UNIVERSITY OF WINCHESTER

Watch the ball: An exploration of gaze behaviour while batting in cricket.

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This Thesis has been completed as a requirement
for a postgraduate research degree of the University of Winchester

Declarations

No portion of the work referred to in the Thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

I confirm that this Thesis is entirely my own work.

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I confirm that parts of the literature review within this thesis (pages 46-53) has been published in advance of its submission and appropriately referenced in the text. Discombe, R. M., & Cotterill, S. T. (2015). Eye tracking in sport: A guide for new and aspiring researchers. *Sport and Exercise Psychology Review, 11*(2), 49–58.

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Dedication

To my parents, Mandy and Michael, and my wife, Victoria, for their love and support.

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It is difficult to mention everyone who has helped me in this scholarly venture. If I were to thank everyone individually, it would require an additional chapter. I have experienced numerous challenges and embarked on a number of different ventures both academically and personally throughout my time completing this thesis and I am indebted to everyone who has supported me through the way.

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ABSTRACT

Watch the ball: An exploration of gaze behaviour while batting in cricket.

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This programme of research sought to investigate the gaze behaviours of amateur and elite level cricket batters using both table-mounted and mobile eye-tracking systems. Three original studies were conducted in both laboratory settings and real-world cricket environments to better understand batter gaze behaviours. Study one used a table mounted eye-tracker to explore what semi-elite cricket batters fixated upon during the bowler's delivery approach (pre-delivery) and how the batters tracked the ball through its flight when facing bowlers of varying speeds. The pre-delivery results highlighted that the gaze behaviour of the batters did not significantly change as a result of viewing varying bowling styles and velocities. Contrary to previous research, the ball flight data revealed that as the bowling velocities increased the amount of ball flight batters tracked significantly decreased. Study two was conducted in a real cricket environment; with amateur batters wearing mobile eye-tackers while batting against human bowlers of varying speeds. The pre-delivery results from this study revealed no significant differences in gaze behaviour when facing different bowlers. The ball flight results from study two suggested that batters tracked the ball significantly longer when facing slower bowling velocities. The final study was a comparison of elite (international and professional batters) and amateur (club) batters gaze behaviours. This study highlighted some key differences in the pre-delivery gaze behaviour between the elite and amateur batters, as well as the methods that they employed to track the ball during the flight. Additionally, both studies two and three analysed whether there was a change in gaze behaviour or methods used to track the delivery when batters made correct compared to incorrect decisions. The results revealed that incorrect decision-making was not the result of a change in pre-delivery gaze behaviour, but that the ways in which batters track the ball could impact decision-making.

Applied implications of the research programme are presented alongside recommendations about how the findings can be applied to develop the vision of batters.

Keywords: Cricket, Batting, Eye-Tracking, Gaze behaviour

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Chapter 1.0
Introduction to the Research Programme

The present chapter will introduce the reader to the research programme by briefly highlighting the importance of this body of research and presenting the aims, research questions and hypothesis for each of the three studies. The chapter will conclude by presenting the content for each of the subsequent chapters.

1.1. Visual performance in cricket

The provision of sport science and sport psychology within cricket has dramatically increased over the past 40 years (Barker, Neil, &. Fletcher, 2016), however, cricketers and cricket clubs rarely employ vision experts. This is somewhat surprising considering it is estimated that between 85 and 90 per cent of sensory information relating to our environment is gathered through our visual system (Loran & MacEwen, 1995). Therefore, without effective visual systems, humans find interpreting the world around them extremely challenging. In sports such as cricket, where objects travel at extremely rapid velocities, the need for effective vision is crucial. With modern day cricket clubs employing a large number of support staff covering most areas of sport science, it is somewhat surprising that vision specialists are not on their lists.

It makes intuitive sense that if a cricketer can improve their vision and perceptual abilities, they will be more attuned to, and able to pick up, the key information within their environment more quickly. This could be the difference between success and failure. What makes the exclusion of vision specialists in professional cricket more surprising is that research has shown that cricket specific perception can be improved with the implementation of a correct intervention (e.g., Brenton, Muller & Dempsey, 2019; Hopwood, Mann, Farrow, & Nieldem, 2011). Research has also highlighted that elite athletes in many different sports have better visual abilities than non-elite counterparts (e.g., Barns & Schmid, 2002; Ghasemi, Momeno, Rezaee, & Gholam, 2009; Junyent, Aznar-Casanova, Encina, Cardona & Forto, 2011; Ryu, Abernethy, Mann, Poolton, & Gorman, 2013; Wimshurst, Sowden, & Cardinale, 2012; Zweirko, 2008). It is also believed that the visual system of an athlete has a large impact on their decision-making effectiveness (Panchuk, Vine, & Vickers, 2015). Decision-making is a fundamental component of cricket due to the extreme time constraints under which players are required to perform (Cotterill & Discombe, 2016). Therefore, successful performance can be attributed to the effectiveness of an athlete's decision-making abilities. Indeed, it is believed that fixations allow attention to be directed to specific details from the scene in order to guide decision-making or motor control skills (Panchuk et al., 2015).

Cricket batters spend thousands of hours practising in the nets, fine-tuning technique, working on their fitness and improving their mental game, however, vision is an area of sport science that remains untapped by professional cricketers even though research clearly highlights the importance it can have in sporting success. Cricketers and coaches have yet to fully embrace the importance of visual system has on effective performance, an area that may provide players with the edge over their competition.

1.2. Eye-tracking

Vision is a fundamental component of many sports; and one piece of technology that has allowed researchers, practitioners, coachers, and players to accurately and scientifically assess vision is eye-trackers. Eye-tracking technology offers researchers the opportunity to understand the instruments underlying real time cognitive processing and how this impacts successful motor performance (Moran, 2009). The underlying rationale for using eye-tracking technology in sport is the relationship between eye-movements, attention, decision-making, and motor performance (Panchuk et al., 2015). While the focus of attention can move covertly (Posner, 1980), it is now generally accepted that eye-movements usually coincide with an obligatory shift of attention. Therefore, it is suggested that you move your eye to another location, your attention automatically follows (Deubel & Schneider, 1996; Panckuk et al., 2015; Shepherd, Findlay, & Hockey, 1986; Vickers, 2007). Eye-tracking accordingly represents a window to assess not only the visual system, but also the attention of an athlete.

In fast-paced sports like cricket, squash, tennis and badminton the gaze behaviours of elite athletes have become a vital area within the study of vision in sport (Appelbaum & Erickson, 2016). Eye-tracking technology, however, has been used in numerous performance domains long before the world of sport realised its potential, for example, in neuroscience, psychology, industrial engineering, marketing/advertising, and computer science (Duchowski, 2002). However, in the 1980s and 1990s eye-tracking research in sport started to emerge in the literature, including ice hockey (Bard & Fleury, 1981); baseball hitting (Bahill & LaRitz, 1984); badminton (Ripoll, Papin, Guezennec, Verdy, & Philip, 1985); and golf putting (Vickers, 1992). Due to the limitations with technology available at the time, these early studies were limited with what they could achieve, however, the they opened the door to the exciting field of eye movement research within sport science.

Eye-trackers provide numerous research opportunities within the sport domain, including comparing the visual strategies and spatial awareness of elite vs. amateur performer, highlighting where successful athletes direct their vision and attention prior to skill execution, and comparing an athlete’s vision during successful and unsuccessful trials (Discombe & Cotterill, 2015). The exciting opportunity for athletes, coaches and practitioners is that once this information and knowledge is acquired, it can be packaged and developed into interventions to enhance performance. One example of this can be found in the sport of golf, where Campbell and Moran (2014) used eye-tracking technology to investigate differences between elite and amateur golfers when it came to reading greens before a putt (Discombe & Cotterill, 2015). Their findings suggest that the professional golfers used a more economical gaze pattern and utilised different cues in the environment when compared to amateur and club players (Campbell & Moran, 2014). Subsequently, this information was used to teach amateur golfers how to successfully read the green. This has the potential to substantially improve their overall performance, after all, putting accounts for about 40 per cent of the shots played in a typical round (Gwyn & Patch, 1993).

Experimental studies have also demonstrated the importance of specific gaze behaviours. One behaviour that has received a great deal of attention within the literature has been the Quiet Eye (QE). Williams, Singer, and Frehlich (2002) reported that when QE duration was experimentally reduced in a billiards task, the accuracy of both experts and novices suffered. Harle and Vickers (2001) highlighted the effectiveness of QE training with a team of basketball players. Harle and Vickers (2001) demonstrated that basketball players who undertook QE training increased the accuracy of their free throws by 22.62 per cent across two seasons, while in control groups no increase in athletic performance was noted. Similarly, and perhaps somewhat surprisingly, Vine, Moore, and Wilson, (2011) further demonstrated similar performance benefits from just a single one-hour QE training session. Vine and colleagues recorded putting successes across 10 rounds of competitive golf for twenty-two elite (low handicap golfers). The results showed that one hour of QE-training resulted in 1.9 fewer putts per round, compared to pre-training testing. Results also showed that the QE trained group successfully made 5 per cent more putts from the distance of 6 to 10 feet following the training. While these types of eye-tracking studies have enhanced our knowledge and led to important and effective visual training interventions, the majority of eye-tracking studies have been carried out either in the laboratory or in closed skill sports. The main reason for this is that when tracking vision in dynamic situations, the researcher must sacrifice some experimental control and overcome the challenges of tracking vision in in the real-world setting (Panchuk et al., 2015). There is, therefore, still a need for more real-world ecologically valid eye-tracking research, particularly in fast dynamic sports such as cricket.

1.3. Eye-tracking in cricket

While there has been eye-tracking research conducted within the sport of cricket that has specifically focused on batting (e.g., Croft, Button & Dicks, 2010; Land & McLeod, 2000; Mann, Spratford, & Abernethy, 2013, McRobert, Williams, Ward, & Eccles, 2009), numerous questions still remain unanswered. From an ecological standpoint, the methodological designs of the aforementioned studies are flawed. One of the most obvious of these flaws is that the two of three of these research projects (Croft et al., 2010; Land & McLeod, 2000) utilised traditional ball projection (bowling) machines. The bowling machines completely remove all pre-delivery cues available to the batters. While these studies were some of the first to examine how cricket batters track the ball in the flight, they did not provide any information about what cues batters use pre-deliver to predict where the landing location of the ball. The use of a bowling machine also presents another question about the generalisability of the results, as it is entirely possible that batters track the ball differently when facing a bowling machine compared to a human bowler.

In an attempt to address this issue, Mann et al. (2013) incorporated ProBatter with their methodology. ProBatter was at the time a state-of-the-art bowling machine which projects life size video footage of a bowler as they run into bowl. The ball then subsequently appears and is delivered from a hole in the screen to coincide with the bowler’s ball release. While the methodology in Mann et al’s. (2013) study might seem more ecological and representative of a ‘real world scenario’ due to the inclusion of ProBatter, the validity of this machine has yet to be tested. Like the previous eye-tracking studies in cricket, Mann and colleagues do not present any eye-tracking data pre-delivery, therefore key information about the cues batter use pre-delivery are still not understood.

McRobert and colleagues were the first to use eye-tracking equipment to examine what advance cues batters fixate upon pre-delivery. They used ten elite and amateur batters who were required to respond to life-size video footage from fast and spin bowlers. Each video presented the bowler’s preparation, run-up, gather, delivery action and release, follow-through, and the first 80ms of ball flight following release before the video finished. While this study was the first to highlight the gaze behaviours and visual search strategies of cricket batters when presented with pre-delivery information, numerous unanswered questions still remain. The study fails to examine the gaze behaviour of the batters when viewing medium pace bowling, as this bowling velocity was not assessed. It also fails to track the participants' gaze during ball flight, as the video footage stopped shortly after ball release. It is unknown whether the removal of the ball flight information, and the addition of the think-aloud protocol in McRobert and colleague's study, altered the pre-delivery visual search strategy and the gaze behaviour of the batters. Batters were instructed to watch the pre-delivery video footage (i.e. preparatory phase, run up, ball release) and then predict where the ball would land. Would the removal of the ball flight alter the way the batters perceived the run up and release?

Eye-tracking research in cricket has examined each phase of the delivery (pre-delivery and ball flight) separately. The reasons for doing this are logical; using a bowling machine or a video clip of a bowler's pre-delivery affords the researcher more control of the experimental variables and presents a climate where eye-tracking data can be comfortably collected. However, by separating the pre-delivery from the ball flight, the task does not truly represent the challenges that batters face in the real world. Therefore, more research is still needed to assess the pre-delivery and ball flight eye-movements of cricket batters. The logical order of this research should start from a controlled laboratory-based research methodology, where the researcher has high experimental control, and progress into the naturalistic 'real world' environment to see if the findings can be replicated.

1.4. Statement of the problem

Effective vision and perception are both of paramount importance when it comes to cricket batting, yet there is a lack of research and focus on improving vision in cricket. Eye-tracking affords researchers the opportunity to explore the strategies that elite and amateur batter employ in order to successfully execute the task of intercepting a ball travelling at great velocities; which in turn can be used to enhance performance. There have been attempts to use this technology within the sport of cricket, however the separation of pre-delivery information and ball flight means that a full understanding of the visual strategies of batters has yet to be uncovered. As such, there is no concrete advice about how to train batters' vision for cricket. A comprehensive research project is therefore needed in order to enhance the knowledge in this area and gain a full understanding of what pre-delivery visual cues batters use to predict the line and length of the ball and how batters track the ball during the ball flight. Another area that is important to investigate is whether there is a difference in the visual strategies of elite batters and amateur batters and whether changes in these strategies impact on the decision-making of cricket batters.

Conducting a research project exploring the visual strategies batters employ when facing a range of bowlers, will not only expand the knowledge within the area but will be the starting point for an effective visual perception training programme. The results can be used to plan and develop visual perception interventions for amateur and elite level cricketers. The findings will also provide valuable information and guidance for coaches about the best methods to teach batting while enhancing the batters' visual, decision-making and anticipatory abilities. Any sport science or sport psychology intervention should be based on strong scientific knowledge, indeed, the understanding that applied sport psychology must be based on scientific principles is embedded in all professional bodies' codes of ethics and professional accreditation criteria (Winter & Collins, 2015). Acquiring this scientific knowledge is therefore the vital first step in developing effective visual training interventions.

1.5 Overview of the research programme

The primary aim of this programme of research is to provide a comprehensive understanding of the gaze behaviour and search strategies utilised by cricket batters. Eye-tracking technology will be used to monitor the gaze of batters from the start of the run up all the way through to bat ball contact, something that has not been achieved in previous research projects to date. The research will employ both a laboratory based visual search study, as well as two vision-in-action field-based experiments. A comparison of elite vs. amateur cricketers' gaze behaviour will also be provided, as well as an exploration as to whether the visual strategies employed by batters differ when they make correct vs. incorrect decisions. It is hoped that by acquiring this knowledge and providing a detailed understanding of batters' vision and gaze behaviour, the research can be used to develop and provide recommendations for effective visual training interventions.

1.5.1 Study one aims

The aim of study one is to track the vision of batters from the beginning of the bowler's run up all the way through the ball flight. The study will investigate the visual search strategies and gaze behaviours of cricket batters when presented with video footage of bowlers of varying speeds and bowling styles. This design will include slow bowling/conventional off spin bowling (72-88 km/h or 20-24m/s, with spin imparted on that ball) which has been neglected by the previous experiments, medium pace bowling (120-128 km/h or 33-35m/s) and fast paced bowling (129-137 km/h or 36-38 m/s). The study will examine how the batters track the ball during its flight, something that to date has previously been neglected for fast pace and spin bowling. The study will also examine what information the batters fixate on during the crucial pre-delivery phase for all three types of bowling. Therefore, the batters' visual search and gaze patterns will be tracked from the start of the bowler's run up all the way through the ball flight, which has previously never been incorporated in eye-tracking cricket studies.

1.5.2 Study one research question and hypotheses

1. What eye-movements (fixations, fixation location and fixation duration) do batters produce prior to the release of the ball (i.e., during the preparatory phase and bowler's run up) when presented with video footage of human spin, medium pace, and fast paced bowlers?
    - It is hypothesised that batters will fixate on different aspects of the bowler's body including the wrist, the hand and the head of the bowler. It is also hypothesised that the batter will fixate on the ball and the point of release, as suggested by McRobert et al. (2009) and Müller, Abernethy, and Farrow (2006).
2. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowler's run up) when presented with video footage of human spin, medium pace, and fast bowlers?
    - It is hypothesised that batters will fixate on different aspects and segments of the bowlers' body when facing spin compared to facing medium-paced or fast bowlers as suggested by McRobert et al. (2009).
3. Do batters use predictive saccades or smooth pursuits in order to follow the ball during its flight when viewing video footage of human bowlers of varying velocities (i.e., spin bowling, medium pace bowling, and fast paced bowling)?
    - It is hypothesised that batters will try to utilise smooth pursuit for all/the majority of the ball flight when facing spin bowling, as the ball's velocity will be slow enough to track throughout its flight.

- It is hypothesised that batters will not pursuit track the ball through the entire ball flight when facing medium-paced or fast bowlers. Instead, they will utilise predictive saccades as suggested in the previous research (Croft et al., 2011; Land & McLeod, 2010; Mann et al., 2013).

4. Do batters use a difference strategy (i.e. predictive saccade vs. smooth pursuit) to follow the ball during its flight when viewing video footage of spin bowling compared to medium pace or fast pace bowling?
    - It is hypothesised that there will be a significant different in the way batters follow/track the ball during its flight when facing bowlers of varying speeds.

1.5.3 Study two aims

While numerous studies have tracked the vision of sportsmen, few have conducted the research in situ. Instead, the majority of these studies have used video footage on a computer screen or projected the footage onto a laboratory wall (e.g. McRobert et al., 2009). There are numerous benefits to laboratory-based procedure. Using a table mounted eye tracker allows the researcher to have strict control over the environment and all the variables and therefore generates some highly accurate eye-tracking data. The table mounted systems also offers extremely high sample rates (up to 1000 frames per second) compared to the head mounted systems (rates of up to 50 frames per second when conducting the experiment). This means that the data collected will comprehensively be more accurate when compared to a head mounted systems and the amount of unknown data will be reduced (Holmqvist et al., 2011). Laboratory-based studies have increased and advanced our knowledge within the field of gaze behaviour, anticipation, decision-making and visual search. However, viewing pictures or video footage presented via a display screen still represents an artificial task (Duchowski, 2002). Video displays, may be methodologically convenient however, have flaws when trying to accurately simulate and represent a real natural environment. Some information is inevitably diminished or lost, for example, three-dimensional information aiding depth perception (Mann et al., 2010). Recent advancements in technology, specifically with wearable eye-trackers, now allows for the collection of eye movement data in more natural situations.

