual, biomechanical, emotional and psychological characteristics and specific task constraints are all argued to have a facilitory or limiting effect on skill of the performer-environment system. There are, however, very few studies that focus their analysis at the individual level of analysis. For example, Dicks et al. (2010) examined individual differences for a visual anticipation task where experienced association football goalkeepers attempted to intercept penalty kicks. The result showed variation in response time with some goalkeeper's initiating their response earlier and others later. They also reported descriptive differences in the percentage of goals saved. In the context of this study, batsmen in cricket may have to overcome many task and environmental challenges when attempting to make quality contact with the ball. These include but are not limited to variations in pitch conditions, for example, hard versus soft surfaces, different types of bowlers, fast versus slow or spin, weather conditions, humid conditions, which may assist the bowlers to 'swing' the ball impacting on the trajectory of the ball and its final point of arrival to the batsman. In addition, the face of the striking implement is not much wider than the ball itself, requiring specific manipulation of the bat into a precise position to allow the ball to be struck in the middle of the bat. Therefore, understanding how individuals use visual-perceptual information to guide actions under time constraints has the potential to extend theoretical understanding of sport expertise.

To cope with performance constraints, whilst skilled actions exhibit some stable characteristics, it is also apparent that skilled performers are not locked into rigidly stable solutions (e.g., coordination pattern), but can modulate their behaviours to achieve consistent performance outcome goals (Araújo et al., 2007). Pinder et al. (2012) studied the stable characteristics involved in cricket batting and found that when the length of delivery (ball landing position) was altered to require the batsmen to make a decision regarding the length of the ball they received, various movement patterns were observed when the batsmen attempted to strike the ball. The observation of this potential influence on motor skill coordination introduces the concept of motor equivalence, which refers to the equality of motor skill outcome or goal achievement from different movement patterns or muscle contractions (Mattos et al., 2011; Mattos, Kuhl, Scholz, & Latash, 2013). Combining of sport expertise and sport biomechanics methodologies has the potential to advance understanding of whether individualised perceptual-motor coordination patterns can be used to achieve goals (motor equivalence) in striking sport skills.

The purpose of this in-situ study was to combine methodologies from sport expertise and sport biomechanics in an attempt to gather information about individual differences in the pick-up of visual information to time weight transfer and bat movements (coordination) within a group of expert cricket batsmen. This study used emerging elite cricket batsmen (as the exemplar skill) to examine the timing of weight transfer together with bat kinematics (action variables) within an in-situ temporal occlusion task (perception). Due to the lack of studies that have investigated individual differences, in particular, between expert performers, only tentative hypotheses were made. Based upon the existing literature, it was hypothesised that: (i) there may be some individual differences in the pick-up of visual-perceptual information to time action variables between emerging elite cricket batsmen, and (ii) there may be descriptive differences in measures of bat-ball interception between emerging elite batsmen.

Method

Participants

Eight emerging elite cricket batsmen, six right-handed and two left-handed, (M_{age} = 21.33 years, age range 18 - 27 years), from the Western Australian Cricket Association (WACA) High Performance unit were recruited to take part in this study. The batsmen were a representative sample taken from 12 batsmen comprising the emerging elite batting squad within the WACA High Performance group, resembling 75 percent of the elite emerging batting population in the region of Perth, Western Australia. In comparison to in-situ studies conducted on other elite sporting populations this experiment equates very positively (see Müller & Abernethy, 2006 n = 6; Dicks et al., 2010 n = 7). Four right-handed fast bowlers from the WACA High Performance squad were also recruited to bowl to the batsmen throughout the testing sessions. Ethics approval was obtained from Murdoch University ethics committee (Permit number 2012/190).

Experiment Design

The primary purpose of this experiment involved a between-subject design with individual batsmen compared against each other separately on each of the dependent variables. The independent variables for this experiment were two temporal occlusion conditions: (i) vision of bowler's action (advance information) and ball flight prior to ball bounce, and (ii) a no occlusion control condition where all the advance information and ball flight was visible to the batsmen, as well as the different ball types collapsed together, based to an extent upon Müller et al. (2009). The occlusion condition was included to manipulate the duration of visual information provided to the batsman to guide perceptual-motor anticipation for timing of weight transfer, as well as to provide an opportunity for bat-ball interception (see Müller et al., 2009). The occlusion condition was the primary focus under which the dependent variables were analysed as it challenged early pick-up of visual information to guide action. The no occlusion condition was included to ensure that the occlusion condition was not overly challenging and ensure that the batsmen engaged with the challenging task. The bowlers delivered three types of balls, specifically, a full length outswinger (a ball that lands closer to the batsman and swings to the right side), a full length inswinger (a ball that lands closer to the batsman and swing to the left) and a short ball (a ball that lands further away from the batsman and bounces higher) according to Müller et al. (2009). Short length balls landed at least 4m away from the batsman's stance position on the force plates, whilst full length balls landed within 4m of the batsman's stance position according to Müller et al. (2009). Each batsman faced a total of 60 deliveries composed of three ball types x two temporal occlusion conditions x ten repeats. All eight batsmen faced the same group of four right- arm swing bowlers over the testing sessions. A modified softer ball was used to prevent potential injury to the batsmen (see Müller et al., 2009).