A valid criticism of much of the perceptual-motor expertise research investigating fastball sports is that studies have consistently dissociated perception and action, with many methodologies incorporating a simplified verbal or written response. However, numerous fMRI and neuroscience evidence (Goodale, Milner, Jakobson, & Carey, 1991; Króliczak, Cavina-Pratesi, Goodman, & Culham, 2007; Milner & Goodale, 1995) suggest that simplified responses that do not allow the athlete (batter) to produce the real action (e.g., intercept and hit the cricket ball) are likely to misrepresent or underestimate the true ability of skilled performers (Mann et al., 2010). Indeed, Mann et al. (2010) argue that an interceptive movement, or at the very least an intention from the athlete to intercept, may be necessary to elicit responses from the same neuro pathways as the real action of batting in cricket. Therefore, in order to create a task that activates the same neuro pathways, maintains perception and action, and provides an environment that is an accurate representation of the task of batting, more ecological real-world research is still required.

The second study will allow for the interception of a cricket ball to occur, therefore preserving perception and action coupling and maintaining a high level of ecological validity. The participants will perform in their regular environment, will be wearing their own cricket equipment, and will bat (perform) in accordance to their own style and tactics. Critically, study two's methodological design allows for the actual movements of the batter to occur, i.e. for the batter to intercept the ball, and make bat-to-ball contact. The aim of study two is to investigate the gaze behaviours of cricket batters in situ, while facing human bowlers of varying velocities and bowling styles. This will include slow bowling/conventional off spin bowling which has been neglected by the previous research in the field (Croft et al., 2010; Land & McLeod 2001; Mann et al., 2013), and medium-fast paced bowling. Due to the important role that eye-movements play in the decision-making process, a secondary aim of the study is to investigate whether there is a change in gaze behaviour between successful and unsuccessful decision-making.

1.5.4 Study two research question and hypotheses

1. Which locations do batters consider to be the most important environmental cues (i.e., which are the most fixated upon locations) when facing human spin and medium-paced bowlers in situ?
    - It is hypothesised that batsmen will fixate on varying aspects of the bowler's body (mainly upper body) in accordance with McRobert et al. 2009.
2. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the

preparatory phase and bowler's run up) when facing human spin and medium-paced bowlers in situ?

- It is hypothesised that there will be a significant difference in the gaze behaviour of batters as they face the different types of bowling (spin vs. medium-paced) in accordance with McRobert et al. 2009.

3. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowler's run up) when batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
    - It is hypothesised that there will be a significant difference in the gaze behaviour (fixations, fixation duration and fixation location) prior to ball release when batters make a correct decision compared to an incorrect decision.
4. Do batters use predictive saccades or smooth pursuits in order to follow the ball during its flight when facing human bowlers of varying velocities (i.e., spin bowling and medium-paced bowling)?
    - It is hypothesised that batters will try to utilise smooth pursuit for all/the majority of the ball flight when facing spin bowling, as the ball's velocity will be slow enough to track throughout its flight.
    - It is hypothesised that batters will not pursuit track the ball through the entire ball flight when facing medium-paced bowlers. Instead, they will utilise predictive saccades as suggested in the previous research (Croft et al., 2011; Land & McLeod, 2010; Mann et al., 2013).
5. Is there a significant difference in the method for tracking the ball (the percentage of ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post-bounce ball flight tracked, and the percentage of ball flight participants fail to track) when facing human spin compared to medium-paced bowlers?
    - It is hypothesised that there will be a significant difference in gaze behaviour when facing spin bowling compared to medium pace bowling, with batters tracking a longer duration of ball flight when facing spin bowling.

6. Is there a significant difference in the method for tracking the ball (the percentage of ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post-bounce ball flight tracked, and the percentage of ball flight participants fail to track) when batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
    - There will be a significant difference in the method of tracking the ball (the percentage of ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post-bounce ball flight tracked, and the percentage of ball flight participants fail to track) when the participant make a correct decision compared to an incorrect decision.

1.5.5 Study three aims

Study three will compare elite vs. non-elite batters' gaze behaviours when facing spin, and medium-paced human bowling. There is a vast amount of research being conducted to compare the differences between elite and non-elite performers, as this line of enquiry not only offers academic benefits, but also has applied implications (Eklund & Tenenbaum, 2014). This type of research is considered by many to be a vital area and a "hot topic" in psychology (Swann, Moran, & Piggott, 2015), and sport offers the ideal platform for this form of study. Information gained from this research can highlight the difference and mechanics involved in sport performance, which underpins experts' superior performance when compared to novices. This information can be used not only to highlight the difference between the two populations but can also be applied to develop certain important skills in amateur players, develop interventions, adapt training sessions, create models and protocols of development and learning and potentially be used for talent identification purposes.

Study three will help to answer some of the unknown questions relating to vision, attention and cricket batting. For example, do elite players fixate on the same areas as less skilled players during the bowler's run up? Are these areas consistent when facing spin and medium-fast bowling? Is there a significant difference in the gaze behaviour of elite and non-elite batters prior to release of the ball? What method do elite batters use to follow the ball during its flight (smooth pursuit or predictive saccade) and is this method the same as non-elite players? Do the visual strategies employed by elite and amateur batters impact their ability to make effective decisions? It is hoped that this information can provide vital information, which could potentially be used to help coach players in the future. This information can provide the platform for a vision-based cricket training programme, giving young aspiring cricketers the best possible chance of reaching their goals.

1.5.6 Study three research question and hypotheses

1. What eye-movements (fixations, fixation location and fixation duration) do elite and amateur batters produce prior to the release of the ball (i.e., during the preparatory phase and bowler's run up) when facing spin and medium pace bowlers?
    - It is hypothesised that batsmen will fixate on varying aspects of the bowler's body (mainly upper body) prior to the release of the ball in accordance with McRobert et al. 2009.
2. Do elite and amateur batters produce different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowler's run up) when facing spin bowling compared to medium pace bowlers?
    - It is hypothesised that there will be a significant difference in the gaze behaviour of both elite and amateur batters as they face the different types of bowling (spin vs. medium-paced) in accordance with McRobert et al., 2009.
3. Is there a significant difference in eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) between the elite and amateur batters?
    - According to the literature (e.g., Vaeyens, Lenoir, Williams, & Philippaerts, 2007; Williams & Ford, 2008) it is hypothesised that there will be a significant difference in the eye-movements of elite compared to amateur batters. It is expected that the elite players will have more consistent search strategies when compared to amateur batters.
4. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) when they make a correct decision regarding shot selection, compared to when they make an incorrect decision regarding shot selection?
    - There will be a significant difference in the gaze bahaviour prior to ball release (fixations, fixation duration and fixation location) when both elite

and amateur batters make a correct decision compared to an incorrect decision.

5. Do elite and amateur batters use different methods to track the ball during its flight when facing spin compared to medium pace bowling?
    - It is hypothesised that batters will try to utilise smooth pursuit tracking for all/the majority of the ball flight when facing spin bowling, as the ball's velocity will be slow enough to track throughout its flight.
    - It is hypothesised that batters will not pursuit track the ball through the entire ball flight when facing medium-paced bowlers. Instead, they will utilise predictive saccades as suggested in the previous research (Croft et al., 2011; Land & McLeod, 2010; Mann et al., 2013).
6. Is there a significant difference in the method for tracking the ball (percentage of ball flight tracked), when elite and amateur batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
    - There will be a significant difference in the method of tracking the ball, specifically the duration of pursuit tracking, between correct decision-making and incorrect decision-making.
7. Is there a significant difference in the method for tracking the ball during its flight (percentage of ball flight tracked) between elite and amateur batters?
    - It is hypothesised that elite batters will pursuit track a significantly high percentage of ball flight compared to amateur batters.

1.6. Thesis chapters

Chapter two will present a review of literature which, will start with a presentation of the current understanding of visual attention and the association between gaze and attention. Chapter two will then progress and introduce eye-tracking, how eye-trackers work and the importance of eye-tracking research within sporting context. The main literature within the field of vision, occlusion and eye-tracking in sport and more specifically eye-tracking within cricket will then be presented to the reader. It is hoped that after reading chapter two, the reader will have a strong understanding as to why this programme of research is necessary. Following the review of literature, chapters three, four and five will present the findings from the three original studies carried out within this research programme.

Chapter six will present a general discussion relating to the full research programme and discuss the main findings that emanated from chapters three, four and five, as well as the cross-study findings and implications of these findings. Chapter six will also present a discussion relating to eye-tracking methodological design, specifically in relation to naturalistic vs. laboratory research. The chapter will conclude with some recommendations for future research and limitations of the current research programme. The final chapter in this thesis, chapter seven, will be present the implications of the research for applied practice. Chapter seven will discuss how the findings from the three original studies within this programme of research alongside previous research, can be applied in the real world. Chapter seven will start with a discussion of how coaches and practitioners can use the key findings to develop video-based visual perception training programmes and discuss the best practice and structure that these training sessions should take. The chapter will also present discussions relating to the use of modern technology, specifically virtual reality, and limiting the use of traditional coaching tools (bowling machines). Chapter seven concludes by providing advice to bowlers about how they can use these findings to try and deceive batters and gain an advantage.

Chapter 2.0
Review of Literature

The present body of research examines the visual strategies of amateur and elite cricket batters by using eye-tracking technology. It is therefore necessary for the reader to have a solid understanding of the principals and theories relating to eye-tracking and the study of attention as well as knowledge of the theoretical underpinning for this programme of research. Accordingly, this review of literature will start with a presentation of the theoretical foundation underpinning the research. The current understanding of visual attention and the association between gaze and attention will then be presented. The chapter will then progress and introduce eye-tracking, how eye-trackers work and the importance of eye-tracking research within sporting context. The main literature within the field of vision, occlusion and eye-tracking in sport and more specifically eye-tracking within cricket will then be presented to the reader. It is hoped that after reading this chapter the reader will have a strong understanding as to why this research programme is necessary.

2.1 Theoretical foundations

Researchers investigating skill acquisition and motor control have continually explored theoretical perspectives that explain the underlying processes of control, co-ordination and the development of human movements (Anson, Elliot, & Davids ,2005). While biomechanics, physiologists, coaches and other sport scientists have developed their ability to measure skilled performance, psychologists and skill acquisition researchers have been unable to develop a unified theory of the processes involved in process of skill acquisition (Anson et al., 2005). In general, two theoretical perspectives have traditionally been presented within the skill acquisitions and motor learning literature: information processing and ecological psychology/ecological dynamics approaches.

2.1.1 Information processing

Information processing focuses on how information is gathered, processed and stored, and how this information is used to execute skills or motor tasks. Information processing theorists explain motor performance as similar in many ways to how a computer functions (Schmidt & Wrisberg, 2008). Indeed, the invention of the computer provided the perfect metaphor for information processing. Much like a computer, information from the environment enters the central nervous system (CNS) (input), is stored in memory and is then used in order to perform a movement (output) (Schmidt & Wrisberg, 2008). Cognitive psychologists, as the name suggests, are therefore interested in the role that the brain plays in acquiring, storing and performing skills (McMorris, 2004). While there are variations between models of information processing, most models attempt to explain the process through three main sections: stimulus identification (perception), decision making, and response programming (action) (Schmidt & Wrisberg, 2004) (see figure 2.1)

According to information processing theorists, input is all of the information within the environment. Humans seek out information within the environment via our senses and this input then travels into our systems via the CNS. When the input reaches the CNS the individual needs to perceive and make sense of that information. Two individuals may theoretically 'see' exactly the same visual scene and hear the same auditory signals, however, they may interpret the experience completely differently (McMorris, 2004). This is because perception is based on interpretation of the environment and perception must therefore be considered indirect from an information processing perspective (Heuer & Sanders, 1989). The first role of the CNS during information processing is consequently to make sense of what the information means, a process referred to as perception (McMorris, 2004). Due to the vast amount of information available from the environment, information processing theorists highlight the need to filter irrelevant cues (cues that do not have any impact on the task at hand) and focus only upon the task relevant information. Selective attention, i.e. attending to the relevant cues while ignoring the irrelevant cues, is therefore a fundamental component of information processing. Information processing theorists highlight the role of memory in this process. The interaction between what is stored in our long-term memory (LTM) and what is being held in our short-term memory (STM) forms the basis of our interpretation of the situation: what we select and attend to, as well as how we decide on our response. The ability to determine which cues are relevant and which are not takes place in the STM. If this STM is forewarned by the LTM regarding the important aspects of a given environment, they will likely be able to gather all the meaningful information (McMorris, 2004). The interaction between our STM and LTM also influences our decision making. Decision making is the process of committing to a particular course or action. Specific definitions of decision making from the literature define decision making as "the selection of one option from a set of two or more options" (Klein, Calderwood & Clinton-Cirocco, 1986, p.186) or "a set of evaluative and inferential processes that people have at their disposal and can draw on in the process of making decisions" (Koehler & Harvey, 2004, preface xv.). The latter definition highlights the processes that people can draw upon in order to make decisions. From an information processing theory perspective, information stored in the LTM and STM can guide our decision making and actions. If an individual knows that in a given situation a certain action worked well for them in the past, then the same or similar actions will likely lead to successful outcomes now.

Once a decision has been reached about the most appropriate course of action, the final stage of the processing of information highlights how we organise our response. The action or movement that is required is sent via the CNS and through the peripheral nervous system to our muscles so that a movement can take place (McMorris, 2004). Once skills are learnt, they are stored as motor programmes within the LTM. Motor programme can be executed and can trigger a movement with minimum effort or organisation (McMorris, 2004). Individuals recognise what motor programme (stored movement) is required for the action and then execute that motor programme, meaning that humans are able to carry out an act or action without a conscious effort. Classical information theories suggested that we store one motor programme in our LTM for every action we have learnt. Both complex actions such as bowling the ball in cricket and simple actions such as running are all stored as motor programmes. Any variations of these actions, e.g. bowling a short-pitched delivery in cricket as opposed to a full pitched delivery, or bowling on a different pitch or in different conditions, would be stored as its own separate motor programme. One major criticism of motor programmes and the information processing approach was therefore the amount of storage capacity motor programmes would require in order to store all of our actions as motor separate motor programmes. To address this concern, Schmidt (1975) introduced the concept of generalised motor programmes based on work within his schema theory. Schmidt (1975) suggests that we store one generalised motor programme for a certain skill and action and can adapt this for different situations and conditions. Therefore, referring to the previous example, the cricket bowler would store one action (generalised motor programme) for bowling and would be able to adapt this generalised motor programme to meet the demands of the conditions, the pitch and change the length and speed of the delivery.

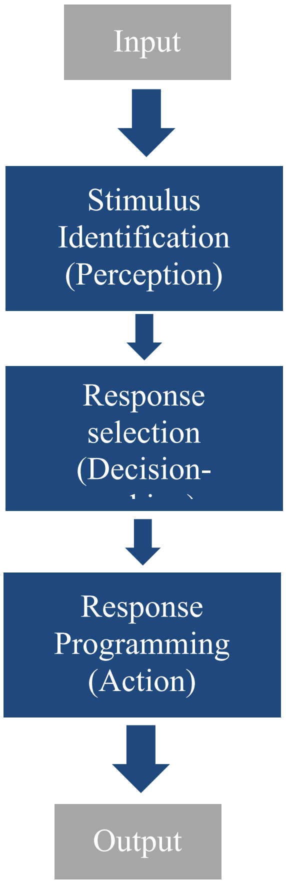

Figure 2.1: A generic model of information processing from Schmidt and Weisberg (2008), containing the three sections of stimulus identification, response selection and response programming on which most models of information processing are based.

2.1.2 Ecological approaches

Contrary to the cognitive view of information processing, ecological psychology focuses more on what can be observed rather than inferred and therefore sits more within the school of behaviouralist psychology (McMorris, 2004). The forefathers of ecological psychology were James Gibson (1958, 1966, 1979) and Nikoai Bernstein (1967), who countered the view of information processing with the direct perception or ecological psychology approach. The Gibsonian view of perception suggests that the relationship between human and the environment is perceived unaided by cognitive factors such as memories or interpretation (Vickers, 2007). Visual information from the environment is perceived directly and picked up through perception. Ecological psychology therefore attempts to explain motor control and movement without the involvement of the CNS. Ecological psychologists may acknowledge that the CNS has a small part to play in human movement, however they do not believe that it should be the focus of research as researchers can only speculate as to the role of the CNS system (McMorris, 2004).

Instead of trying to explain what happens within the CNS during movement (information processing), ecological psychology focuses on the relationship between the individual and the environment. Gibson (1958) realised that the vast majority of animals use their vision to guide movement and therefore when the environment is totally dark, movement or locomotor behaviour stops for the majority of animals. This idea led to one of the key aspects presented by Gibson: the optical array and the optical flow (Gibson, 1958). At any given time, there are numerous sources of light that reach the human eye. According to Gibson, this can be thought of as an optical array which contains all of the information about the environment available to the individual. This optical array provides the individual with definite and unambiguous information or a 'projection' of the environment including information about the size, shapes, textures, locations and the different objects within the space. When the head or the eyes are moving (which is usually the case for humans), the optical array is different from one observation to the next, meaning that the optical array continually changes and updates (Lee, 1980). The fact that the optical array changes from one moment to the next is described by Gibson (1958) as the optical flow. The optical flow refers to changes in the optical array caused by the movement of the individual or movement within the visual scene. As we move through an environment, the optical array reaching the retina changes. Ecological psychologists claim that humans do not need to process all the information through the stages suggested within information processing theory and instead the optical array and the optical flow guides our movements (Vickers, 2007).

Gibson (1979) also introduced another fundamentally important aspect of ecological psychology: affordances. According to Gibson, the environment offers individuals opportunities or affordances at any given time and therefore dictates what we as humans can do in the given situation (McMorris, 2004). Gibson argued that "the affordance of an environment is what it offers to the animal" (Gibson, 1979, pp. 127). For example, a pathway that is flat and even affords the opportunity for an easy walk, whereas a pathway that is cracked, uphill and loose underfoot affords a much more dangerous walk (Vickers, 2007). Our environment is constantly full of affordances and the individual must seek out these affordances in order to act upon them. Unlike information processing theorists who believe that perception always occurs before action, ecological psychologists believe that these two constructs are linked and therefore coined the phrase perception-action coupling (see figure 2.2). In order to perceive an affordance, the individual must search the environment for that affordance and therefore they are acting upon the environment. Seeing an affordance is consequently reliant on movement in order to receive the affordance in the first place (McMorris, 2004). As we act and move, we use sensory information (perception) to help us control our movement (action) (McMorris, 2004).