Instruments

The experiment was conducted in a performance laboratory. The laboratory included a full length cricket pitch (20.12m) surrounded in part by an indoor batting cage, with a half-length synthetic cricket pitch on the surface of the laboratory floor to provide similar conditions as a synthetic cricket wicket often utilised for indoor cricket practice. An adequate area was also available behind the full length pitch to allow the bowlers sufficient space for bowling run-up. A Qualysis Motion Capture System that synchronised two high-speed cameras (sampling at 200 frames per second) with two Kistler force plates (sampling at 1500Hz) was used to measure the force-time data (i.e., initiation and completion of weight transfer). Camera one was positioned behind the batsman like where the field placement of 'first slip' in cricket normally stands. The footage from this camera captured the bowler's approach, ball release and ball flight, together with the crucial information indicating the time within the ball's flight at which the occlusion of vision occurred indicated by illumination of a light emitting diode (LED) in the camera's field of vision. Camera two was positioned side on to the batsman's bat to capture the kinematics of the batsman. Vision occlusion glasses (PLATO, Model P1, Translucent Technologies Inc., Toronto, Ontario, Canada) worn by the batsman were manually triggered by a hand-held wireless remote controller, enabling the operation of liquid crystal glasses used in this study and occlusion of the batsman's vision (in-situ temporal occlusion of vision) (see Müller et al., 2009). The process involved two wireless receivers accepting an ultra-high frequency (UHF) signal emitted by a UHF transmitter contained within the wireless hand-held controller. The signal sent to receiver one turned on an LED contained in the field view of the high-speed camera positioned at first slip. The LED in the cameras field of view indicated instant when during the ball flight the batsman's vision was occluded. The second receiver, housed in a waist belt attached around the hips of the batsman, triggered the conversion of the lenses in the occlusion glasses from clear to opaque. Due to the difficulties associated with manual triggering of occlusion at certain events, prior to the experiment proper, the bowlers were filmed in high-speed from side-on and the time between back-foot landing and ball release was calculated for each bowler. Then this time from back-foot landing to ball release (relative to each bowler) plus 200ms was factored into the remote controller to attempt to create occlusion prior to ball bounce (see a similar approach in Mann, Abernethy, Farrow, et al., 2010).

Procedure

Each testing session block took approximately three hours (1.15 hours per batsman) where each batsman faced four bowlers. Before the testing began, each batsman prepared themselves for a batting session with standard cricket protective equipment, that is, they wore leg guards, protector, thigh guard, batting gloves and a compulsory batting helmet for protection of the batsmen's face and occlusion glasses. After the force plates were calibrated, the batsman stood on the plates in their normal batting stance, ensuring that only one foot was located on each force plate. The batsmen were instructed to utilise the gap in-between the force plates as the batting crease. In order to familiarise the batsmen with the experimental conditions, each batsman received ten deliveries including random occlusion or non-occlusion conditions. After familiarisation, the experiment proper began and the batsmen faced the required ball types and occlusion condition matrix in a fully randomised order according to previous research (see Müller et al., 2009). On each trial, the experimenter who was at the bowler's end of the pitch indicated to the bowler what ball type to deliver, and then, during the trial either triggered the glasses to occluded vision or did not trigger the glasses (no occlusion).

Dependent Measures

In the occlusion condition, trials were post-hoc sorted using a frame-by-frame analysis of the high-speed video record to ensure temporal occlusion had been created prior to ball bounce as done in the literature (see Müller et al., 2009). As ball flight information leading towards ball bounce and ball bounce had been previously reported to be a critical point for use of visual information to strike a ball in cricket batting (Müller et al., 2009), as well as that it is not possible for batsmen to adjust their stroke based upon visual information within one visual reaction (McLeod, 1987), only those trials that occluded within one visual reaction time prior to the time of ball bounce (180ms) were included in the analysis under the occlusion condition. This was also done to minimise the variability in occlusion point from the time of ball bounce between participants. From this post-hoc sorting, equal numbers of trials for each individual batsman were derived for the occlusion and no-occlusion conditions, as well as for full and short length balls, but length of the balls were collapsed together for statistical analysis. In order for repeated measures statistical analysis to be conducted equal numbers of trials in both the occlusion and no occlusion conditions were necessary. As trial numbers were mostly greater under the no occlusion condition, the no occlusion trials were selected in order of their appearance in the random matrix until a number that matched the number of trials under the occlusion condition was equalled. The grouping of full and short deliveries together for analysis was done to ensure a decision-making element (i.e., judgement to coordinate movement pattern to strike) was factored into study design and analysis.

The primary dependent variables in this experiment (kinetics and kinematics) included: (i) weight transfer initiation, (ii) weight transfer completion and (iii) bat downswing initiation, all from the time of ball release, as well as (iv) bat downswing duration. To obtain values for weight transfer initiation and completion, the final definitive foot movement for strokes made forward (i.e., movement of the lower body forward using front-foot for balls that landed closer to the batsman) and backward (i.e., movement of the lower body backward using back-foot for balls that landed closer to the batsman) was analysed according to previous literature (Abernethy, 1984). A separate dependent measure of bat-ball interception was recorded, that is, a rating of quality of bat-ball contact.

The kinetic and kinematic dependent variables were defined as:

(i) Weight transfer initiation, the time point from ball release where the front-foot vertical ground reaction force was equal to or at zero and when the corresponding back foot anterior-posterior force increased from a stable baseline value (e.g., becomes more negative), indicating the push forward for a front-foot stroke (Elliott, Baker, & Foster, 1993). This definition is reversed for back-foot strokes.

(ii) Weight transfer completion, the time point from ball release of the peak vertical ground reaction force on the front-foot (Katsumata, 2007). For back-foot strokes this would be peak vertical ground reaction force on the back-foot.

(iii) Bat downswing initiation, the time point from ball release when the bat begins to move in a direction to intercept the ball (Weissensteiner et al., 2011).

(iv) Duration of bat downswing, the time from downswing initiation to bat-ball interception (Weissensteiner et al., 2011) or where the ball was adjacent to the edge of the bat.

The rating of bat-ball interception was conducted ‘live’ and defined as: (a) ‘good’ contact (ball struck in direction bat was swung), (b) ‘bad’ contact (ball struck in a different direction bat was swung) and (c) ‘no’ contact, according to Müller and Abernethy (2008). Average velocity of the delivered balls was calculated by viewing footage from the high-speed camera and applying the formula velocity (m/s) = distance from the point of ball release from the popping crease at the bowlers end of the pitch (17.71m), divided by the ball transit time from the time of ball release until the instant of bat-ball interception or where the ball passed the edge of the bat if contact was unsuccessful (in ms), and then converted into kph, according to the literature (Müller et al., 2009).

Statistical Analysis

The primary dependent variables in this study were initiation and completion of weight transfer, bat downswing initiation and duration of bat downswing. These variables are ratio scale so they were analysed on an individual trial basis for each participant using parametric tests (see Land & McLeod, 2000; Mann et al., 2013). The secondary dependent variable was quality of bat-ball interception. This variable is a categorical scale so non-parametric tests were used (Field, 2009). A series of statistical tests were conducted as follows. First, an 8 (participant) by 2 (occlusion condition) factorial ANOVA with repeated measures on the second factor was run to determine if there was a significant difference in average velocity between participants and across occlusion conditions. This was done to determine whether velocity had been kept within a similar range for each batsman and if not whether covariate analysis was required when analysing the primary dependent variables. Second, a one-way ANOVA was run to determine if there was a significant difference between participants in occlusion time prior to ball bounce. Third, four separate 8 (participant) by 2 (occlusion condition) factorial ANCOVAs with repeated measures on the second factor and average velocity as a covariate were run to determine whether there were differences in timing of each of the primary dependent variables across the occlusion conditions relative to individual participants. This statistical analysis helped justify whether between-subject comparisons of the primary dependent measures could be focused upon the occlusion condition only, if there was no difference in the timing variables across occlusion conditions. Fourth, four separate ANCOVAs with average velocity as the covariate were run to compare each of the timing variables between participants in the occlusion condition with least significant difference (LSD) post-hoc pairwise comparisons. For the secondary dependent measure, a chi-squared test was used to compare frequencies of quality of bat-ball contacts that were five or above based upon guidelines by Field (2009), in groupings of 'good' and 'bad' ('all' contacts) to 'no' contacts between participants in the occlusion condition. Groupings of 'all' contacts to 'no' contacts provided an indication of positioning the bat for interception based upon the use of ball flight information prior to ball bounce (Müller et al., 2009). The purpose of comparing the frequencies of these grouping between participants was to determine whether there were individual differences in the achievement of the outcome goal of positioning the bat for interception. Because the methodology of this study was a first of its kind in terms of individual participant comparisons, alpha level was set at .05 with no adjustments made for any post-hoc pairwise comparisons (see Perneger, 1998). All assumptions in relation to the parametric and non-parametric statistical tests were checked and not violated, according to the procedures outlined by Field (2009). For example, normality checks indicated skewness and kurtosis were within acceptable limits. In addition, the assumption of homogeneity of regression slopes for ANCOVA was checked and not violated.

Results

Experimental Manipulation Checks

Table 1 outlines descriptive data for average velocity, trial numbers under occlusion and no occlusion conditions, as well as occlusion time prior to ball bounce.

Velocity. Factorial ANOVA revealed a main effect, $F(7, 119) = 9.038$, $p < .001$, indicating that average velocity was significantly different between participants at each occlusion condition. There was, however, no significant interaction between participant and occlusion condition ($p > .05$), indicating that average velocity did not vary based upon the individual participants and across occlusion conditions. This finding required the treatment of average velocity as a covariate in future analyses under the occlusion condition for each dependent variable.

Occlusion time. One-way ANOVA revealed no significant difference in occlusion time prior to ball bounce between participants, $F(7, 119) = .581$, $p = .770$, indicating that post-hoc sorting of occlusion trials prior to ball bounce was successful.

Participant, occlusion condition and timing variables. Factorial ANCOVAs revealed that there was no significant interaction between participant and occlusion condition for each of the timing measures; weight transfer initiation, $F(7, 237) = 1.139$, $p = .339$, weight transfer completion, $F(7, 237) = .598$, $p = .757$, downswing initiation, $F(7, 237) = .745$, $p = .634$, and downswing duration, $F(7, 237) = 1.081$, $p = .376$. There was, however, significant main effects for participant in relation to each of the timing measures; weight transfer initiation, $F(7, 237) = 6.193$, $p < .001$, weight transfer completion, $F(7, 237) = 2.278$, $p = .029$, bat downswing initiation, $F(7, 237) = 16.507$, $p < .001$, and bat downswing duration, $F(7, 237) = 21,341$, $p < .001$. Therefore, because the timing measure for participants did not differ across occlusion conditions, further comparison of the timing measures between participants was focused on the occlusion condition.