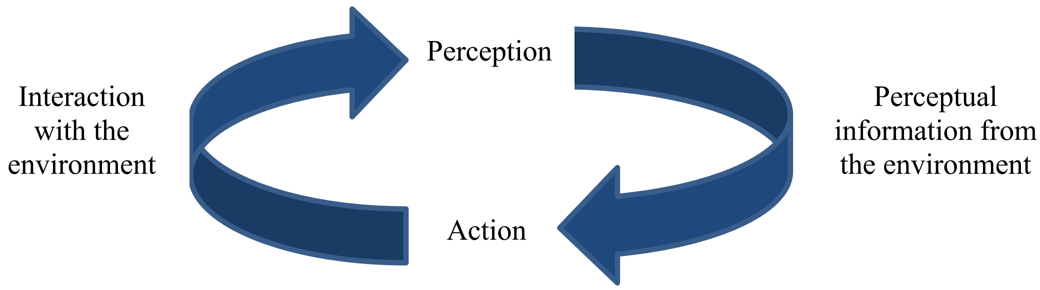

Figure 2.2: A schematic illustrating Perception–Action Coupling adapted from (Hamill, Lim, & van Emmerik, 2020).

At the same time as Gibson's work, Bernstein's ideas led to the dynamic systems approach (Bernstein, 1967). Bernstein (1967) proposed the 'degrees of freedom problem', where he suggested that the central issue to any comprehensive theory of motor control is to account for how and when individuals gain control over and regulate multiple degrees of freedom during an action (Summers, 2004). Degrees of freedom refer to the separate elements of the body that are able to move independently and need to be controlled during co-ordinated action, e.g. limbs, joints, muscles etc. To attempt to solve the problem of degrees of freedom, the idea of constraints was introduced (Summers, 2004). Constraints are the boundaries put in place that limit the movement or number of configurations that the dynamics system can take at any given time (Summers, 2004). Bernstein suggests that when first learning a skill, individuals go through three stages. The first stage is freezing, where we limit movement in order to freeze the degrees of freedom. When we develop and improve, we start to incorporate more movement and challenging techniques in order to free some of the degrees of freedom. The final stage, when we have fully mastered the skill, is exploitation, where the individual can exploit the degrees of freedom and develop techniques that can be performed in any situation or context and result in a positive outcome (Vickers, 2007). Dynamics systems suggests that the peripheral nervous system organises our movements and that these movements are simply obeying scientific law rather than as the result of memory or formal instructions from the CNS (Summers, 2004).

According to some (e.g. Summers, 2004) the most influential general framework that has been developed from the ecological perspective and dynamic systems perspective is Newell's (1986) constraints led theory (see figure 2.3). The constraints led perspective suggests that skill acquisition depends on the interaction between the individual (or the organism), the task, and the environment. Individual constraints refer to the characteristics of the individual. The psychological, physical and emotional make-up of the performer constrains what is possible and may shape the way that the individual approaches the task (Brymer, 2010). Environment constraints refer to both the physical factors, i.e. the immediate environment, and the socio-cultural factors, i.e. friends, families, culture and expectations. Finally, the task constraints refer to the goals and the rules of the task that is being attempted. The development of skill and the learning process refers to the individual search for the most effective solution to the task at hand which is constrained by the individual, environmental and the task constraints (Summers, 2004).

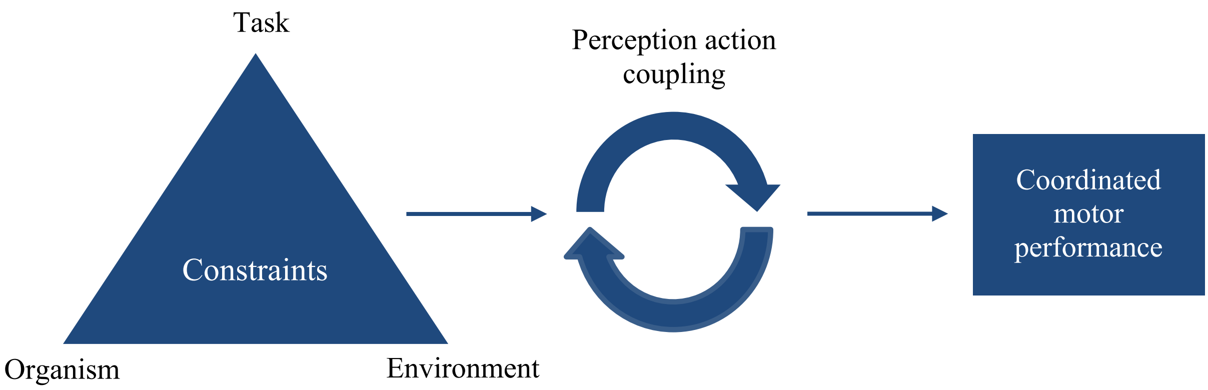

Figure 2.3: A schematic illustration of Newell's constraint led perspective (1986).

The views of ecological psychology (constraints led and dynamic systems) and information processing differ considerably. Information processing suggests that movement is controlled by the CNS whereas ecological psychology argues that the environment guides our movement and that the CNS only has a role to play when it comes to making a decision about the action to perform. Once that decision is made, perception-action coupling guides and controls our movements through the environment. While some researchers hold onto their strongly held beliefs that their own theory is the only way to explain movement and skill acquisition, the majority accept that neither theory can comprehensively explain skill acquisition and skilled performance (McMorris, 2004). Information processing theory is considered by some to be the most appropriate way to understand and examine decision making, whereas ecological psychology explains the processes involved in movement and skill execution fundamentally better (McMorris, 2004). While there are always going to be the 'die hard' psychologists who passionately support their view and oppose anything different, many researchers believe that a combination of both theories where you take the most appealing aspects of each and form a hybrid theory is the way forward to the field (McMorris, 2004). Indeed, even the most vehement information processing theorist would struggle to say that the environment has nothing to do with movement. Likewise, ecological psychologists must concede that the CNS, memory and past experiences can also guide execution of skill and specifically decision making, otherwise you would never get two individuals responding the same way to the same stimulus.

2.2 Hybrid approaches

While some researchers fully acknowledge the role of cognition and the CNS in movement, others who align with the ecological dynamics perspective argue that the CNS has no or very little input in guiding human movement. Recently, there has been an argument to move towards a 'mesh' or 'hybrid' approach to skill acquisition as a combination of both approaches being the most comprehensive way to explain human movement. Christensen, Sutton, and McIlwain (2016), however, argue that cognitive processes are present and make a vital contribution to every skilled action, and that no action is or can be performed without cognitive input. As such, Christensen et al. (2016) introduce their Mesh theory of skill acquisition. The Mesh approach stemmed from Christensen et al. (2016) challenging the traditional opinion that when a skill is fully learned it can be performed automatically without any cognitive input. The majority of skill acquisition literature suggests that experts can perform skills automatically; indeed, in the real world of sport and coaching there is a commonly held belief that experts perform without thinking or rely on 'muscle memory' to perform to the highest level (Christensen et al., 2016). The basic idea on which Christensen et al.' (2016) theory is centred is "that cognitive control is not eliminated in advanced skill, but is rather shifted primarily to higher-level action control" (pp.38). Therefore, cognitive control is always present and any comprehensive theory and interpretation of skill acquisition and human movement must therefore acknowledge the role the CNS has on movement. This Mesh approach argues the need to explore and understand cognitions in the real world and incorporating factors of both information processing and cognitive psychology with more ecologically valid and in situ research. Such an approach has the potential to broaden the field of ecological skill research, develop a clearer understanding of skill in "in the wild" (Christensen & Sutton, 2018 pp. 158) and provide the basis for numerous experimental designs. Hardened ecological psychologists may argue that the Mesh approach fails to present a strong theoretical commitment, however, Christensen, Sutton and McIlwain (2018) argue that strong theoretical commitments are not needed as a starting point for any real world or naturalistic research.

This programme of research is underpinned by a hybrid or Mesh approach (Christensen et al., 2016) that is somewhere between the two perspectives of ecological psychology and information processing. While hardened theorists of either side may argue that their approach is correct and the best way to explain human movement, most psychologists would argue that it is impossible to completely explain human movement and skill acquisition from either information processing or an ecological perspective (McMorris, 2004). As a result, the best way to approach the programme of research and answer the research questions is to utilise aspects of both approaches in accordance with the aims of each study. The programme of research reflects the progression within the literature from information processing to more contemporary ecological psychology studies. The studies begin with laboratory-based study (study one), which would be considered by most to be underpinned by information processing. Within this study, movement is restricted and the data collection takes place in an extremely artificial environment. Ecological psychologists would argue that both these factors ignore the role of the environment and how this impacts movement, decision making and eye movements. Some psychologists would argue that behaviour cannot be fully understood unless it is performed within the specific environmental context in which those behaviours would naturally emerge (Renshaw, Davids, Shuttleworth, & Chow, 2007) and artificial tasks performed in the laboratory do not necessarily represent the participants' real behaviour (Araujo, Davids, & Passos, 2007). Therefore, to increase the ecological validity within this programme of research, studies two and three moved away from the laboratory setting towards a more ecologically valid environment. Ecological validity within this programme of research consequently refers to the extent to which the testing environment is similar to the real world where the participant would perform. It can be defined as "the extent to which the environment experienced by the subjects in a scientific investigation has the properties it is supposed or assumed to have by the experimenter" (Bronfenbrenner, 1977, p. 516). Moving from the laboratory to the 'real-world' not only increases the ecological validity, but also means that the representative task design of the study is much closer to those that the participants would experience in a real game of cricket or training session. In the study of vision, perception and action and skill acquisition, representative task design has been defined "as the generalisation of task constraints in experimental designs to the constraints encountered in specific performance environments" (Pinder, Davids, Renshaw, & Araujo, 2011), i.e. the representative design relates to how similar the task is to the task that the participants would face in the real world.

2.3 Visual attention

Due to the importance of the visual system, over the past 30 years, most studies centring on attention and visuomotor control have focused primarily on visual attention. The first paper to highlight attention was published in the Vision Research journal in 1976 and during the 1980s, only six more papers were published (Carrasco, 2011). The number of articles published on attention has dramatically increased since 1980s, with over 600 published articles today. The rate of published visual attention research has exponentially increased and the number of publications has more than doubled every 5 years from 1970 through to 2005 (Carrasco, 2011), showing that visual attention is one of the most popular topics in psychology. One theory as to why this topic has drawn so much interest, is the fact that vision is considered by most to be our chief sense and more of our neural cortex is devoted to our visual system than any of our other senses (Eysenck & Keane, 2015). Indeed, it is believed that visual attention serves to affect almost all types of behaviours (Farivar, 2003).

Every time an individual opens their eyes, they perceive a vast, sometimes overwhelming amount of visual information. Despite this, humans are able to experience an effortless understanding of the visual world that is presented to them (Carrasco, 2011). This understanding requires us to select relevant information while filtering out the irrelevant noise. Visual attention can therefore be described as the process that "turns looking into seeing" (Carrasco, 2011 p. 1484). William James (1890/1950, p. 402) emphasised this in asserting, "my experience is what I agree to attend to". Attention allows us to successfully perform visual tasks and overcome the shortcoming of the human visual system's i.e. its limited capacity. In doing so our attention highlights the relevant, while ignoring the less relevant stimuli within our visual environment. Selective attention, therefore, is of fundamental importance as it enables us to gather relevant information and guide our behaviour (Carrasco, 2011). We achieve this by foveating on a certain point or aspect of the visual scene. Selective attention is the generic term for these mechanisms, and it leads our experience to be dominated by one thing rather than another. This allows people to select the visual cues that is most important to their task in hand or current situation (Chun & Wolfe, 2005).

The study of visual attention is applicable to any environment that requires an individual to use their visual system (Chun & Wolfe, 2005). In order to perform any action efficiently attending to and selecting the correct visual stimuli is crucial because at any point in time far more visual stimuli are present within the environment than can be successfully processed (Chun & Wolfe, 2005). Due to several limitations and the capacity of the visual system, visual attention should therefore be considered a selective process (Carrasco, 2011). In order to cope with the vast number of visual stimuli, the human visual system uses a number of different attentional mechanisms and these perform two vital roles. First, attention is used to select key information and to ignore the irrelevant stimuli (Chun & Wolfe, 2005). Second, attention can facilitate and enhance the selection of information according to the current state and goals of the individual (Chun & Wolfe, 2005). With attention, individuals "are more than passive receivers of information; they become active seekers and processors of information, able to interact intelligently with their environment" (Chun & Wolfe, 2001, p.273).

2.3.1 Top down/bottom up

How an object is located and processed within the visual field depends on whether a top-down or bottom-up process is used, otherwise known as endogenous or exogenous attention (Posner, 1980). During endogenous or top down attention, attention is considered to be under the direct control of the individual (e.g., I choose to attend to a certain point on a computer monitor). This is also sometimes referred to as goal-driven attention (Yantis, 1998). Endogenous attention is voluntary, explicit, effortful, and individuals specifically select to attend to one location over another. Attention can also be guided exogenously, by an environmental stimulus (e.g. noise, flash of light etc.), which can draw attention automatically to a different location (Chun & Wolfe, 2005). This is referred to as bottom-up, or stimulus-driven attention. A camera flash, which catches your eye, is an example of exogenous attention. Exogenous attention draws attention automatically, is rapid, and often only maintains attention for a brief time (Posner, Snyder, & Davidson, 1980). The extent to which top-up or bottom-down processing occurs governs the amount of control an athlete has over their gaze and visual attention.

There are numerous bottom-up, exogenous stimuli that can capture an individual's attention. For example, sudden luminance changes, edges, colour, textures and motion. An abrupt onset of bottom-up stimuli can draw attention even when the informative is not helpful to the task in hand. This can even happen when individuals are instructed to ignore the stimuli (Jonides, 1981; Remington, Johnston, & Yantis, 1992). An important aspect of bottom up processing is saliency. Salient or noticeable features are those, which immediately stand out relative to their neighbours, and are usually independent of the nature of a particular task (Itti & Koch, 1999). If a visual stimulus is salient, it will 'pop out' of the visual scene, especially if it is novel or occurs in an event that is unusual. If this occurs, the salient stimuli will likely draw the attention of the performer.

During top-down endogenous attention, attention is controlled by our memories, experiences and knowledge of certain situations rather than sensory information (Corbetta & Shulman, 2002). Top-down processing originates from the higher cortical areas and is linked to awareness, insight, and understanding. Sport is driven by a combination bottom-up processing, such as novelties, unexpectedness, and top-down factors such as goals, game plans, anticipation, and intentions. The extent to which one factor dominates over the other is a hot topic of debate within the sporting world, and a question that is important to answer (Vickers, 2007). Context and experience play a crucial role when it comes to top-down processing. For example, elite experienced players may have learnt to ignore the bottom-up stimuli and maintain top-down focus, however novices may not have mastered this skill. They have not yet developed the ability to discriminate and assign meaning to higher order stimuli, which make the task easier to perform. Indeed, even elite players might attend to bottom-up stimuli in unfamiliar surroundings, such as in their first big final match, or in front of their first big crowd.

2.3.2 Gaze and attention

While it is generally accepted that humans use a combination of exogenous and endogenous attention, whether our attention and gaze are linked is an area of hot debate (Vickers, 2007). Attentional selection occurs over space and time (i.e., visual spatial attention) (Chun & Wolfe, 2005). It allows humans to direct attention to a particular location within their visual field and prioritise this location over others. Perhaps the most popular metaphor that has been used to understand attention over the years is the spotlight metaphor. The metaphor has become popular within the field as it highlights some fundamental aspects of attention; for example, the understanding that attention can be directed at the will of the individual like a beam of light and uncover the meaning of the environment (Chun & Wolfe, 2005). One of the key methodological designs used to explore the spotlight theory of attention is cueing experiments. In cueing paradigms, participants are required to respond as quickly as possible to a flash of light or another visual stimulus. Prior to the flash of light, a cue is presented to the participant. The function of the cue is to draw attention to a specific target or location. Cues have been presented in various different forms, including, brightening or outlining an object (Posner & Cohen, 1984), the onset of a simple stimulus (Eriksen & Hoffman, 1973; Posner et al., 1980), or as a specific symbol. For example, an illuminated directional arrow which indicates the direction where attention should be focused (Jonides, 1981; Posner & Cohen, 1984). These cueing experiments show that the cues improve detection of and speed of response to specific stimuli presented at the cued location (Chun and wolfe, 2005). Therefore, Posner et al. (1980, p. 172) described attention as a "spotlight that enhances the efficiency of the detection of events within its beam".

2.3.3 Dissociation of attention and gaze

It is easy to look in one location and attend to something else. For example, a footballer maybe looking at one teammate, but attending to another, who is in a different location on the pitch. When this occurs the location of the gaze and the location of attention are separate or dissociated. Numerous studies have shown that gaze can be easily dissociated from attention (e.g., Posner, 1980; Treisman & Gormican, 1988). These studies typically employ methodologies that require participants to use covert and overt attention. Spatial attention can be either overt (I.e. when individuals moves their vision to a specific and relevant location and then focus their attention at this location), or covert (i.e. when attention is deployed to a certain location without any eye-movements, through our peripheral vision or other senses) (Carrasco, 2011). Covert attention allows humans to monitor their environment without the need for eye movements. Hermann von Helmholtz was the first scientist to investigate and demonstration the existence of covert attention (Helmholtz, 1896. cited in Bennett & Hacker, 2013). Helmholtz carved a pinhole into a wooden box. The box was completely darkened and Helmholtz fixated upon the light caused by the pinhole. On the background of the box was printed a range of large letters. Helmholtz found that with a momentary illumination, caused by a spark of light, of the completely darkened field (an illumination that was too short for measurable eye movement to occur), he was able to recognise the groups of letters surrounding his fixations. Helmholtz's observation indicated the existence of a mechanism, which shows attention can be moved independently from eye-movements (Nakayama & Mackeben, 1989).

Since the work of Helmholtz (1896) numerous researchers have explored covert attention. Posner (1980) in particular carried out an extremely influential study in this area. In his study, participants were required to respond as quickly as possible when they detected the onset of a light on a computer monitor. Before the light was presented, the participants were shown one of two cues. Either a cue was presented in the middle of the screen (usually at the same location as the participants focus, which was relying on overt attention), or a cue presented in the participant's peripheral visual field (detection of this cue would therefore rely on covert attention). These cues told the participant where the location of the subsequent target light would occur. The cues were mostly correct cues (i.e. they correctly informed the participant where the target light/object would appear), but sometimes were incorrect (i.e. provided false information to the participant about the location of the target light/object) (Eysenck & Keane, 2015). Posner (1980) famously discovered that valid cues produced quicker responses compared to neutral cues and invalid cues, which produced slower respond times. The goal of this experiment was to see if differences in reaction time would occur as a result of the use of covert or overt attention. Reaction times during both conditions did not differ showing that attention could be shifted just as quickly with or without a shift in gaze.

Based on these results, Posner (1980) and many others concluded that the neural systems used to direct gaze and attention were separate. Since it was easy to dissociate gaze and attention, i.e. look at one location and attend to another, knowing where the gaze was in a specific space contributed little to knowing where the individual's attention was. Eye-movement and eye-tracking studies were therefore given less weight when compared to studies investigating the internal processes of attention.

2.3.4 Evidence against dissociation of gaze and attention

The extent to which a shift in gaze indicates a shift in attention has gone through two major schools of thought. The studies mentioned above (Helmholtz, 1896; Posner, 1980; Treisman & Gormican, 1988) suggest that it is easy to separate, or disassociate the locus of gaze with the locus of attention and this, until recently, was the dominating belief

(Vickers, 2007). Therefore, the use of eye-trackers to measure the point of gaze tells us little about the locus of attention. However, recently there has been a major shift in the literature. Research has reported that under certain conditions a shift in the gaze is preceded by a shift in attention (Corbetta, 1998; Deubel & Schneider, 1996; Henderson, 2003; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher & Blaser, 1995; Shepherd et al., 1986). There is now evidence to support the idea that when a saccade is made to a new location there is a corresponding shift in attention in the direction of the saccade (Vickers, 2007). This suggests that when individual shifts their gaze to a new location, they also move their attention to the same location. However, it is important to stress that once the gaze and attention have been moved to the new location, how long the gaze is positioned at this location may not always indicate how long attention is held at there. Individuals may still covertly direct their attention to another part of the visual scene even when their central gaze remains on a location (Vickers, 2007).

Shepherd et al. (1986) used a similar set up to the study conducted by Posner (1980) and others. They did however manipulate spatial attention by randomising the probability of a peripheral stimulus would occur, e.g. 50/50, 80/20 and 20/80 probability that a peripheral stimulus would appear in the same or opposite position to the actual target location. The cue arrow served the purpose of generating expectations of the target location. In the 50/50 trials the cues provided no information about which side the target location would appear. In the 80/20 and 20/80 conditions the cues provided accurate spatial information and a clear advantage was found for the cues position. The longer the duration between the onset of the cue and the onset of target location the greater the advantage and shorter the reaction time. The reaction times were similar for both the overt and covert condition, with one major exception. When the participants were required to saccade in the direction of the cued arrow but still maintain their attention on the central point they were not able to do so. Therefore, when a saccade was made, there was also a shift in attention to the direction of that saccade.

There is also physiological evidence supporting the fact that a saccade is followed by a shift in attention e.g. Corbetta (1998). Corbetta (1998) produced a metanalysis examining functional neuroimaging studies in humans and single unit recording studies in monkeys to determine if the neural basis of covert attention and its relationship with saccadic behaviour. Corbetta argues that the parietal cortex and frontal cortex signal produced and recorded during covert attention, are the same as those seen when an individual (human or monkey) voluntarily allocated attention to a visual location.

Essentially proving that common neural structures are involved in moving gaze and shifting visual attention. Corbetta (1998) concludes his paper by arguing that the hypothesis that attention and eye-movements are separate processes, can and should be rejected.

By utilising both overt and covert attention we can successfully process information from different locations during a fixation (Hoffman & Nelson, 1981; Posner, 1980; Posner, Nissen, & Ogden, 1978). Our eye-movements are therefore not random but guided by the information picked up within our peripheral vision prior to the movement (Hoffman, 1998). Therefore, it can be considered that attention plays an important role in the programming and execution of eye-movements, including, saccades, smooth pursuits, and vergence movements (Hoffman, 1998). Indeed, many researchers argue, that it is our covert attention that guides our overt attention, i.e. our covert attention preceded eye-movements. Once an athlete shifts their gaze to a new location, they also shift their attention to the same location.

2.4 Eye-tracking and the visual system

The idea that the eyes can reveal insight into the inner workings of the mind has been well established anecdote from many philosophers, and as such there has been significant scientific interest and research conducted within the area. With the general consensus that attention is guided by eye-movements, and that a shift in attention is subsequently followed by a shift in gaze (Deubel & Schneider, 1996; Corbetta, 1998; Henderson, 2003; Hoffman, 1998; Hoffman & Subramaniam, 1995; Kowler et al., 1995; Shepherd et al., 1986), the study of eye-movements via eye-tracking has taken off over the past 50 years. The development of sophisticated eye-tracking technology, both mobile and stationary, has afforded researchers the opportunity to understand the nature of eye-movements and their role within performance domains.

2.4.1 The visual system and the eye

To understand the benefits of using eye-tracking technology, the first step is to appreciate the workings of human vision and the visual system. The eyes are the dominant sensory organs of the brain (Hubel & Weisel, 1968) and work together to produce binocular vision. This process starts when light is reflected off objects within our visual field and travels into our eyes through the pupil. This light then travels through the lens, which flips the image upside down and the image is projected onto the retina (the back of the eyeball) (Discombe & Cotterill, 2015). The retina is filled with light-sensitive cells called cones and rods; these transduce (convert) the incoming light into electrical signals, which are then sent via the optic nerve for processing in the visual cortex (Holmqvist et al., 2011). Rods are more numerous (about 120 million), extremely sensitive to light and located everywhere in the retina except at its very centre. Rods are used exclusively for vision at very low light (Palmer, 1999). Cones are less abundant (about eight million), are less sensitive to light, and heavily concentrated in the centre of the retina. Cones are responsible for our visual experiences under most normal conditions. They are very sensitive to visual detail and provide us with colour vision (Discombe & Cotterill, 2015; Palmer, 1999).

There is a small area of clear vision at the bottom of the retina called the fovea. The fovea can be conceptualised as a tiny pit, with a high concentration of rods and cones, and is responsible for our central, sharpest vision (Williams, Davids, & Williams, 2000). Cones are over represented in the fovea, while they are sparsely distributed in the periphery of the retina (Discombe & Cotterill, 2015). The image produced when we foveate (focus) on an object is clear and colourful, while the images produced by the peripheral area are blurry and less colourful. Only when we foveate or fixate on an object can we see the object clearly, or in high definition. The fovea spans approximately 2° of the visual field; this means we only see a clear sharp picture in a limited section of our visual field. This 2° of visual field is roughly the size of your thumbnail at an arms-length away (Land, 2006). It is, therefore, crucial, that to see the world and selected objects clearly, we have to bring the light onto the fovea and to do this we have to move our eyes (Bojko, 2013) (Discombe & Cotterill, 2015).

On average we make three to five eye-movements every second (Holmqvist et al., 2011). We make numerous vertical movements, diagonal movements and rotations of the eye. Other common eye-movements include vergence, which is when the eyes travel in different/opposite direction (e.g. when the eyes move closer together to track an object travelling towards us). Finally, there is version, which is when the eyes move in the same direction, for example, when we track a ball being hit back and forth in a game of tennis (Carpenter, 1998; Discombe & Cotterill, 2015).

2.4.2 Eye-movements

Most studies in eye-tracking research focus on fixations, saccades, and smooth pursuits (Bojko, 2013). Fixations are technically not a movement at all but an absence of movement. The eye stays relatively still to allow for visual perception to take place (Holmqvist et al., 2011). Fixations usually last between 100ms to 300ms (Holmqvist et al., 2011), and there is a general acceptance (Bojko, 2013; Duchowski, 2002; Deubel & Schneider, 1996; Corbetta, 1998; Henderson, 2003; Hoffman, 1998; Hoffman & Subramaniam, 1995; Kowler et al., 1995; Shepherd et al., 1986; Vickers, 2007) that when we record a fixation we also record attention (i.e. the belief that when we fixate on an object, our attention is also on that location). In between these fixations for visual perception we have saccades. Saccades are rapid shifts of the line of sight made to bring the fovea (the centre of best vision) from one selected location to another, so a saccade is essentially a rapid movement from one fixation to another (Kowler, 2011). Saccades are a useful and efficient way for the brain to sample the visual environment; they are extremely quick movements (the quickest movement the body can produce) and usually only take 30ms to 80ms to complete. During a saccade the eye moves at such a high speed that it be said that we are technically blind (Discombe & Cotterill, 2015; Holmqvist et al., 2011).

Another common eye-movement measured during eye-tracking studies are smooth pursuits. Smooth pursuits occur when we slowly track an object, for example, a ball flying through the sky. Technically, smooth pursuit is not under voluntary control (Kowler, 2011), we can't perform a smooth pursuit unless we have something to follow. For example, if you look at a white wall you could not make a smooth pursuit from one side to the other; you would make numerous fixations and saccades (Discombe & Cotterill, 2015). If, however, a light was shone on the wall, and moved from one side of the room to the other, you could produce a smooth pursuit to follow the light.

2.4.3 Eye-tracking

The measurement of eye movement involves two basic challenges: measuring the movement of the eye and mapping the gaze to the 'real' external environment (Feng, 2011). Attempts to objectively measure eye-movements in science go back over 100 years (Duchowski, 2002, 2003; Wade & Tatler, 2005), and these early methods of eye-tracking could be extremely intrusive and uncomfortable for the participant (Duchowski, 2007). Some of these early methods included electrooculography systems, (placing electrodes around the eye to monitor vertical and horizontal eye-movements) and the magnetic search coil method (placing small coils of wire embedded in a modified contact lens onto the eye, usually after administering an anaesthetic, which can then track the movement of the eye) (Discombe & Cotterill, 2015).

A breakthrough in eye-tracking research was the development of the first non-invasive eye-tracking apparatus in the early 1900s, based on photography and light reflected from the cornea (Wade & Tatler, 2005). This system can broadly be considered as the forerunner of contemporary video-based, corneal reflection eye-tracking systems. Today 95 per cent of all modern eye-trackers use a video-based pupil and corneal reflection (CR) system (Hammoud, 2008; Holmqvist et al., 2011). These systems are considered the most user friendly and practical devices available (Duchowski, 2007). The basic premise of pupil and CR eye-trackers is to illuminate the eye (usually with infrared light) causing a highly visible reflection known as the CR. The eye-tracker then identifies and tracks the position of the pupil and the CR. Once the camera and processor have this information it can calculate the position of the eye, and the position of the participant's gaze, by calculating the distance and angle between the CR and the pupil (Discombe & Cotterill, 2015; Majaranta & Bulling, 2014; Vickers, 2007).

There are three main types of CR eye-trackers available: Table/desk-mounted, head-mounted, and remote systems. Each of these different systems has its own benefits and drawbacks. The desk-mounted systems (see Figure 2.4) are generally the most accurate of the different types of system available. When using this type of eye-tracker you essentially restrict the head movement of your participant, before showing the participant stimuli (pictures or video footage) on a computer screen. The fixed position of the head, and the highly refined cameras used within these types of systems provides extremely accurate and reliable data. The strength of this type of systems is also its primary weakness (i.e. it is restrictive). With a participant required to remain stationary while watching a computer screen, therefore the options of data collection are limited and restricted to a laboratory setting. As a result, this has significant implications for the representative design and ecological validity of any studies conducted (Araujo, Davids & Passos, 2007; Discombe & Cotterill, 2015).

Figure 2.4: An example of a desk-mounted eye-tracking system: The Eyelink 1000 (Discombe & Cotterill, 2015)

Remote eye-tracking systems (see Figure 2.5) work in a similar way to the desk-mounted eye-tracking systems in that they can only be used in front of a computer screen (Holmqvist et al., 2011). The major benefit of these systems, compared to the desk-mounted systems, is that you are not required to restrict the head movement of the participant. These systems allow the participant to sit comfortably without restricting the head. This positioning is more agreeable for participants who are taking part in studies of greater duration. The trade-off for this increased comfort for the participant is a reduction in the accuracy and precision of the measurements and overall data when compared to the desk-mounted systems (Discombe & Cotterill, 2015).

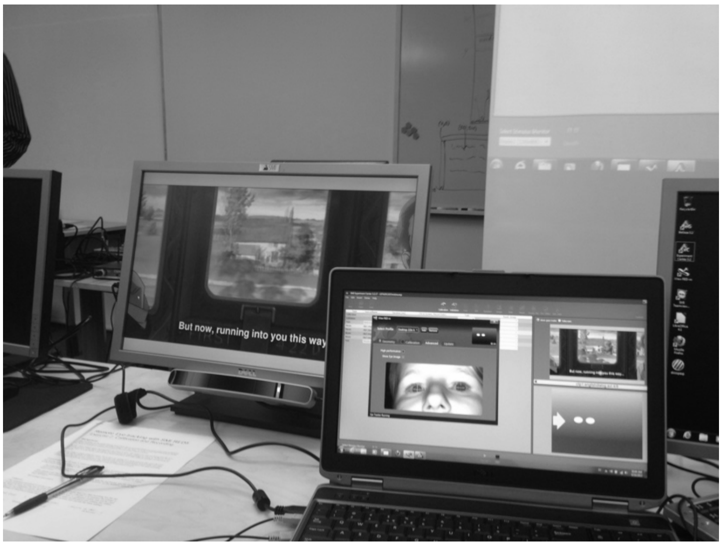

Figure 2.5: Example of a remote eye-tracking system: SMI Red remote eye tracker (Discombe & Cotterill, 2015)

The third and final data collection solution is the head-mounted system. These head-mounted systems (see Figure 2.6) allow participant maximum mobility, and unlike the desk-mounted systems allow data to be collected in more ecologically valid environments such as the taking a conversion in rugby, putting in golf, returning a serve in tennis, aiming at a target while shooting, or during a long distance cycle ride. The head-mounted systems usually use small mobile recording devices (e.g. a mobile telephone or small portable hard drive) that are worn by the participant to collect the data. Data collection using head-mounted systems require the participant to wear special glasses, or a head-mounted camera. This is the only real compromise for the participants and usually would not hinder athletic performance. The head-mounted eye-trackers work differently to the desk or remote systems. Unlike the desk or remote systems where stimuli are presented to a participant on a computer screen, the participant is free to move around and the stimulus therefore is the 'real world'. As a result, the head-mounted systems require two cameras, one pointing towards the eye to track the pupil and CR, and another pointing towards the real world to capture the stimuli. The software provided will then plot the gaze of the participant over the real-world recording, and with most models this can be achieved in real time (Discombe & Cotterill, 2015).

Figure 2.6: Example of a head mounted eye tracker: The SMI 2.0 Glasses (Discombe & Cotterill, 2015).

These advances in head-mounted eye-tracking technology have opened the door for a broad range of more ecologically valid field-based sport and exercise research projects and performance-focused interventions. Researchers can collect gaze behaviour, visual information and search patterns of performers while competing in situ. While this sounds appealing and potentially applicable in a broad range of contexts there are limitations. For example, you cannot ask a rugby player to wear the eye tracker and play a match. Aside from damaging the equipment, the glasses need to go through numerous calibration processes, usually conducted at multiple stages during data collection. Although the head-mounted systems do allow freedom to move around in the natural environment, the participants' head needs to remain relatively stable throughout the study to collect valid data (Holmqvist et al., 2011). As a result of the level of stability required for these systems throughout data collection, studies to date have mainly focused on closed sports skills including putting in golf, basketball free throws, and pistol shooting. Having said that, these head-mounted systems have successfully been used in live sports such as cricket (Croft et al., 2010; Land & McLeod, 2000), table tennis (Rodrigues, Vickers & Williams, 2002), and tennis (Singer et al., 1998).

Eye-tracking technology provides the platform to explore and understand the dynamics and mechanisms underlying real time cognitive processing that lead to expert performance (Moran, 2009). In sport, the first eye-tracking studies were conducted in the 1970s (Bard & Fleury, 1976). In the 1980s/1990s a number of eye-tracking studies emerged within the literature including ice hockey (Bard & Fleury, 1981), baseball hitting (Bahill & LaRitz, 1984), pistol shooting (Ripoll et al., 1985), and golf putting (Vickers, 1992). While these early studies were often limited and restrictive due to the limitations of the technology available, they opened the door to the exciting field of eye movement research within sport science (Discombe & Cotterill, 2015).

2.5 Vision research in sport

The temporal challenges facing athletes when trying to intercept a fast-moving object are extreme to say the least, making this the ideal field for the use of eye-tracking technology. For example, in order for a cricket batter to perform successfully, they would need to filter relevant information, select the most appropriate course of action, and execute that action precisely within a time frame of approximately a few milliseconds. The precision needed to successfully execute any cricket shot is extreme. When you examine the timing required to produce a successful horizontal shot however, (e.g. the pull, hook or cut shot where the batter swings the bat horizontally in an arc at right angles to the trajectory of the approaching ball) you start to understand the severe challenges that batters face. To strike the ball successfully the batter must judge the vertical position of the ball to within ± 3 cm (limited by the laws of the game and the width of the bat) and its time of arrival to within ± 3ms (McLeod & Jenkins, 1991; Regan, 1992). Over the course of a cricket innings a batter may have to intercept a ball bowled to them at a wide range of different velocities, i.e. slow or spin bowling (72-88 km/h or 20-24 m/s), medium pace bowling (120-128 km/h or 33.5-35m/s) and fast pace bowling (137-145 km/h or 38-42 m/s) (Discombe & Cotterill, 2015; Gibson & Adams, 1989; Ferdinands, 2004). This process invariably occurs in an environment where the opponent deliberately tries to disguise their actions in order to deceive and confuse the performer (Müller et al., 2006). Due to the extremely high levels of skill required to successfully intercept a moving ball, it is not surprising that many regards hitting a ball to be the single hardest thing to do in the world of sport (McBeath, 1990; USA Today, 2005).

The advice from the majority of coaches, specifically at amateur level, within these fast-ball sports is for players to ‘keep their eye on the ball’; yet how helpful is this advice? And is it even possible to ‘keep one’s eye on the ball’? In sports like cricket and baseball, for example, a player’s visual system cannot always match the demands of the task (Bahill & LaRitz, 1984; Muller & Abernethy, 2013; Watts & Bahill, 2000). Chronometric analysis has highlighted the length of time it takes a performer to prepare and then execute an interceptive skill will usually exceed the travel time of the object that has to be intercepted (Ripoll, 1994; Singer, 2000). For example, while batting in cricket when ball velocities reach a certain speed, speeds that aren't considered fast in the world of cricket (e.g. 110 km/h or 30.6 m/s), the time needed for perception and movement will exceed the flight time of the ball (Gibson & Adams, 1989). When the bowling velocities become quicker (e.g. 160 km/h or 44.8m/s) the transit time from bowler to batsman is less than 500ms (Müller et al. 2006; Regan, 1997). In contrast, the time it takes for a batter to prepare, react and complete essential foot and bat movements, is at least 900ms (Gibson & Adams, 1989). Similar findings have been reported for other interceptive sports such as baseball, tennis, squash, badminton and table tennis (Glencross & Cibich, 1977; Howarth, Walsh, Abernethy, & Snyder, 1984; Sheppard & Li, 2007). The conclusion from these studies is that in order to successfully intercept a fast-moving object, the performer needs to acquire information prior to the flight of the object, prepare to make movements in advance, and anticipate the direction and outcome of an event.