Table 1

Average velocity, trial numbers and occlusion time relative to participant

Participants	Velocity (kph)		Trial Number		Occlusion Time (ms)
	Occlusion *M*(SD)	No Occlusion *M*(SD)	Occlusion	No Occlusion	*M*(SD)
1	109.62 (5.50)	109.25 (6.40)	16	16	96.87 (45.38)
2	109.00 (9.23)	108.80 (5.97)	15	15	70.33 (54.16)
3	110.21 (6.12)	109.42 (6.18)	19	19	82.89 (49.95)
4	102.21 (6.65)	100.00 (6.64)	14	14	88.92 (58.87)
5	100.79 (5.61)	100.86 (4.88)	14	14	68.93 (57.92)
6	99.53 (9.44)	103.30 (7.06)	13	13	79.23 (58.20)
7	101.00 (6.20)	101.55 (5.74)	20	20	88.75 (47.12)
8	105.68 (7.12)	105.81 (5.94)	16	16	95.93 (64.53)

Note. Occlusion time is prior to ball bounce.

Weight Transfer Initiation

Figure 1 graphs the mean weight transfer initiation time relative to each participant expressed from earliest to latest values. ANCOVA indicated a significant between participant effect, $F(7, 118) = 5.165$, $p < .001$, confirming there was a difference in mean weight transfer initiation time between participants. Post-hoc LSD pairwise comparisons indicated that participant 8 was different to all other participants, participant 7 was different to participant 4 (ps < .05).

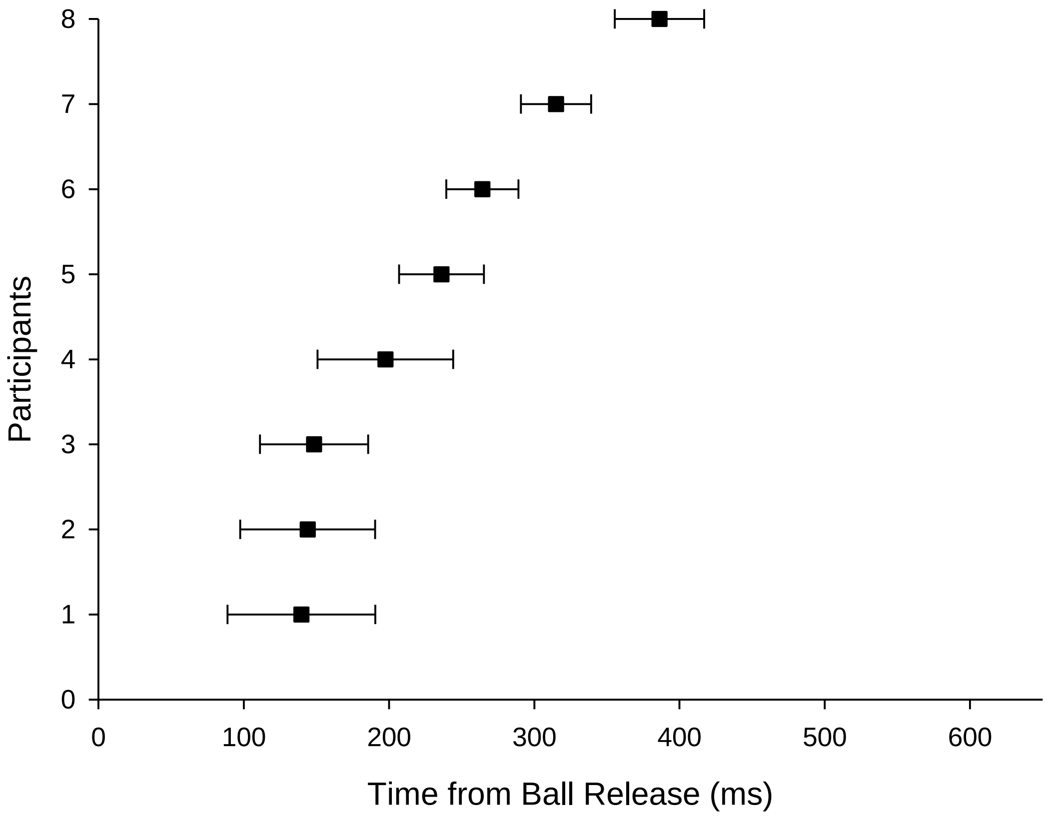

Figure 1. Mean weight transfer initiation time (ms) by participant. Participant timing values are plotted from earliest to latest for this variable. Error bars represent standard error of the mean.

Weight Transfer Completion

Figure 2 graphs mean weight transfer completion relative to each participant. ANCOVA indicated no significant between participant effect, $F(7,118) = 1.394$, $p = .214$, confirming there is no significant difference between participants in mean weight transfer completion time.