2.5.1 Occlusion research

A substantial amount of the vision and perception research within the sporting field has investigated the relationship between anticipation and the utilisation of advance visual cues, specifically the difference between the expert and novice (Williams et al., 2000). Advance cue utilisation refers to an athlete's ability to use early contextual information to accurately predict the outcome of a sequence or sporting event (Abernethy, 1987). I.e. "the specific source(s) of information used by the performer to guide actions" (Williams, Janelle, & Davids, 2004 p. 302). Typically, occlusion techniques have been the main methodology used to examine vision and advance cue utilisation in sport and have taken place both in the laboratory setting and in the field. In the laboratory, occlusion researchers have presented video footage to the participants (on computer screens) while controlling and manipulating the duration and nature of the footage. In contrast, field studies have taken a more ecological approach and measured performance directly by utilising liquid crystal occlusion glasses (Williams et al., 2000).

Two different types of the occlusion techniques have commonly been used in these studies, temporal and spatial occlusion. The most prevalent of these methods is temporal occlusion, which involves participants viewing video footage that progressively plays for a longer (or shorter) period of time, and therefore reveals more (or less) information about the unfolding events up to a certain point (Williams et al., 2000). For example, a cricket batter could be presented with footage of a bowler's run-up, gather, ball release, and early ball flight before the video stops. In contrast to temporal occlusion, spatial occlusion involves selectively masking specific portions or segments of the video presented, for example the arm, shoulder, or head of the bowler (Panchuk & Vickers, 2009). Spatial occlusion has been successfully used to determine which specific advance cues from the opponent's movements are used in order to successfully anticipate the outcome of an event (Panchuk & Vickers, 2009). In occlusion studies participants are not presented with the full visual scene, they are presented with footage either limiting the time, or occluding certain segments of the footage and the asked to predict the outcomes of an event (e.g., landing location of the ball in cricket), or to identify the opponent's action (e.g., direction or type of stroke in racquet sports). The rationale behind occlusion studies is to understand the minimal information needed for a participant to make an accurate prediction or decision about the outcome of the event (Panchuk & Vickers, 2009).

Temporal occlusion studies have repeatedly shown that elite athletes are better than novices at utilising advance cues in the environment and predicting how events will unfold across a wide range of sports. For example: anticipating the direction of badminton shots (Abernethy, 1988a, 1989; Abernethy & Russell, 1987a; Abernethy & Zawi, 2007; Abernethy, Zawi, & Jackson, 2008); predicting the direction of a penalty in football (Causer et al., 2017); anticipating direction of penalties in hockey (Salmela & Fiorito 1979; Savelsbergh, van der Kamp, Williams, & Ward, 2005; Savelsbergh, Williams, van der Kamp, & Ward, 2002); predicting the direction and type of a handball shot (Loffing & Hageman, 2014); predicting the direction of a tennis shot (Buckolz, Prapavesis, & Fairs, 1988; Tenenbaum, Levy-Kolker, Sade, Liebermann, & Lidor, 1996); predicting and returning tennis serves (Farrow, Abernethy, & Jackson, 2005; Goulet, Bard, & Fleury, 1989; Isaacs & Finch, 1983; Jackson & Mogan 2007; Jones & Miles, 1978); and predicting volleyball shots (Wright, Pleasants & Gomez-Meza, 1990); and Together these studies highlight the importance of athletes being able to utilise early information in order to anticipate what is about to unfold.

While temporal occlusion studies suggest that elite athletes are better at using advance cues compared to amateurs, spatial occlusion research attempts to highlight which body segments are considered important in order to gain information. Research suggests that body segments that are involved later in the sporting action, (e.g. the arm and hand in racquet sports and the bowling wrist, hand and arm in cricket) provide important information relating to the anticipation of stroke that will be played, or the directionality of ball to be delivered (Abernethy, 1988a, 1989, 1990a; Abernethy & Russell, 1987a, 1987b; Abernethy & Zawi, 2007; Müller et al., 2006; Shim, Carlton, Chow, & Chae, 2005; Shim, Miller, & Lutz, 2005). Spatial occlusion studies suggest that in contrast to elite players, lesser skilled athletes typically rely on the ball flight of the object rather than body segments in order to predict the outcome of an event (Abernethy, 1990a, 1990b; Abernethy & Russell, 1987a, 1987b; Müller, Abernethy, Eid, Mcbean, & Rose, 2010). Overall, occlusions studies suggest that experts make use of the advance cues available from the opponent's kinetics in order to anticipate the outcome of an event, a skill which non-experts seem to lack (Müller & Abernethy, 2012).

When focusing specifically on cricket, researchers examining the use of advance cues have identified a strong relationship between the ability to anticipate successfully and the skill level of the player (Abernethy & Russell, 1984; Müller et al., 2006; Penrose & Roach, 1995; Renshaw & Fairweather, 2000). When presented with video footage showing only the pre-release movements of medium-paced bowlers, skilled batters had a superior ability when compared to less skilled batters, to consistently predicting where the ball would pitch i.e. where the ball will bounce (Abernethy & Russell 1984; Penrose & Roach 1995). This has been found across a wide range of bowling styles, from left and right armed fast-paced bowlers (McRobert & Tayler, 2005) to spin bowlers (Renshaw & Fairweather, 2000). Spatial occlusion techniques have been employed to occlude specific sources of information from the bowling action (Müller et al., 2006). Müller and colleagues found that information extracted from the bowling arm, hand and ball locations were the primary sources of pre-delivery information for skilled and less-skilled batters when facing fast bowlers. When facing slow or spin bowling however, skilled batters rely largely on information from the bowling arm for anticipation (Müller et al., 2006; Tayler & McRobert, 2004).

The ability to have well developed anticipation skills and make use of early information and cues is consistently found in elite sportsmen. It therefore seems intuitive that sportsmen would need optimal visual functioning to perform demanding interceptive tasks, however this claim is far from established. Mann, Ho, De Souza, Watson, and Taylor (2007) assessed the batting performance of professional (grade level) Australian cricketers when facing a bowling machine and wearing contact lenses that endued differing levels of myopic blur (None, +1.00, +2.00 and +3.00 dioptric over-refraction). The results showed that elite cricket batters experienced no decrease in batting performance levels even when foveal vision was impaired due to the introduction of the +1.00D and +2.00D myopic blur lenses. In fact, Mann and colleagues' findings suggest that batters technically needed to be legally blind before any significant reduction in batting performance occured. It seems that skilled humans might not need to foveate accurately on the trajectory of an object, or the object itself in order to successfully intercept that object (Croft et al., 2010). Instead they can utilise patterns and advance cues in the environment to accurately predict what they are about to experience.

2.5.2 Decision-making and vision

Occlusion research has highlighted the importance of using advance visual information in order to predict the landing location of a delivery in cricket (McRobert & Tayler, 2005; Müller & Abernethy, 2012). In other word, in order to anticipate effectively and make successful decisions the use of advance visual cues is paramount. Due to the extreme time constraints in interceptive sport such as cricket, tennis, badminton etc. athletes are required to process information and make decisions about how to respond in time periods which push the limits of human performance (Cotterill & Discombe, 2016). Therefore, successful performance can be directly attributed to the effectiveness of an athlete's decision-making abilities. Eye-movements have the potential to reveal a great deal about the cognitive processes and the decision-making abilities of an athlete (Just & Carpenter, 1984; Rayner, 1995, 1998). Indeed, the eye-mind hypothesis (Just & Carpenter, 1984) suggests that a strong correlation exists between where an individual is looking and what that person is thinking about. It is therefore believed that fixations allow attention to be directed to specific details from the scene, in order to guide decision-making or motor control skills (Panchuk et al., 2015). Eye-tracking data can therefore serve as a direct assessment of decision-making (Abernethy, 1991; Vachon & Tremblay, 2014).

A number of studies have investigated decision-making using eye-tracking data. One example of this is the Roca, Ford and Memmert (2018), who suggest that more creative football players (players who make more creative decisions) can be distinguished by their eye-movements, as these players produces significantly different visual search behaviour compared to their less creative counterparts. Takeuchi and Inomata (2009) also found that the visual search of an athlete impacts decision-making ability. They recorded expert and novice vision using mobile eye-trackers and found that expert baseball batters used visual search strategies to fixate upon specific task related cues (which the novice players did not do) and were subsequently more accurate and relatively quicker at decision-making than non-expert batters (Takeuchi & Inomata, 2009). Eye-tracking and eye-movement data therefore offers and excellent method to study the decision-making and anticipatory abilities of an athlete.

2.6 Eye-tracking research in sport

Occlusion studies have highlighted the importance of advance information and cue utilisation for interceptive tasks and decision-making. While spatial and temporal occlusion studies identify the minimum information needed to perform a skill successfully, they fail to provide us with data regarding what sports men/women actually look at i.e. where their position their gaze/fixate, what cues they utilise, and what information they naturally perceive when performing these tasks. One methodology that has been employed to answer these questions is eye-tracking. For over three decades, eye-tracking technology has been integrated into athletic research and used to track human performance (Vickers, 2007).

2.6.1 Quiet Eye

The use of eye-tracking equipment has been directly applied as part of sport science support, in order to enhance performance. One of the predominate methods to achieve this, is by monitoring and manipulating Quiet Eye (QE). QE can be defined as the “final fixation or tracking gaze directed to a single location or object in the visual field within three degrees of visual angle (or less) for a minimum of 100ms” (Vickers, 1996). The beginning of the QE starts before the critical movement of the motor task and finishes when the final fixation deviates off the target by more than three degrees of visual angle for more than 100ms (Panchuk et al., 2015). Research highlighting the importance and impact QE can have on an athlete has led to numerous psychologists and sport scientists including QE training in their provision. Research, such as that conducted by Harle and Vickers (2001), has highlighted the effectiveness of QE training with a team of basketball players. Three woman’s basketball teams were involved in the experiment. Two of the teams were used as control group receiving no QE training. The third was the experimental group and were taught to prolong their quiet eye duration. The results showed that the QE training group increased the accuracy of their free throws by 22.62% across two seasons; while in control groups no increase in athletic performance was noted. Similarly, Williams et al. (2002) conducted a series of experiments with pool players to study the QE phenomenon. The study involved 24 American pool players (12 professionals and 12 non-professional players). The findings showed that the professional players had a longer QE period than the amateurs. Moreover, as the task or shot became more complex or difficult, the QE duration increased. Williams and colleagues showed that the duration of the QE period is a critical factor when aiming at a target. The meta-analysis conducted by Mann et al. (2007) also supports the view that experienced and successful athletes have a longer QE period, which, shows that they focus their attention to the details most significant for executing technical and tactical actions (Grushko, Leonov & Veraksa, 2015).

In Causer, Bennett, Holmes, Janelle, & Williams's (2010) study, 20 international level skeet shooters were assigned to one of two groups; either a QE trained group (experimental group) or a control group. The participants in Causer et al.'s study were tested pre and post an eight-week intervention. The results revealed that, the participants in the QE trained group had a significantly earlier onset of QE, tracked the clay for a longer duration and as a result significantly improved their performance. No such improvement was found in the control group. The results so far in the literature showed that after a prolonged QE training programme, performance in targeting tasks significantly improved. Vine et al. (2011) however, demonstrated similar performance benefits from just a single one-hour QE training session. Vine et al. recorded putting success over 10 rounds of competitive golf for twenty-two elite (low handicap golfers). Having been randomly assigned to either a QE training or control group, the golfers attended a one-hour training session individually. The training for both groups consisted of video feedback of their gaze behaviour while they completed 20 putts. However, the golfers in the QE trained group also received instructions and guidance on how to prolong and maintaining QE. The results showed that QE-trained golfers performed 1.9 fewer putts per round, compared to pre QE-training. The control group showed no improvement in their putting statistics. Results also showed that QE trained group successfully made 5% more putts from the distance of 6 to 10 feet following the training. QE training has also been shown to help novices develop targeting skills quicker than more traditional methods of coaching Vine and Wilson (2010).

2.6.2 Eye-tracking and visual search

The visual search of sportsmen has been another research area that has received significant attention in the associated literature. The consensus from this field is that success when performing sporting actions is directly related to the effectiveness of an individual's visual search strategies. Vickers (1992) suggests that more experienced athletes, coaches, and referees, make less saccades. Indeed, when compared with their less successful counterparts, successful decision-makers used more goal-oriented search strategies and fixate their gaze on key elements for longer, which resulted in superior performance, as characterized by faster decision times and greater response accuracy (Vaeyens et al., 2007; Moreno, Reina, Lusi, & Sabiso, 2002, Piras, 2009, 2010; Lee, 2010, Hancock & Ste-Marie, 2013). Research has found that there is a dramatic decline in visual sensitivity during saccades, a phenomenon known as saccadic suppression (Ditchburn 1973; Festinger 1971; Massaro 1975). This essentially means that we cannot see or acquire information during a saccade. Theoretically, due to saccadic suppression, a visual search strategy that includes less fixations (and therefore less saccades) is believed to be more effective (Williams, Davids, & Burwitz, 1994). A more efficient and consistent search strategy involves fewer fixations of longer duration enabling more time to be spent analysing the important stimuli and gaining more information rather than using saccadic eye-movements to search through a display (Williams et al., 2000).

Some of the first experiments to study visual search and decision-making in sport were conducted by the Russian psychologists, Tikhomirov and Telegina (Tikhomirov & Telegina 1967, cited in Grushko et al. 2015). The authors studied the visual search strategies of professional chess players as they planned their strategies and moves. The eye movement strategies were recorded as well as verbal reports from the player documenting how they reached their decisions. It emerged that the most used eye movement strategies of elite chess players were the 'playing out' of certain moves in any given situation. For example, the player's gaze started fixed on the piece which he intends to move and the square on which it stands, and then the player's focus shifts to a vacant square to which his selected piece might be moved.

The research of Bard and colleagues was the first to really establish visual search as an important area within the field of sport psychology (Bard & Carriere, 1975; Bard & Fleury, 1976, 1981; Bard, Fleury & Carriere, 1976). These studies typically investigated the differences in search strategies, when participants were presented with graphical representations of sporting situations. For example, Bard and Fleury (1976) examined the search patterns of five expert and five amateur basketball players when they viewed a typical game scenario. The participants were required to make a decision as quickly as possible by verbalising in the given situation they would shoot, dribble or pass to a teammate. Whilst viewing the slides, subjects' visual search patterns were recorded and while the results showed no significant differences in decision time between the two groups, the results indicated that expert basketball players used significantly fewer fixations prior to a response when compared to the amateur players. The areas that participants attended to also differed with the amateur players mainly fixating on their own teammates, while the elite players also fixated on the defending team and the space available between the defender and basket. Finally, Bard and Fleury found that as the level of complexity increased, or the situation became more tricky, both groups required more fixations prior to making a decision, when compared to less complex situations. This finding has subsequently been supported by several studies, suggesting that search rate may be a function of the uncertainty presented in the display (e.g. Bard and Fleury 1981; Tyldesley, Bootsma, & Bomhoff, 1982).

In the study by Tyldesley and colleagues (1982) study subjects were presented with static slide presentations of a soccer player taking a penalty kick. Groups of amateur players and experienced players were required to guess the direction of the penalty kick. The results revealed that the experienced players responded significantly quicker than the inexperienced players. Moreover, the visual search data revealed that the scanning behaviour of the experienced players was much more structured when compared to the novice players. When viewing a right footed player, the experienced athletes did not focus on the left side of the body at all, instead they focused on the hip and legs of the striking foot. Results also revealed that when the participants had four choices as to the where the ball would travel (the four corners of the goal) they required more fixations than when only two options were available to them (left or right side of the goal). This supports the finding of Bard and Fleury (1976) who found that when the task is more complex individuals require more fixations before making a decision.

Moving on from static images, researcher started to present more dynamic film or video footage during eye-tracking studies. Ripoll, Kerlirzin, Stein, and Reine, (1995) for example, presented kickboxers (with varying ability) with a specially created point of view film. The player faced a screen on which was shown an opponent demonstrating various technical actions, and the kickboxer had to respond to these actions. Two experiments were conducted, the first involved participants responding only to the one specific type of attack from their opponent (the video footage). The second participants were required to respond to all of the presented stimuli. The results revealed that there were significant differences in the speed, accuracy, and strategies of visual search between the differing ability groups. The more experienced and higher rated kickboxers fixated their gaze on their opponent’s head while simultaneously scanning the peripheral areas to try to detect the initiation of an attack via movements of the opponent’s hands or feet (Ripoll et al., 1995). Amateur kickboxers had less controlled visual search strategies, compared to the experts. The expert kickboxers employed more economical visual search strategies compared to the less capable subjects. Ripoll and colleagues argue that expertise is having the ability to detect, and extract information from the pertinent cues in the stimuli.

2.6.3 Eye-tracking and vision-in-action

The vision-in-action approach (Vickers, 1996, 2007) couples athletes' movements and their gaze by recording eye-movements as they perform task in the real sporting world. The vision-in-action paradigm therefore recognizes many factors that are consistent with the constraints-led model, e.g. the task, the environment, the organism and perception-action coupling within a certain perceptual-motor workplace in this case the sporting world (Vickers, 2007). Therefore, the environment you find yourself performing in and the nature of the task determines the athletes' field of view, like it does when actually playing sport. Another benefit of vision-in-action paradigm is that the eye tracker records the gaze of the athlete in three-dimensional space. Therefore, the gaze behaviour is studied over the full length, breadth and depth of the visual-motor workspace (Piras, 2009, 2010). Typical visual search studies only measure gaze behaviour over two dimensions. As depth perception is a crucial element and skill within sport, the vision-in-action approach provides an opportunity to study this area. While the vision-in-action approach provides greater flexibility in terms of the range of skills that can be assessed, and provides a more ecological research design, the approach does have some limitations. The major limitation is the fact that often a vast amount of experimental control is sacrificed when measuring performance using vision-in-action. The data when using this approach is also usually less detailed than that collected in a laboratory. Nonetheless, this approach offers numerous ecological benefits, as well and allowing for more sporting tasks to be researched.