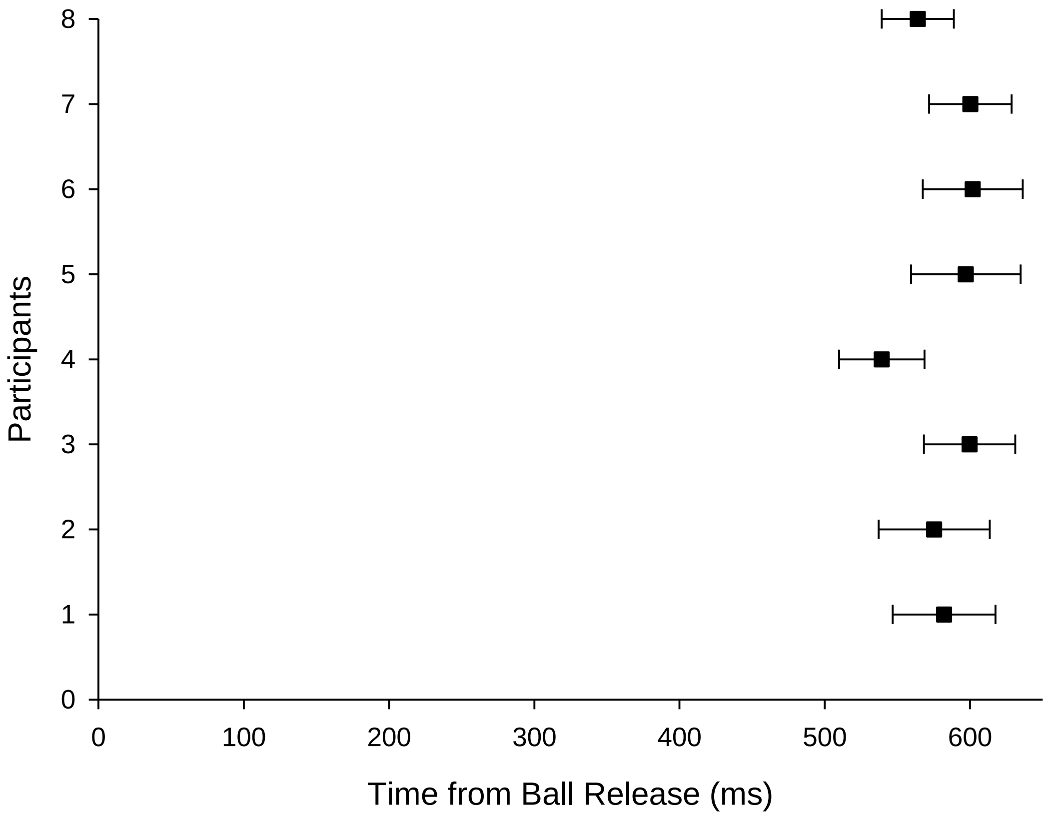

Figure 2. Mean weight transfer completion time (ms) by participant. Timing values are plotted to correspond with participant number in Figure 1. Error bars represent standard error of the mean.

Bat Downswing Initiation

Figure 3 graphs mean downswing initiation time relative to participants. ANCOVA indicated a significant between participant effect, $F(7,118) = 8.364$, $p < .001$, confirming there was a difference in mean bat downswing initiation between participants. Post-hoc LSD pairwise comparisons indicated that participant 7 was different to all other participants, participant 6 was different to participant 5 and 7, and participant 5 was different to participants 6, 3 and 2 (*p*s < .05).

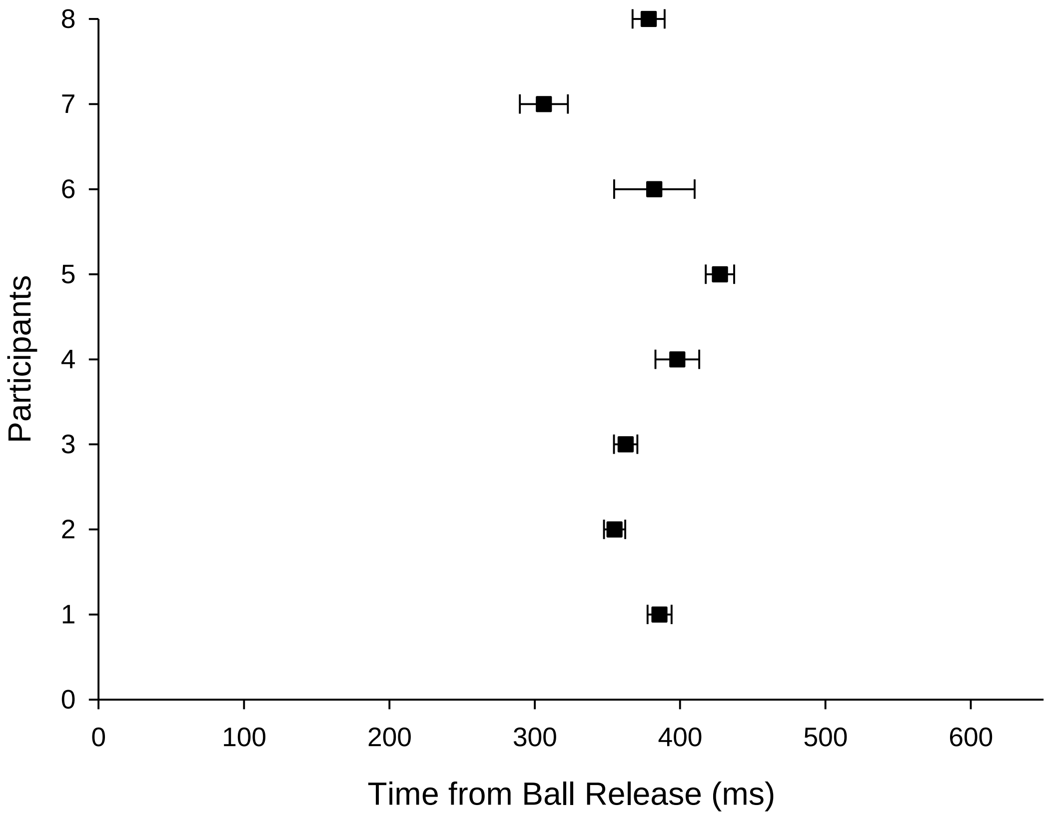

Figure 3. Mean downswing initiation time (ms) by participant. Timing values are plotted to correspond with participant number in Figure 1 and 2. Error bars represent standard error of the mean.

Bat Downswing Duration

Figure 4 graphs mean downswing duration time relative to participant. ANCOVA indicated a significant between participant effect, $F(7,118) = 13.599$, $p < .001$, confirming there was a difference in mean bat downswing duration time between participants. Post-hoc LSD pairwise comparisons indicated that participant 7 was different to all other participants, participant 2 was different to participant 1 and 5, and participant 5 was different to participants 3 and 8 (*p*s < .05).

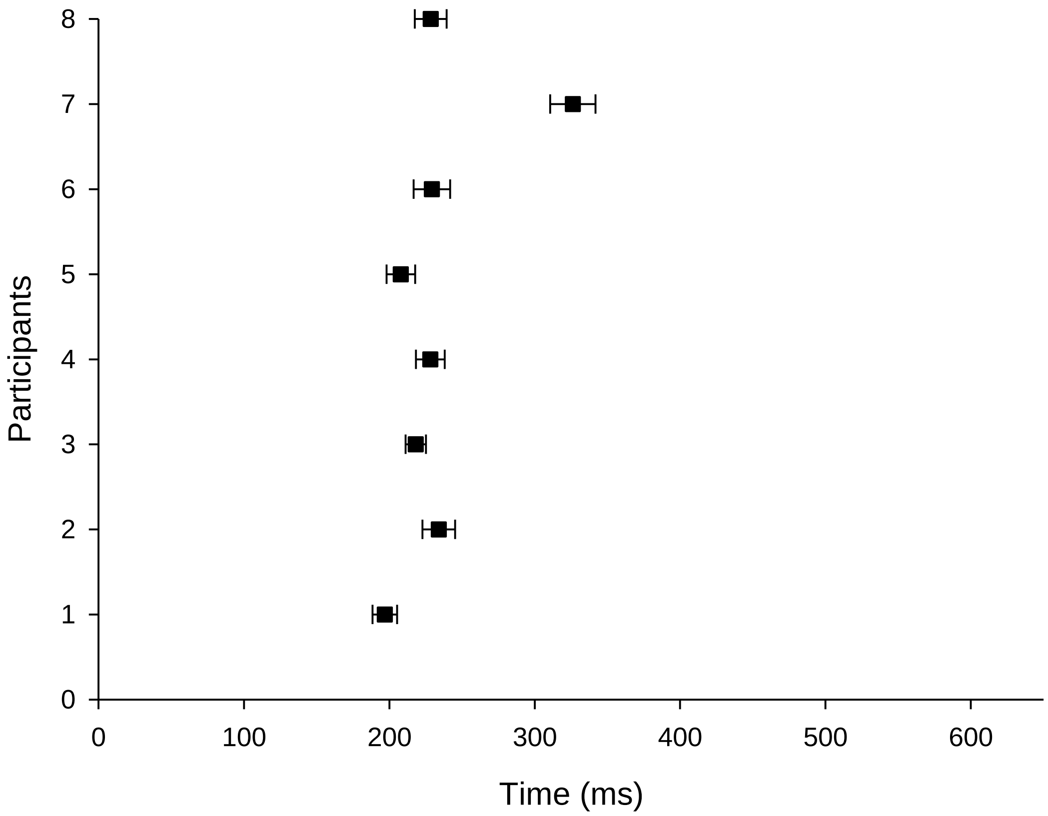

Figure 4. Mean downswing duration time (ms) by participant. Timing values are plotted to correspond with participant number in Figure 1, 2 and 3. Error bars represent standard error of the mean.

Quality of Bat-Ball Contacts

Figure 5 graphs the descriptive frequency data for each participants' 'all' bat-ball contacts against the frequency for 'no' bat-ball contacts. Pearson Chi-Square test indicated there was no significant difference in the frequency of 'all' and 'no' bat-ball contacts between participants, $\chi^2(7) = 3.247$, $p = .861$.

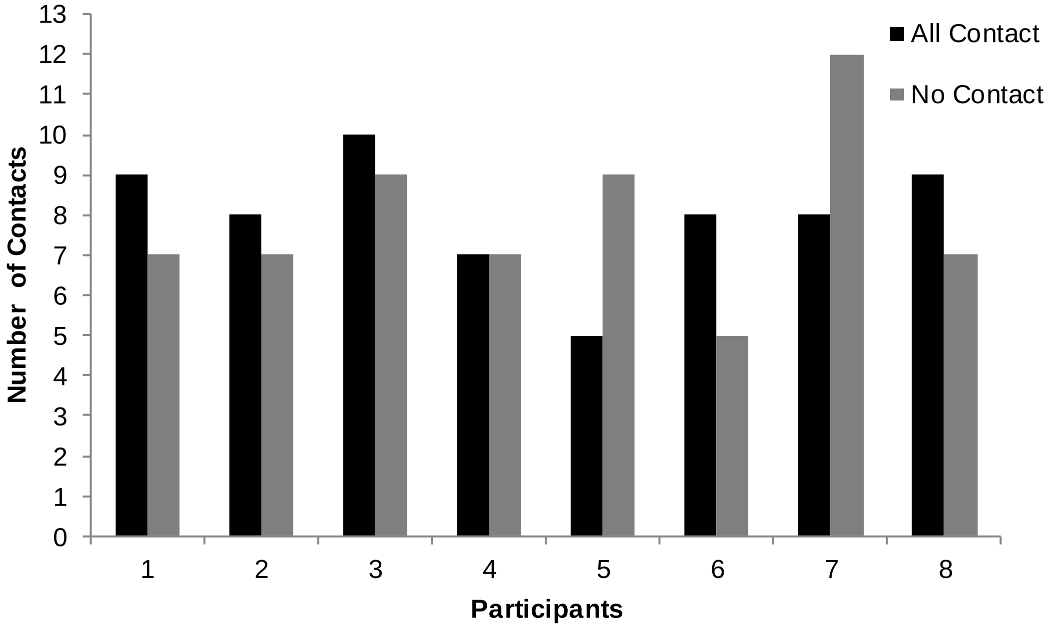

Figure 5. Total frequency of 'all' bat-ball contact versus 'no' bat-ball contact by participant. Frequency of contacts are plotted to correspond with participant number in Figures 1 to 4.