Ripoll, Bard, Paillard, and Grosgeorg, (1982) conduced one of the early vision-in-action studies when they explored the visual gaze behaviour of elite and amateur basketball players. They not only compared the difference between elite and amateur players, but also assessed the differences in gaze behaviour between successful and non-successful basketball shots. They found that expert players, during successful shots, fixated their gaze on the location (basket) sooner and maintained their gaze on this location for longer compared to the amateur players. During the early 1980s/1990s a number of eye-tracking studies emerged in the sports literature including ice hockey (Bard & Fleury, 1981), baseball hitting (Bahill & LaRitz, 1984), badminton (Ripoll et al., 1985), and golf putting (Vickers, 1992). While these early studies were often limited and restrictive due to the limitations of the technology available, they opened the door to the exciting field of eye-movement research within sport science.

The continued improvement of eye-tracking technology has meant that the research within the field has continued to flourish. Piras (2009, 2010) performed two experiments, the first used eye-tracking in judo the second during a penalty kick during a football match. In the first experiment, Piras compared the eye-movements during combat of nine expert judo athletes and 11 beginners. The main technical actions selected were 'lapel attack' and 'sleeve attack,' as well as the corresponding defensive actions. Each athlete stood facing an opponent and were given the command to perform one of two moves either a 'lapel attack' or a 'sleeve attack.' For example, if the participant was commanded to perform a sleeve attack, then his sparring partner would produce an appropriate defensive move. The results revealed that the eye movement patterns of the top-class judo athletes differed significantly from those of the beginners. Of note was that fact that elite athletes mainly fixated upon the central parts of their opponent both when attacking and when defending. They also fixated more on the face of their opponent. Also, the expert Judo athletes used less fixations for longer durations compared to their amateur counterparts.

The second experiment, later published by Piras and Vickers (2011), investigated the eye movement of goalkeepers and penalty takers when taking two types of penalty kicks: one struck by the attacker using the instep, the other with the upper inside part of the foot. The per cent of saves penalties was significantly greater during instep penalties (28%) compared to inside foot kicks (12%), however there were very few differences in fixation frequency, location, duration, or transitions that could be attributed to the type of kick used. Essentially the goalkeepers used the same visual search strategies for both kicks. What was interesting though was the goalkeepers' success rate, was closely linked with the different eye-movements. The number of saccades (i.e. gaze shifts between locations) goalkeepers made was significantly higher when goals were scored compared to those which they saved. Before the attackers struck shots which were saved, the goalkeepers fixed their gaze on the space between the striking leg and the ball, and for a longer time. In contrast, the results showed a link between the successful conversion of a penalty by the forward and a longer fixation of the goalkeeper's gaze on the ball (Piras & Vickers, 2011).

More extreme sports are also starting to be researched, for example, Grushko and Leonov (2014) investigated the gaze behaviour of elite level rock climbers. They found that the most effective visual strategy when climbing an indoor climbing wall was to employ a 'sequence of blocks' strategy. This strategy requires a climber to gradually look through a potential route by blocks of 2-4 handholds or footholds from beginning to the end, paying attention to crux moments of climbing routes (Grushko & Leonov, 2014). This strategy was not only performed by the majority of elite athletes, but also increased in its usage, as the task got more difficult. The elite climbers use this strategy only 52.2% of the time on the intermediate climbs, but when faces with more advanced routes 87% of the climbers employed the 'sequence of blocks' strategy. This research provides clear advice for amateur climbers or coaches who want to teach the most successful method to plan a climb.

Eye-tracking technology provides the platform to explore and understand the dynamics and mechanisms underlying real time cognitive processing that lead to expert performance (Moran, 2009). Eye-trackers provide numerous research opportunities within the sport domain, one of which is the exploration and understanding of where successful athletes directs their gaze and attention towards prior to, and during skill execution. The evidence from these studies (see above) indicates that expert performers show more robust and consistent search strategies, which generally involve fewer fixations, which last for a longer duration. They also indicate that they fixate on more informative areas of their visual stimuli compared to their amateur counterparts. The ability to extract more information of better quality during each fixation contributes enormously to the expert's superior anticipation and performance in sporting contexts. The most accurate information and our clearest vision about the speed and location of approaching objects comes from where we position our gaze, i.e. the fovea and its immediate vicinity (Hallett, 1991). A cricket batsman's eye-movements and where they direct their gaze is therefore likely to highlight what the batsman considers to be the important cues from the pre-delivery, and early ball flight. Monitoring batsman's gaze using eye-tracking technology is therefore an extremely valuable exercise and has the potential to highlight what the batters considers to be the important visual cues when batting.

2.7 Eye-tracking research in cricket

To date there have been four studies that have utilised eye-tracking technology within cricket (Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013; McRobert et al., 2009). Land and McLeod's study signified a significant milestone for cricket vision research. The authors were the first to use eye-tracking equipment to examine how cricket batters successfully perform. The authors recorded the eye-movements of three batters of varying ability, a professional opening batter, a successful amateur who plays minor counties cricket (the highest level you can play without turning professional), and an enthusiastic but incompetent club cricketer. Land and McLeod (2000) used a head mounted mobile eye tracker to monitor the gaze of each batter when facing a ball projection machine (bowling machine). The results from the study were somewhat surprising as they revealed that visual search strategy of all three batters was very similar. The three players did not track the ball throughout the entire flight. Instead they initially focused their gaze on the point of delivery (i.e., the hole in the bowling machine from which the ball emerges). Their gaze was stationary for a period of approximately 0.14s after delivery as the ball dropped into their field of vision. The batters then made a predictive saccade, which brought the fovea (the area responsible for our central, sharpest vision) below the ball, close to point where the ball would subsequently pitch (bounce). The eye and the fovea, which were now positioned ahead of the ball, 'laid in wait' for the ball to bounce (Land & McLeod, 2000). Following the bounce, batters kept their gaze roughly level with the ball for a period of 0.2s, before making a rapid movement downwards with both the eyes and head, as the batters tried to track the final stages of the ball's flight.

The overall visual strategies of the three batters in Land and McLeod's (2000) study were found to be very similar despite the large gulf in the skill levels of the participants. All three participants watched the delivery of the ball, made predictive saccades to the bounce location before the ball arrived there, pursuit tracked the ball accurately for at least 0.2s after the ball had bounced, then tracked the ball more loosely on its final approach to the bat (Land and McLeod, 2000). However, within this common overall strategy, one small difference was found that seemed to reflect their abilities. A short latency for the first saccade distinguished good from poor batters, the amateur batsman was slower to respond to the appearance of the ball, taking at least 0.2 seconds to initiate a saccade. The results suggested that the amateur player did not anticipate the movement of the ball and was waiting until it completed a large part of its flight (0.2s) before initiating the predictive saccade. This visual behaviour was adequate for the medium-slow ball velocities used in Land and McLeod's study, however this 'catch-up' saccadic behaviour would have been inadequate when facing faster bowling (Land & McLeod, 2000). If the ball had bounced 0.2s after release (something that could realistically happen in cricket when facing fast bowling) the amateur player's delayed saccade would have meant that the player would not be able to position his gaze at the bounce point quick enough, and he would have been too late to see the ball. Either his saccade would not have started at this point, or the ball would have bounced during a saccade, which due to saccadic suppression would mean he would not have seen the ball at the point of bounce (Land & McLeod, 2000). In comparison the intermediate player and the elite player reached the bounce point 100ms before the ball.

The results of Land and McLeod (2000) offer the first real understanding of the visual strategies and gaze behaviour of a batsman. However, the study had numerous limitations, the main one being the small sample size of (n=3), and only assessing slow-medium paced bowling (90 km/h or 25m/s), thus ignoring fast paced and spin bowling. The lack of bowling speeds measured by Land and McLeod leaves numerous questions still unanswered. For example, will batters still use the same predictive saccade when the ball is slow enough to track throughout the flight, i.e. when facing a spin bowler? Regan (1997) highlights that slower spin bowlers rely on a combination of ball projector variations (e.g. spin, flight, drift etc.) rather than speed to trick the batters into making a bad decision and playing a rash or inappropriate shot. With the range and various methods of deliveries slow bowlers have in their arsenal do batters need to pursuit the ball longer to gain more information? If there is the possibility to track the ball for the full delivery then surely this will be beneficial to the batsman?

Croft et al. (2010) set out to answer some of the questions left unanswered by the research of Land and McLeod (2000), and examined how different ball velocities influenced the eye movement of batters. They measured gaze behaviour and search strategies of skilled batters when facing a bowling machine at speeds varying from 61.2km/h or 17m/s, to 90km/h or 25m/s, the typical range of velocities employed by spin bowlers. Land and McLeod found that batters facing slow-medium paced bowling (90km/h or 25m/s) typically used a mixture of pursuit tracking and predictive saccades. Croft et al. (2010) findings supported those of Land and McLeod (2000) as they found that batters use both pursuit tracking and predictive saccades. When you closer examine the individual results within Croft and colleagues' study, you find that there are considerable variations both within and between subjects.

Croft et al. (2010) found four distinct gaze strategies within their participants. First, the gaze remains within 2° visual angle of the ball for the majority of the flight, i.e., the ball was pursuit tracked throughout the entire delivery. Second, the ball is initially tracked, then the gaze drops below the ball before returning back to ball trajectory prior to the bounce i.e. a smooth pursuit followed by predictive saccade. Third, the ball was not closely tracked until later in its trajectory, i.e. the ball was only tracked just before bounce. Forth, the ball was not tracked at all according to the criteria of being within 2° visual angle however the gaze and ball directions are similar throughout ball flight. A small number of batters were consistent with the gaze behaviour throughout the trials, however the majority of batters showed no clear pattern to how they tracked the ball, either within trials or across ball velocities. The most surprising finding was that some batters didn't foveate on the ball at all throughout the flight.

Again, like the study of Land and McLeod (2000) the findings from Croft et al. (2010) provide an insight into the gaze behaviour and search strategies of batters when facing slow bowling. However, the lack of consistency with the findings both within and between subjects, fail to give us a clear understanding of how batters tracking the ball during its flight. The variance in findings could potentially be attributed to a poor experimental design. The aim of the study was to assess what visual strategies batters employ against slow bowling. They measured speeds ranging from 17m/s or 61.2km/h to 25m/s or 90km/h, and justified this by suggesting this was the appropriate range of speeds utilised by spin bowling in real life situations. However, the bowling machine used by Croft et al. (2010) was not set up to impart any spin on the ball. This is clearly not representative of spin bowling, and you could argue that at no stage in a real-world match situation, would highly skilled batters face bowling of 17m/s or 61.2km/h without some spin or deviation. This task would unlikely trouble amateur players and would be extremely easy for the skilled cricketers (New Zealand Under 19s) used in this experiment. You therefore have to question if the visual search strategies the elite batters employed in this experiment were representative of the strategies they would employ when facing a real bowler. A bowler who was imparting spin on the ball and at the same time trying to lure the batter into making a mistake.

The aforementioned research (Land & McLeod, 2000; Croft et al., 2010) utilising eye-tracking equipment within cricket has numerous flaws. The most striking of which, is the use of ball projection machines. Unfortunately, due to the artificial environment there are doubts that these findings would be replicated in a natural setting (Mann et al., 2013). It is well known that a player's ability to utilise advance cues is fundamentally important in fast-ball sports (Savelsbergh et al., 2002). Numerous occlusion studies (Abernethy & Russell, 1984; Müller et al., 2006; Penrose & Roach 1995; Renshaw & Fairweeather, 2000) have highlighted a clear correlation between anticipation ability and skill level of batters. These researchers suggest that as a result of experience and the hours gathered practicing within their environment, highly-skilled players are able to perceive and interpret advance visual cues more effectively that lesser skilled players in order to make effective predictions. Batting against a bowling machine is extremely different to batting against a bowler (Bartlett, 2003), as using bowling machines completely disregards the pre-delivery information that is available to the batters in a naturalistic environment. Indeed Pinder, Rensham and David (2009) found that facing a bowling machine is extremely different to batting against a human bowler. While batting against a medium–fast bowling machine compared to a bowler of the same speed, batters produced significant adaptations to their movement, timing and coordination of shots (Pinder et al., 2009). The removal of pre-delivery information can alter the movement pattern and execution of certain shots (Davids, Renshaw & Glazier, 2005; Gibson & Adams, 1989). Gibson and Adams (1989) found superior timing accuracy when batting against a human bowler compared to batting against a bowling machine. Davids et al. (2005) provide similar results, they found that facing a real bowler compared to a bowling machine, overall movement time was shorter, the backswing started later, initiation of the front foot movement occurred earlier, the downswing occurred later, and peak bat height was higher. Until researchers fully understand and acknowledge the differences between these two forms of batting, the ecological validity and representative design of the previous research (Croft et al., 2010; Land & McLeod, 2000) will remain in doubt (Araujo et al., 2007; Bartlett 2003).

In order to address some of the flaws in the previous research, Mann et al. (2013) incorporated the ProBatter machine to recreate a more naturalistic environment. ProBatter is a state-of-the-art bowling machine which projects life size video footage of a bowler as they run into bowl. The ball then subsequently appears and is delivered from a hole in the screen to coincide with the bowler's ball release. The designers of ProBatter argue "the life-like simulator allows batters to experience game-like conditions resulting in improved timing, rhythm and realistic match performances" (ProBatter Sports, 2011, "Cricket", para. 1.). The research conducted by Land and McLeod (2000) and Croft el at. (2010) suggest batters loosely track the ball towards the end of the ball flight rather than closely tracking it for the full trajectory, i.e. that batters do not watch the ball and 'see the ball' as it makes contact with the bat. This directly contradicts numerous anecdotal quotes and statement from batters (both elite and amateur), and years of coaches' advice, which argues that batters should 'watch the ball directly onto the bat'. In order to examine if it was possible to track the ball directly onto the bat Mann et al. (2013) compared the head and gaze position of two of the world best batters with a club cricketer. The elite cricket batters in Mann et al. (2013) study demonstrated two differences in their visual behaviour when compared to the amateur batters. First, the authors showed that the elite batters had a superior ability to align the direction of their head with the movement of the ball. This theoretically means that the players could follow the ball simply by moving their head and keeping their eyes still (Mann et al., 2013). Mann and colleagues present the analogy of a ‘miner’s torch’ to better understand this concept. If a metaphorical torch was attached to the helmet of a batter with tight head-ball coupling, the light would illuminate the ball from the moment of release through to the moment of bat-ball contact. In contrast, the light from the torch of a batter with poor head-ball coupling would not remain on the ball through the flight. The tight head-ball coupling highlighted by elite batters in Mann and colleagues’ studies, means that the ball would have remained very close to central vision, if they simply kept their eyes still and only moved their head. Therefore, theoretically no eye-movements would not be needed to accurately track the ball (Mann et al., 2013).

Instead of relying purely on the head-ball movement, the batters in the Mann et al’s. (2013) study all made predictive saccades. The second key finding from Mann and colleagues’ study was that there was a distinct difference between the saccadic behaviour of the elite batters compared to the club cricketers. The elite batters produced two separate saccades; the first saccade was to predicted ball-bounce location, and the second to the predicted bat-ball contact location. The previous research of Croft et al. (2010) and Land and McLeod (2000), only report the batters making one predictive saccade. Interesting Mann et al. found that the club cricketers within their study, also only used one predictive saccade. In contrast, the elite batters made two saccades for every good and short pitch delivery. This ensured that unlike the club cricketers, the elite batters could track and keep their gaze on the ball for nearly 100% of the good-length deliveries and approximately 90% of the short-length deliveries (Mann et al., 2013), as well as when it made contact with the bat. This saccadic behaviour was used by the elite batters to direct and position their gaze ahead of the ball before it made contact with the bat. The gaze of the club players tended to lag behind the ball. Indeed, the data from Mann et al. suggests that the elite players gaze was aligned with or ahead of the ball throughout the flight, whereas the club players either aligned their gaze with the ball or lagged behind.

While the methodology in Mann et al’s (2013) study might seem more ecological and representative of a ‘real world scenario’ due to the inclusion of ProBatter, this has yet to be scientifically proven. For example, ProBatter, just like any bowling machine has a release point which is fixed. This may limit its value for batters when facing a short-pitched delivery (Portus & Farrow, 2011). Typically, the most significant pre-release information of short pitch deliveries is gathered in final moments before release of the ball from the bowler’s delivery arc (Portus & Farrow), this is not able to be replicated with ProBatter. Also, when facing ProBatter the batters still know exactly where the ball will be delivered from i.e. the hole in the screen behind which the bowling machine is positioned. The batters will therefore position gaze at this location before the ball is released and may not attend to any of the pre-delivery information. When facing real bowlers, they are not able to position their gaze at the point of release in advance, as the precise location of this information is not available. Mann et al., (2013) present no analysis or discussion relation to the pre-delivery information presented to the batters, or where the batters positioned their gaze prior to the 'release' or firing of the ball. It is not yet known if ProBatter is any better at replicating a real-world situation than a traditional bowling machine. Indeed, Portus and Farrow (2011) argue that a systematic series of research investigating the decision-making of batters, shot execution (kinematics and kinetics), and gaze tracking studies are required before any suggestion can be made that ProBatters is a significant improvement to standard bowling machines.

The aim of using ProBatter was to make the experimental design more ecologically valid, however adversely this has meant that the batters had to stand significantly closer to the point of delivery than the true length of a pitch. Mann et al's. (2013) experimental design had the batters standing < 17.7m from the bowling machine, when in a real-world situation, they would be standing 20.12m away from the bowler. It is questionable whether using ProBatter made Mann's et al's. (2013) more ecologically valid or inadvertently less. Until real human bowlers are used, or footage of human bowlers are used, the validity of the results from the previous three studies (Croft et al, 2010; Land & McLeod, 2000; Mann et al. 2013) will be questionable.

To date only one study has used eye-tracking equipment to investigate what pre-delivery information the batter fixates on and extract when viewing human bowlers (McRobert et al., 2009). McRobert and colleagues explored how advance cue utilisation influenced batter's anticipation by using an artificially simulated cricket batting task. Ten elite and amateur batters were required to respond to life-size video footage from fast and spin bowlers. Each video included the bowler's preparation, run-up, gather, delivery action, follow-through, and the first 80ms of ball flight after ball release before the video finished. The participants were required to take their normal batting stance while holding a cricket bat and attempt to play a shot that would intercept the theoretical flight path of the ball, while they had their vision tracked with an eye-tracker. After playing a stroke in response to each video clip, participants completed a verbal as well as a pen and paper response marking the anticipated location of the ball.