Discussion

The purpose of this study was to unite approaches used by researchers in the fields of sport expertise and sport biomechanics in an attempt to gather information about individual differences in the pick-up of visual information to time weight transfer (kinetics) and bat movement (kinematics) within a group of emerging elite cricket batsmen. The study was conducted under experimental conditions where bowlers and batsmen competed against each other that exhibited a high degree of representative task design. The results support hypothesis one showing that individual differences do exist in the coordination pattern of emerging elite batsmen. The results partially support hypothesis two where descriptive individual differences were found in quality of bat-ball contacts between emerging elite batsmen, but statistical analysis indicated that the descriptive differences were not significantly different.

Based upon the chronometric analysis, some of the emerging elite cricket batsmen appeared to utilise early visual information within the temporal occlusion condition to anticipate and time weight transfer initiation significantly earlier, whilst others initiated weight transfer significantly later (see Figure 1). This indicates there were some individual differences in the pick-up of visual-perceptual information to time kinetics within a group of emerging elite cricket batsmen. Similarly, significant differences were found between some batsmen in the pick-up of early visual information to time earlier and later initiation of bat downswing, as well as duration of bat downswing (see Figure 3 and 4). This again supports the notion of individual differences, but in this case residing in the pick-up of visual-perceptual information to time kinematics within an emerging elite group. Theoretically, these findings are consistent with Newell's (1986) constraints theory, which suggested that motor skill performance evolves through the individual that exploits the task and environment constraints to coordinate the body's degrees of freedom to achieve the motor skill goal. In relation to Müller and Abernethy (2012) model of striking skill expertise, the findings imply that more than one pattern or model exists for visual-perception that guides biomechanical action variables. Given that very few individual difference studies exist in the literature, further research is needed to confirm the findings of this study, which may then warrant refinement of aspects of Müller and Abernethy's model of striking sport expertise to acknowledge the importance of individual differences.

In terms of the findings of this study to previous literature in sport expertise, it is not possible to make direct comparisons as methodologies are different. The findings of this study are consistent with Dicks et al. (2010) who reported that some soccer goalkeepers initiated responses earlier, whilst other goalkeepers initiated responses later when they anticipated in order to save penalty kicks. The findings of this study indicate that one of the conclusions made in the sport expertise literature that experts use early visual information to respond earlier than less skilled players (e.g., Müller et al., 2009), may vary when considered in terms of an expert sample's perceptual-motor skills. That is, as a group, it appears that experts respond earlier than a group of less skilled players (Weissensteiner et al., 2011), but as evidenced by the findings of this study there are small-scale differences in earlier and later responses by individual expert players. These earlier and later responses may be relative to the specific striking skill and the component phase of the specific striking skill. In baseball, the batter only makes a forward step, which appears to be initiated at the point of ball release (Hubbard & Seng, 1954) with earlier completion of weight transfer by a MLB batter in comparison to ABL batters (Müller et al., in press). In cricket batting, the batter has to transfer weight both forwards and backwards to strike a ball. There were no significant individual differences, however, in weight transfer completion in this study, with completion of weight transfer occurring after initiation of bat downswing (see Figure 2). Again, this finding seems to be at odds with suggestions in the sport expertise literature of earlier positioning of the lower body component of the striking skill to cope with the time constraints to time upper body bat movements (Müller & Abernethy, 2012). This may again be relative to the specific striking skill of this study that required forward and backward body positioning. Alternatively, perhaps the more accurate description should be that experts pick-up early visual information to time earlier initiation of lower body movement (weight transfer initiation), rather than earlier positioning of the lower body (that may imply weight transfer completion). Further research is needed to better understand how individuals couple visual-perceptual information to biomechanical action variables, which can be masked when using group designs.

Trends in the data of this study also reveal how perceptual-motor coupling is individualised in relation to component phases of the striking skill. That is, some batsmen such as participants one and four appeared to initiate their weight transfer earlier (see Figure

1), but correspondingly coupled later initiation of bat downswing (see Figure 3). This trend in the data is consistent with studies by Pinder et al. (2009) and Stuelcken et al. (2005) who found that batsmen could initiate lower body movements earlier, but delayed downswing of the bat to enable use of later ball flight information. These types of timing between lower and upper components of the striking skill may be related to the time constraints under which the batting skill is performed. If the lower body component (weight transfer) is initiated earlier, then there is likely time to wait to initiate bat downswing relatively later for effective bat-ball interception. Although, if the lower body component (weight transfer) is initiated later, then the bat downswing will need to be initiated relatively earlier in order for effective bat-ball interception. Future research that investigates the sequencing of components in the striking skills at the individual participant level would further advance understanding of how these skills are performed under high time constraints.

An important and unexpected finding of this study was that no significant difference was found in the frequency of bat-ball contacts between individual batsmen. When this finding is considered in relation to the finding that significant individual differences did exist in the action timing measures, it appears that different coordination patterns appear to be used to achieve a similar motor goal in terms of frequency of bat-ball contact to no contacts. Although there were clear descriptive frequency differences between participants, these were not significantly different statistically. These findings imply that motor equivalence may be an underlying feature of motor skill performance in expert striking skills, as has been reported for other motor skill tasks such as reaching towards a target (Mattos et al., 2011). Qualitatively, it is apparent from observing sport performers that their exists multiple different movement patterns to achieve the motor skill goal, but again, further investigation is required possibly using the methodology in this study to determine if motor equivalence is a consistent underlying mechanism of expertise in striking sports.

Quantification of individual differences in the pick-up of visual information pick-up to guide weight transfer (kinetics) and bat movement (kinematics) can be very useful to the athlete and high performance coaches. For example, analysis like the one conducted in this study may highlight individual capabilities and deficiencies of one performer in comparison to others, with the information then used to design individualised coaching and development programs to enhance or remediate motor skill performance. In the case of a skill such as cricket batting, this information may help answer questions around attainment of, but not limited to, individual batting averages, batting strike rates, and modes of dismissal for the expert batsman. Individualised measures of performance as used in this study are critical as performers invest significant time into skill development and improvement.

Whilst this study made some advancements based upon other studies in the expertise literature, there may have been some potential limitations that need to be considered. Full and short length deliveries collapsed together for analysis may have limited the extent to which individual differences were observed possibly due to variability in the data set. However, analysis of both ball lengths together (as done to an extent elsewhere, see Müller & Abernethy, 2006) was done to ensure that decision-making to move forward or backward was representative of the game context. The number of trials collected and that could be post-hoc sorted for each batsman under each of the full and short length conditions may have restricted the findings. Significant individual difference in timing variables were still found, but in future planned automatic triggering of occlusion glasses prior to ball bounce may eradicate this limitation and increase trials for both timing measures and frequency of bat-ball contacts.

Conclusion

Individual differences in the use of visual-perceptual information to coordinate timing of weight transfer and timing of bat movements exist between emerging elite cricket batting. Whilst different coordination patterns appear to be used, positioning of the bat for striking was not significantly different between individual batsmen. This indicates that motor equivalence may be an underlying control mechanism of complex whole-body striking skills such as expert cricket batting. Integration of sport expertise and sport biomechanics methods appears necessary to understand these subtle individual differences that exist within groups of expert performers. Further studies are required to confirm the findings of this study with the skill of cricket batting or another striking sport skill. This is a fruitful avenue of research to extend theoretical understanding of expertise and practical value to player development.

Chapter 4

Conclusions and Future Research Directions

The purpose of this thesis was to further knowledge in the field of sports expertise in two areas. The focus was to (a) provide a critical review of literature in a position statement that would assist the implementation of perception-action coupled representative task experiments, and (b) to search for the possible existence of individual differences within an emerging expert group of cricket batsmen participants by combining sport expertise and sport biomechanics methodologies.

In relation to the position paper, a critical review of the literature in relation to expertise in striking sports was conducted to justify the implementation of perception-action coupled representative task experiments, undertaken in this thesis, but also for future work in the field. The conclusion reached by the paper was that potential impediments exist to the future experimental design and implementation of in-situ experiments. The position paper concluded that greater understanding of the difficulties associated with implementing an in-situ experiment (that has high external validity) is required, which may help ensure that in-situ studies become more frequent than currently is the case (see Müller & Abernethy, 2012). Key methodological aspects that can help include, the use of multiple opponents across participant to minimise fatigue and logistics, familiarity of the opponent to the performer does not necessarily indicate a confounding variable, variability in the presentation of stimulus information is representative of natural skills, expertise in sport research is always going to be based upon smaller sample sizes compared to other fields of research such as stroke rehabilitation, trial numbers may depend upon access to participants, small-scale and individual differences that consist of sampler sample sizes are equally valuable to answer theoretical and applied questions, an opponent rather than a projection machine is vital for in-situ research, as well as a combination of timing and accuracy measures are useful to understand movement patterns to achieve motor skill goals. Careful consideration of these factors as researchers look to create more ‘natural’ motor skill tasks under which to test expert performers should lead one to arrive at the conclusion that these factors only enhance representative task design.

Investigation of individual differences within an emerging expert group of cricket batsmen has advanced the literature, which had previously revealed that a group of experts was superior in terms of perceptual-motor skill to a group of less skilled players in striking sports (Mann, Abernethy, et al., 2010a; Müller & Abernethy, 2012; Weissensteiner et al., 2011). It was concluded that motor equivalence appears to exist within a group of emerging elite cricket batsmen, where there were significant individual difference in coordination, but no significant difference in attainment of bat-ball contacts. The identification of motor equivalence between the coordination patterns of expert performers may not have been possible had the methodologies from sport expertise and sport biomechanics not been combined. Therefore, continued collaboration between the disciplines is vital. The implication of the finding for sport expertise theory is that more than one model (or coordination pattern) appears suitable to achieve the motor skill goal. From a cricket coaching perspective this indicates that players should be provided the opportunity to explore different movement patterns to achieve the motor skill goal, without being over coached on one particular model.

Future Research Directions

The findings contained within this thesis provide fertile areas for further research. Motor equivalence could be investigated further within striking skills such as cricket batting to determine whether different coordination patterns can be used to attain ‘good’ bat-ball contacts. In addition, motor equivalence could be investigated across different skill levels to determine whether it is an underlying mechanism only for experts. Furthermore, the methodology used in this experiment could be used in a pre- and post-test control group anticipation training study to determine how coordination and quality of contacts changes due to an intervention. Retention and transfer tests could provide an indication of the stability or flexibility of coordination and/or motor equivalence in retention and adaptation to varied settings, respectively.

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