The results from McRobert et al. (2009) showed that as expected and in accordance with previous research (Penrose & Roach 1995, Renshaw & Fairweather 2000), skilled participants were significantly more accurate at anticipating the location of where the ball would bounce compared to the less skilled batters. The eye-tracking data highlighted a number of consistent differences in visual search strategies between the elite and amateur batters. Amateur batters extracted information primarily from the ball-hand location, and spent more time fixating irrelevant locations (i.e. directing their gaze completely away from the bowler) compared to the skilled batters. In contrast, the elite batters used a more systematic search strategies, with the authors speculating that they used their past experiences and greater knowledge to ignore irrelevant locations and fixate upon task-relevant sources of information (McRobert et al., 2009). The elite batters adopted more comprehensive search patterns, fixating on more locations for longer periods of time, including the bowling arm, head–shoulder, trunk–hips and the predicted ball release area. The eye-tracking data from the McRobert et al. (2009) study shows that all batters change their visual search strategies when viewing different bowling types. When facing spin bowling, all the participants used fixations of longer durations and spent more time fixating on the ball and hand compared to fast bowlers. In contrast, more central regions of the body provide the majority of information when viewing fast deliveries.

While this study was the first to highlight the gaze behaviours and visual search strategies of batters when presented with pre-delivery information, numerous unanswered questions still remain. The study fails to examine the location of the batter's fixations and what information the batters find useful when viewing medium pace bowling, as this bowling velocity was not assessed. The study also fails to track the participants' gaze during ball flight as the video footage stopped shortly after ball release. Previous research has shown that batters make predictive saccades to position their vision ahead of the ball towards the location of the ball bounce. It is unknown if the batters in this study followed a similar protocol, or if the removal of the ball flight information, and the addition of the think-aloud protocol in McRobert and colleague's study altered the pre-delivery visual search strategy and the gaze behaviour of the batters. Batters where instructed to watch the pre-delivery video footage (i.e. preparatory phase, run up, ball release) and then predict where the ball would land. Would the removal of the ball flight alter the way the batters perceived the run up and release? Would changing one impact upon the other? Combining both the pre-delivery information and the ball flight, i.e. tracking vision from the start of the run up and through the entire ball flight therefore seems to be crucial in order to get the 'full picture'.

2.8 Summary

Eye-tracking offers researchers more than a tool to track the vision of an athlete. When an athlete shifts their gaze to a new location, they also shift their attention to the same location (Corbetta, 1998; Deubel & Schneider, 1996; Henderson, 2003; Hoffman & Subramaniam, 1995; Kowler et al., 1995; Shepherd et al., 1986; Vickers, 2007). You can therefore conclude that eye-tracking data goes beyond measuring eye-movements and highlights the shifts of attention an athlete produces. The interdependence between eye-movements and attention allows researchers to monitor attention and explore the decision-making and anticipation of an athlete. Eye-tracking allows researchers to explore the relationship between athletic performance and eye-movements (Panchuck et al., 2015). Using the information gathered from this research, practitioners are able to develop, plan and experimentally test visual interventions that have the potential to dramatically improve decision-making, anticipation and thus, sporting performance.

Cricket offers researchers the ideal platform to explore vision, attention, and decision-making. The fast-paced nature of cricket often has spectators marvelling at the 'super human' abilities of elite players. Indeed, superior athletic performance can often be readily apparent to the observer; however, the perceptual-cognitive mechanisms that contribute to the experts' advantage are much less evident (Mann et al., 2007). Eye-tracking technology provides the platform to explore and understand the dynamics and mechanisms underlying real time cognitive processing that lead to expert performance (Moran, 2009) and cricket provides the perfect sport to achieve this. A number of existing temporal occlusion studies from cricket literature have demonstrated that more skilful batsmen are able to make better predictions of ball direction and delivery type from the pre-release information of varying types of bowling speeds and styles (e.g., Abernethy & Russell, 1984; Müller et al., 2006; Penrose & Roach, 1995; Renshaw & Fairweather, 2000). Spatial occlusion research (e.g. Müller et al., 2006) has also highlight what cues (segments of the body) were present when batters make successful decisions. However, the occlusion literature does not tell the full story of what visual information batters use to anticipate and decide how to play a delivery. When all of the pre-delivery information is present, we still do not know what information batters utilise in order to make effective decisions. In order to achieve this, cricket researchers need to utilise eye-tracking technology.

There have been a number of studies that have used eye-tracking technology within cricket, and while the inclusion of this technology in has clearly 'opened our eyes' to how batters track the ball, the numerous flaws with the research in the area still means we don’t fully understand the phenomenon. Typically, the studies have used very slow bowling velocities and only measured a small number of bowling styles which, are not representative of real human bowling. Cricket is a complex sport pertaining numerous different types of bowlers of varying speeds. The ball can be delivered at velocities reaching 160 km/h or 44.8 m/s at highest level of the sport, thus travelling the distance between the bowler and the batsman(22 yards) in less than 500ms (Müller et al., 2006). To increase the challenges for the batsmen, the ball can deviate unpredictably either laterally or vertically, during its flight or after bouncing on the pitch (Müller et al., 2006). The previous research (Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013) typically overlooks this, and only measured the gaze behaviours of batters against one type of bowling; slow to medium pace. Land and McLeod (2000), and Croft et al. (2010), used speeds between (60-90 km/h or 17-25 m/s) which are extremely slow, especially when you consider no spin was imparted on the ball, this type of bowling is very rarely found in the world of cricket. While the ball speed used in Mann et al. (2013) study (120 km/h or 33.3 m/s) was considerably faster when compared to speeds in the earlier studies, the bowling speeds examined were still not representative of a human fast bowler. While the previous research has examined slow bowling (albeit with a lack of spin imparted on the ball) and medium pace bowling, fast bowling has been overlooked when it comes to determining how the ball is tracked during its flight.

The most striking flaw with previous research, however, is the fact that all of the three studies assessing how the ball is tracked during its flight (Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013) used bowling machines. The participants had no pre-delivery information to view before ball release and as such the cricket batters essentially ‘parked’ their gaze where the ball would exit the bowling machine. It wasn’t in the scope of these studies to assess the pre-delivery search strategies of the batters, however, these studies have completely ignored the importance of pre-delivery information for interceptive tasks. Not only have these studies ignored the importance of pre-delivery cues they have also overlooked the fact that batting against a bowling machine changes that movement patterns and coordination of skilled of cricketers (Renshaw, Oldham, Davids, & Golds, 2007; Pinder et al., 2009). If the kinetics of batmen differs when facing a bowling machine compared to a human bowler, how do we know that the gaze behaviour of the batter does not also change?

A through research project is therefore needed in order to exploring the visual strategies batters employ when facing a range of bowlers, and whether these strategies impact the batter's decision. This knowledge will be the starting point for an effective visual perception training programme and the results can be used to plan and develop visual perception interventions for amateur and elite level cricketers. The findings will highlight valuable information for coaches, practitioners and players about relating to the best methods to teach batting while enhancing the batters' visual, decision-making and anticipatory abilities.

Chapter 3.0
Methodology

This chapter outlines the philosophical approaches adopted throughout this programme of research. A discussion relating to research philosophy and specifically the research philosophy adopted throughout this programme of research is presented. The chapter also highlights the research strategies adopted within this research programme in order to best answer the research questions that emerged from contemporary knowledge and understanding in the area of interest.

3.1 Philosophy

Research philosophy refers to the beliefs and assumptions held by the researcher relating to the creation of knowledge (Saunders, Lewis, Thornhill & Bristow, 2019). During every stage of the research process, whether it is a conscious decision or not, a number of assumptions will constantly be made by the researcher relating to the realities encountered within the research (ontological assumptions) and assumption relating to the nature of knowledge (epistemological assumptions) (Saunders et al., 2019). Ontological assumptions are

> claims and assumptions that are made about the nature of social reality, claims about what exists, what it looks like, what units make it up and how these units interact with each other. In short, ontological assumptions are concerned with what we believe constitutes social reality (Blaikie, 2000, p. 8).

All research starts with ontology; once the researcher has an understanding of their ontological approach, it impacts and effects the subsequent stages of the research project including the epistemological and methodological positions (Grix, 2002). If ontology is about what we know and assumptions relating to our reality, then epistemology refers to "how we know what we know" (Grix, 2002, pp. 177). Blaikie (2000, p. 8) defines epistemology as "the possible ways of gaining knowledge of social reality, whatever it is understood to be. In short, claims about how what is assumed to exist can be known" (Blaikie, 2000, p. 8). Epistemology is the study of knowledge and focuses on the process used to gather information and to discover knowledge. The ontological and epistemological approach dictates the choice of methods, data collection and the techniques used to analyse and interpret the data. Before starting any research project, it is therefore crucial to consider the different research philosophies, and the most appropriate one for the project under consideration.

3.2 Philosophical paradigms

Traditionally within the social sciences, researchers have adopted one of two main philosophical paradigms: either positivist or constructivist (Tashakkori & Teddlie, 1998). Positivism is a philosophical position that focuses on observable and objectively measurable facts. A positivist worldview suggests that objectivity is always possible and generalisable, and that universal truths exist (Guido, Chavez, & Lincoln, 2010). Due to these beliefs, researchers design experiments to eliminate bias and produce objective facts and knowledge within their investigations (Guido et al., 2010). Positivist research therefore usually involves methodological designs that can be scientifically verified where knowledge is generated through the scientific approach or mathematical proof (Blanche, Durrheim, & Painter, 2006). The key tenets of positivism are to test hypothesis via experimentation and subsequently predict phenomena. Knowledge from a positivist perspective is considered factual, rational and objective and can only be acquired through the scientific method. The positivist approach therefore utilises quantitative data collection methods. The positivist approach has been the dominant influence within the field of sport and exercise psychology (Brustad, 2008), however, it has received major criticism. While the positivist paradigm with its objective and scientific approach may be appropriate for studying natural phenomena, it lacks applicability when considering the social world, specifically human interactions and behaviour (Rehman & Alharthi, 2016). Indeed, these social interactions are in stark contrast with the universal truth view highlighted within positivism as humans have free will, the ability to interpret the world, and bring about their desired individual state (Buchman, 1998). The appropriateness of the application of the positivist paradigm within social sciences is therefore dubious.

By contrast, constructivist researchers have predominately focused on qualitative approaches to research by exploring participants' interpretation, understanding and explanation of the world around them and how they experience situations (Moran, Matthews, & Kirby, 2011). Constructivist research attempts to explain and understand social phenomena "through the eyes of the participants rather than the researcher" (Cohen et al., 2007, p. 21). Constructivists refuse to adopt positivists' beliefs that there is one universal truth. Instead they harbour the opinion that there are multiple realities that are constructed socially and individually (Rehman & Alharthi, 2016). Truth cannot be generated or created through experimental scientific approach; truth cannot be uncovered or created as truth is mediated by our senses and interpretation and is therefore subjective (Rehman & Alharthi, 2016). Without understanding and considering individuals' backgrounds, experiences, social status, relationships, cognitions etc., truth and reality cannot be accessed. Constructivist researchers therefore aim to understand social interactions by gathering the views and opinions of those involved in the interaction. The main method utilised to achieve this is qualitative research collected from participants through interview, observation, case studies or engaging with and observing participants for an extended period of time (Rehman & Alharthi, 2016). The main critics of the constructivist approach argue that due to the subjective nature of the research it should be considered 'soft' and that the methodologies are not scientifically rigorous (Grix, 2004). Indeed, one of the drawbacks to constructivist research is the difficulty in generalising the findings to a larger population or creating theories that can be generalised to larger populations (Grix, 2004). Another criticism of the constructivist paradigm approach is the involvement of the researcher. Because the researcher is usually involved in the data collected process, critics claim that they can never be truly objective. The positivist and constructivist paradigms have wildly different and conflicting but passionate ideologies and these beliefs highlight fundamentally different methods and approaches to research. One paradigm that attempts to reconcile both positivism and constructivism is pragmatism (Saunders et al., 2019).

3.3 Pragmatism

Pragmatism originated in America during the late nineteenth century from the work of philosophers Charles Pierce, William James and John Dewey (Saunders et al., 2019). For a pragmatist, finding the correct methodology in order to answer the research questions and problems facing the researcher is the primary concern. Research, therefore, starts with the problem and the goal of the research is to provide a practical solution to answer the problem at hand (Saunders et al., 2019). Due to the fact that pragmatists are more interested in answering research questions rather than the sticking to abstract philosophical distinctions, research may have considerable variation in terms of how 'positivist or 'constructivist' the research turns out to be (Saunders et al., 2019).

The initial work undertaken by Dewey in the late nineteenth and early twentieth centuries focused on the redirection of attention away from philosophical constructs and instead focusing on how the human experience guides research and inquiry (Dewey, 1920). Dewey highlighted how experiences and beliefs always involve a human element; all situations and experiences need to be interpreted (Morgan, 2014). Without an interpretation of a situation or experience, beliefs cannot occur. Dewey claims that these interpretations form habits which ultimately guide our decision-making and future actions. These habits guide us throughout our day-to-day lives and do not require us to make conscious decisions in the face of routine daily obstacles. For example, we do not need to make a conscious decision to make or have lunch at lunchtime as this behaviour becomes habit (Morgan, 2014). In contrast to habits, inquiry or conscious thoughtful decision-making is needed in situations that are more complex or problematic. Inquiry, as Dewey suggests, is needed when situations become too problematic to refer to past experiences or habits. Whether using habits or inquiry to guide actions, these actions will always occur within a given situation or environment; they are related to context and emotions and are shaped by society (Morgan, 2014). These beliefs formed the basis of Dewey's pragmatic philosophy. Rather than the traditional discussion relating to the nature of truth and to what is considered 'real', Dewey suggests that all research, all enquiry, is rooted in life itself, in understanding life, emotions and the inherent and social context (Morgan, 2014). Dewey's pragmatism therefore opposed traditional metaphysics and relied upon a "process-based approach to knowledge, in which inquiry was the defining process" (Morgan, 2014, p. 1047). Dewey (1910) argues that there is no clear distinction between everyday life and research; research is just one form of inquiry that is performed more carefully, thoughtfully and at a conscious level (Morgan, 2014). Dewey's model of inquiry (see figure 3.1) highlights the research process from a pragmatist perspective. This process links thoughts and beliefs into action plans. The model highlights the steps involved in inquiry or research from highlighting a problem that requires research through to considering the potential solutions to answer that problem and finally taking action.

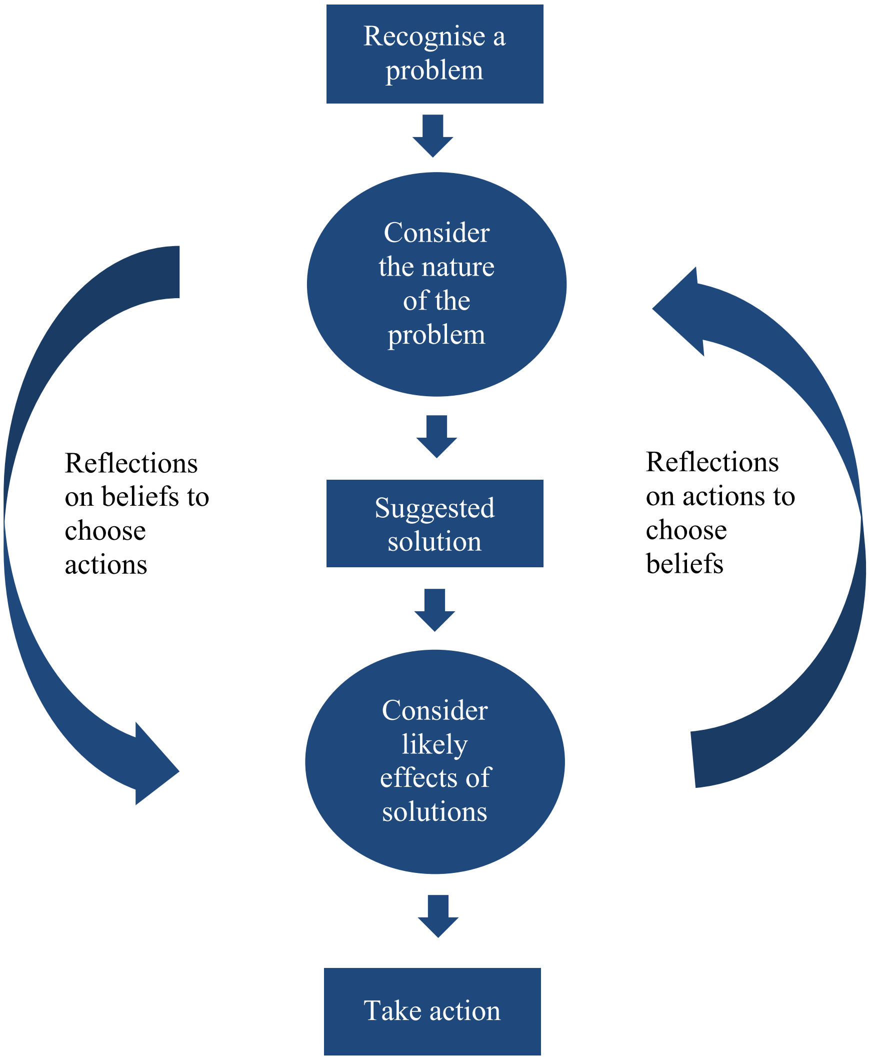

Figure 3.1: Dewey's model of inquiry (Morgan 2014).

A debate regarding whether pragmatism should be considered a philosophical paradigm exists within the epistemological and ontological research. Dewey's pragmatist (1920) approach places the human experience at the centre of the inquiry process by posing a question: what is the nature of human experience? A pragmatist approach therefore replaced the traditional focus on ontology and epistemology with a focus on the human experience and research process (Morgan, 2014). Therefore, the pragmatist approach should be considered a paradigm in its own field (Morgan, 2014).

A pragmatic paradigm argues that the best and most logical way to expand knowledge is through the adoption of a problem-solving approach (Giacobbi, Poczwardowski & Hager, 2005). Pragmatism can and should serve as an important philosophical paradigm within the field of social research. Traditionally, a pragmatist approach has been associated with mixed methods research, with many researchers adopting a pragmatic philosophy focusing on the practical approach of using the best methodology available to answer the research question. Recently, however, arguments have been made that this philosophical approach has merit and is an appropriate paradigm regardless of whether the research is quantitative, qualitative or mixed methods (Morgan, 2014). Pragmatists recognise that knowledge can be acquired through multiple sources and methods. There are numerous ways of interpreting the environment and world around us and therefore there are numerous ways to research within this world. Pragmatists will not always utilise multiple research methods. They will, however, always utilise the most effective, credible and reliable method of data collection available in order to effectively answer the question at hand.

As highlighted previously, the philosophical approaches and frameworks used within a programme of research dictate the data collection methods, the analysis procedures and the conclusion and recommendations made based on the findings. There are numerous philosophical and methodological approaches available to the researcher and Saunders et al.'s (2012) research onion presents a clear visual representation of the wide variety of theoretical and methodological routes research could take on their research journey (see fig 3.2). The research onion clearly highlights how the 'outer layer' of philosophy dictates the choices throughout and ultimately the way in which data is collected and analysed. In order to underpin the current thesis, figure 3.3 clearly demonstrates the layers of the research onion for this programme of research. The figure clearly presents the views of the researcher and the approaches that were selected to underpin this programme of research. The philosophy adopted throughout this research programme was a pragmatist approach. This was due to the researcher's beliefs that the most logical and robust way to answer the research questions was the most appropriate method and, as such, both quantitative and qualitative data collection methods were utilised. The research was deductive as opposed to inductive, as it started with a research question and hypothesis and sought to answer these questions. The programme of research used an experimental design, taken from a specific population at one point in time by utilising both quantitative and qualitative (mixed methods) data analysis tools. Those tools consisted of eye tracking technology to collect quantitative data relating to the eye movements of the participants as well as qualitative questioning to generate the views and opinions of the participants in relation to the effectiveness of their decision-making.

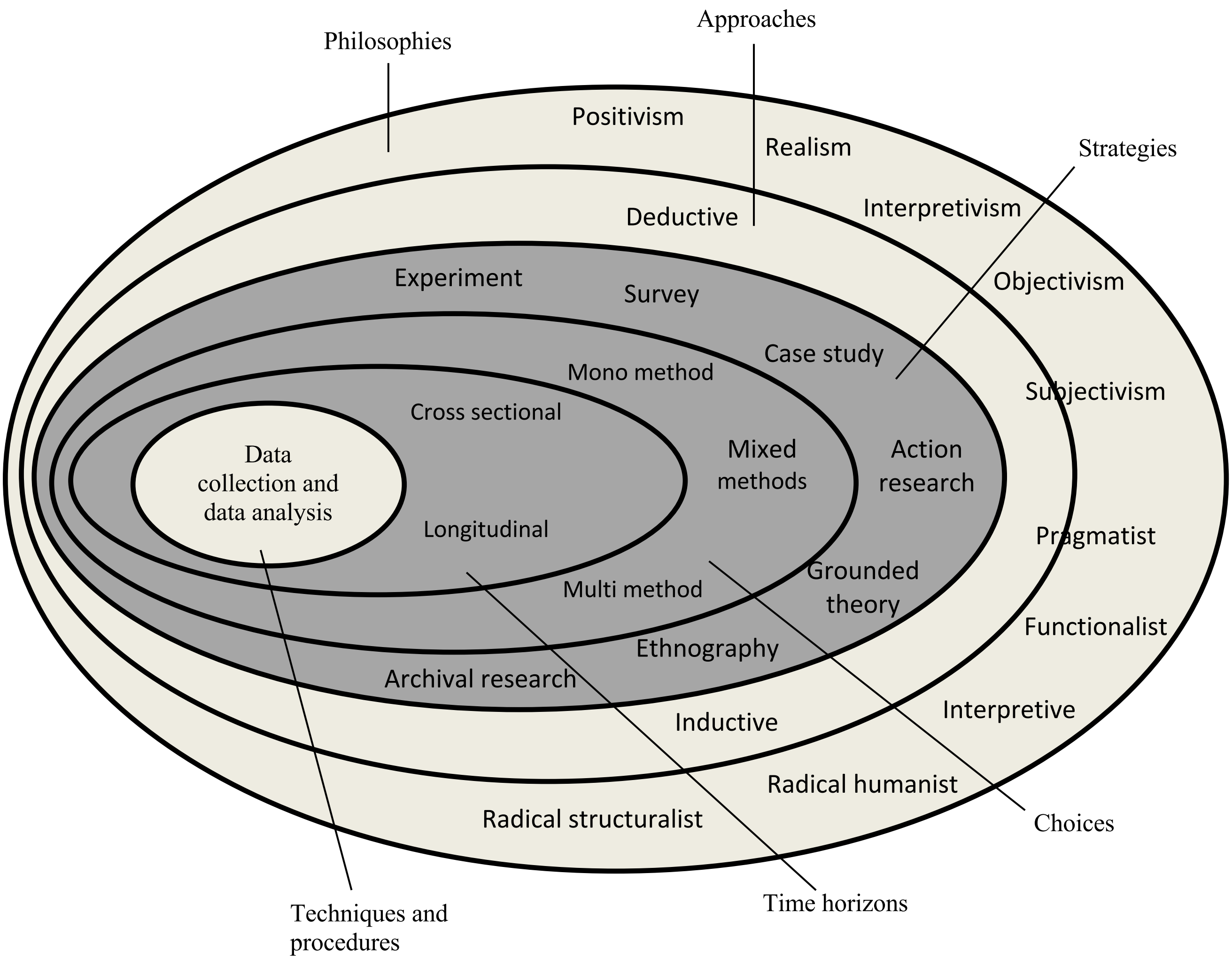

Figure 3.2: The Research Onion (Saunders, Lewis & Thornhill, 2012).

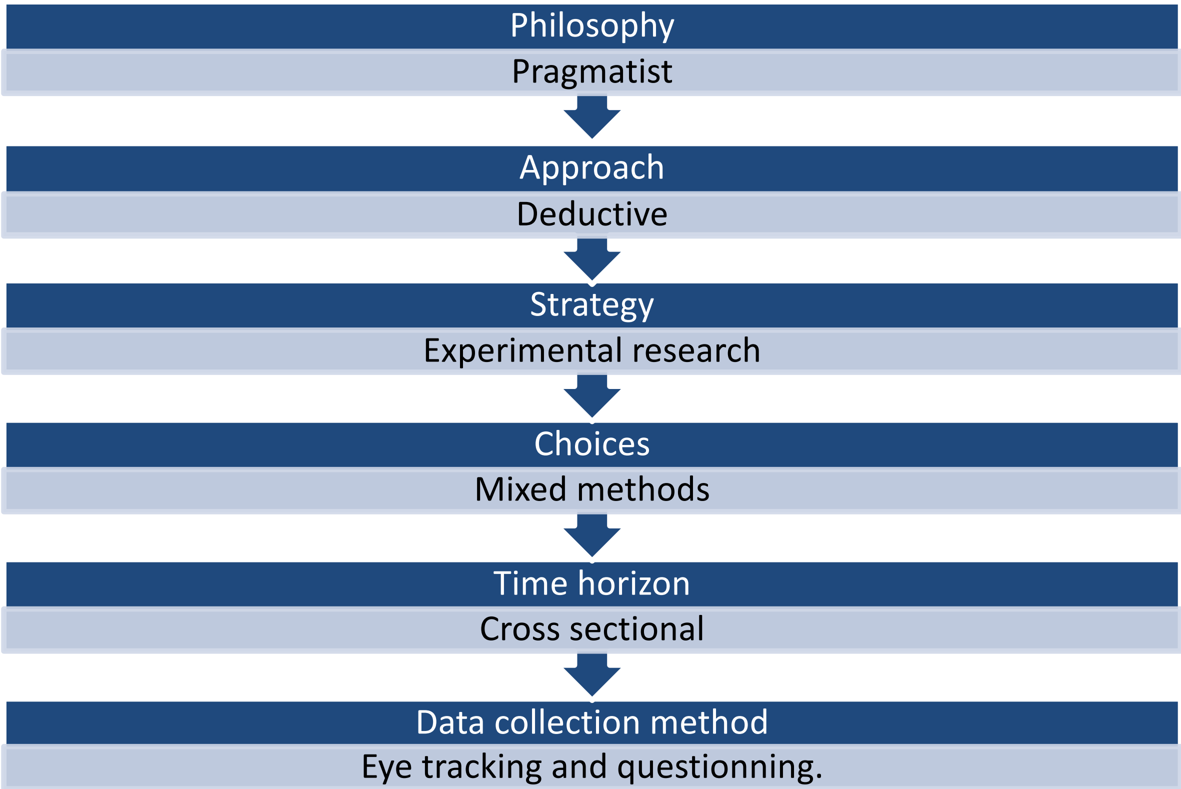

Figure 3.3: Selected philosophical and research approaches underpinning this programme of research.

3.4 Qualitative, quantitative and mixed methods

Pragmatism is frequently adopted as a philosophy by researchers utilising a mixed methods approach to their research. A pragmatic paradigm does not exclusively favour either qualitative or quantitative research, however, in its simplistic form, does suggest that the best methodology to solve the research problem is the most effective methodology to use. Over the past century, there has been a passionate debate relating to benefits and pitfalls of the quantitative and qualitative research paradigms. The debate has led to a divide between researchers and philosophers who wholeheartedly support their preferred approach and often view themselves in competition with researchers who favour the opposing view (Onwuegbuzie & Leech, 2005). The view that these approaches are conflicting has led to the belief of some that adopting both a quantitative and qualitative methodology simply should not be attempted. However, from a pragmatist perspective, if both quantitative and qualitative methodologies are the best approach to answer the research questions then they should be utilised. Indeed, the argument has been made that adhering so stringently to one methodology and promoting a purist view of mono-method research is the single biggest hinderance to the development of the social sciences (Sechrest & Sidani, 1995; Onwuegbuzie & Leech, 2005).

Both quantitative and qualitative research have their strengths and weaknesses. Research adopting a quantitative approach draws on mathematics, statistics and probability testing and is primarily concerned with collecting numerical data and using this data to test hypotheses (Flick, 2015; Zawawi, 2007). This approach is viewed as an objective, factual and often the more robust or scientific approach to research when compared to qualitative research methodologies. In comparison, qualitative research is less focused on numbers and probability testing and instead seeks to explore the meaning of constructs and participants' views, opinions and interpretations. Qualitative research uses data in the form of words and language and attempts to develop a greater understanding of the social world. Together, these approaches form the basis for the large majority of the social science research. However, they are not without their criticisms. The quantitative research paradigm is often criticised for ignoring the human element, how individuals interpret the surroundings and the interaction between the participant and the environment (Bernard, 2012). In social science research, quantitative approach often fails to provide an underlying meaning or reason as to why certain things occur and is often not helpful in understanding the issues being investigated thoroughly, as it ignores the opinions and thoughts of the participant. It can often be considered inflexible and sometimes artificial in nature (Zawawi, 2007). Qualitative research addresses these issues, however, is often criticised for a lack of generalisability. By focusing on individuals' thoughts and opinions, it is also considered less objective and factual when compared to the quantitative approach.

Mixed methods research is an appropriate way to address the weaknesses of both the quantitative and qualitative approaches. When problems which cannot be answered by using one of the above approaches present themselves, then the best method to adopt is a combination of the two, i.e. a mixed methods approach. In the majority of research adopting a mixed methods approach, the researcher starts by adopting a quantitative approach in order to gain facts and numerical data and then progresses to a qualitative approach to gain a greater understanding of these (Zawawi, 2007). The current programme of research was underpinned by a pragmatic paradigm and therefore used the most appropriate method to collect data depending on the study and the research questions. Study one within this programme of research adopted a purely quantitative approach. The study was laboratory based and focused solely on numerical data collected through a table mounted eye tracking system. On the other hand, studies two and three used a combination of both quantitative and qualitative data collection methods. The vast amount of data collected within studies two and three was generated through quantitative measures, i.e. using mobile eye tracking glasses to generating numerical values for fixations and eye movement. However, throughout the second and third studies, the decision-making aspect of the data collection was acquired via qualitative methods. This involved asking the participants for their opinion regarding the effectiveness of their decision-making. Participants were asked to consider whether their decision-making was effective after each delivery. From a pragmatic standpoint, this was the most effective and logical approach to take in order to answer the research questions for each study.

3.5 Research Strategies

The current programme of research used two main methods for collecting data. The majority of data was collected qualitatively via eye-tracking technology. The decision-making data in studies two and three was collected qualitatively using questioning.

3.5.1 Eye-tracking

Eye-tracking is an extremely exciting research area within the field of sport and exercise. Both desk-mounted and mobile eye trackers afford the researcher the opportunity to monitor the eye movements and the gaze behaviour of their participants. Eye tracking technology provides the platform to investigate and understand the cognitive processes involved in performing a sporting task and the processes involved that lead to expert performance (Moran, 2009). There are three main types of eye-trackers currently available on the market today: table/desk-mounted, head-mounted, and remote eye-tracking systems. Each of these different systems has its own benefits and drawbacks. Two of these types of eye trackers have been utilised within the programme of research. The first, utilised in study one, was a desk mounted eye-tracker: the Eye-Line 1000. This type of eye tracker is by far the most accurate of the three systems available. These systems present footage on a computer screen and require participants to be seated and have restricted head movement. Restricting head movements and utilising highly refined and powerful cameras means that the data collected is highly accurate and precise. The strength of this system is also its main weakness, i.e. it is restrictive. The participant needs to remain stationary while watching the computer screen, therefore this method has significant implications for the representative design of the task and the ecological validity of the study (Araujo et al., 2007).

Studies two and three utilised a mobile eye-tracker. Over the past two decades, these systems have become cheaper, faster and more accurate, resulting in more field-based eye-tracking studies (Duchowski, 2007). This rapid improvement in technology has allowed researchers to move away from the laboratory setting and to collect data in more natural environments. Eye-tracking technology was utilised in all three studies within this programme of research. This technology was the only way to track the gaze behaviours of the participants both pre-delivery and during the ball flight.

3.5.2 Questioning

In studies two and three, data was collected in order to determine whether the participants believed that they made the correct decision after each delivery. It is important to account for individual differences when studying decision-making. For example, what might be considered a risky or inappropriate shot selection for one batter would be considered normal or effective for another. One person might play the sweep shot extremely well, whereas another might have cut this out of their game and consequently making it a risky shot when they do play it. Therefore, in order to determine whether the shot selection and decision-making was correct, it is important to gain the view of the participant themselves and not rely on observations or coaches' assessments.

Considerations were made as to whether decision-making could be assessed through observations made by either the participants' coach or the researcher, however, due to the subjective nature of decision-making, the only way to determine whether the decision made was correct was to ask the participant themselves. To determine whether the participants in studies two and three believed that they made the correct decision regarding shot selection, dichotomous yes/no questioning was used. A yes/no question is defined as an interrogative sentence whereby the answer can only be yes or no (Kanayama, Miyao, & Prager, 2012). The benefits of using dichotomous questioning was twofold. Firstly, it was a quick method that was appropriate to use within a cricket training session. The questions could easily be asked to the participant between each delivery. Secondly, it was the simplest method available to gain the viewpoint of the participant. The participant was able to reflect on the past delivery and make a decision regarding the effectiveness of their own decision-making. The researcher asked the following questions after each delivery: 'Yes or no, do you believe you made the correct decision in terms of shot selection?' The researcher also asked the following question: 'Yes or no, do you feel you successfully executed the shot?'

3.6 Data analysis approaches

The qualitative data within study two and three was utilised to categorise deliveries into correct vs. incorrect decisions and therefore was crucial to inform which data was included within the quantitative tests. The current programme of research utilised a number of different statistical tests within SPSS. The following subsection details the data analysis methods utilised and why they were the most appropriate choice for the statistical data sets collected across the three studies.

3.6.1 Study one

*Study one**:** Repeated measures* analysis of variance (*ANOVA) or non-parametric equivalent Fridmans test.* In a one-way repeated measures ANOVA, each participant is exposed to two or more different conditions. A repeated measures ANOVA requires one group of participants recorded on the same scale on three different occasions or under three different conditions (Pallant, 2011). Within study one, there was one group of batters (7 participants) and they were tasked with viewing the video footage of three different types of bowlers (3 conditions). Therefore, the most appropriate statistical test available was the repeated measures ANOVA. The ANOVA is the preferred technique compared to multiple Paired Samples T-tests, as it controls the error rate and thus reduces the probability of making a type 1 error. The repeated measures ANOVA revealed whether there was a statistical difference in pre-delivery eye movements or ball flight eye movements somewhere among the three conditions of spin, medium pace and fast bowling. Post hoc pairwise comparisons using a Bonferroni adjusted alpha value was then utilised to determine between which groups the difference occurred.

3.6.2 Study two

Study two: paired samples T-tests or non-parametric equivalent Wilcoxon Signed Ranks tests. Paired Samples T-tests are appropriate when you have one group of participants and they are tested on two occasions or within two conditions (Pallant, 2011). The Paired Samples T-test tells you whether there is a statistical difference in the data between the two conditions. In study two, there was one group of participants (7 batters) and they were tested under two conditions (spin and medium-paced bowling). Therefore, the appropriate statistical test was the Paired samples T-test or Wilcoxon Signed Ranks tests if the data was non-parametric. Paired Samples T-test or Wilcoxon Signed Rank tests were therefore administered to determine if there was a statistical difference between gaze behaviour both pre-delivery and during the ball flight across the two conditions of spin and medium-paced bowling. The qualitative subjective questioning was used to determine whether the participants made a correct or incorrect decision. This information was then utilised to categorise each delivery as either correct or incorrect decision-making. Paired samples or Wilcoxon Signed Rank tests were then administered to determine whether there was any difference in the quantitative eye movement data when the participants made a correct vs. incorrect decision.

3.6.3 Study three

Study three: paired samples T-tests (or non-parametric equivalent Wilcoxon Signed Ranks tests) and independent Samples T-Tests (or non-parametric equivalent Mann-Whitney U Test). Paired Samples T-Tests or Wilcoxon Signed Ranks tests were administered to determine if there was a statistical difference in the gaze behaviour of the participants pre-delivery or during ball flight between the two conditions of spin and medium-paced bowling. These Paired Samples T-Tests or Wilcoxon Signed Ranks Tests were administered for both the elite and the amateur players separately. In accordance with study two, the subjective questioning was used to categorise whether both the elite and amateur participants made a correct or incorrect decision for each delivery. This information was then utilised to categorise each delivery as either correct or incorrect decision-making. Paired Samples T-Tests or Wilcoxon Signed Rank tests were then administered to determine whether there was any difference in eye movements when both the elite and amateur participants made a correct verses incorrect decision. An Independent Samples T-test is appropriate when you have two independent groups (in study three elite and amateur) and you wish to compare their mean scores on the same variable (i.e. their gaze behaviour pre-delivery and during ball flight) (Pallant, 2011). Therefore, the most appropriate test to compare elite vs. amateurs gaze behaviour within study three was the Independent Samples T-Tests or Mann-Whitney U Tests. These tests were administered to determine whether there was a difference in pre-delivery gaze behaviour between the elite and amateur participants and again for the ball flight data.

3.7 Summary

The current programme of research adopted a pragmatist research philosophy by utilising the most appropriate methodology for the research question at hand. This included utilising multiple eye tracking systems in different environments, including a laboratory-based study and naturalistic environments in studies two and three. The views of the participants' decision-making were also assessed via dichotomous questioning throughout studies two and three. The current thesis offers a cross-sectional time horizon and uses various different data collection methods and multiple statistical testing. While there has been a divide in the social sciences between quantitative and qualitative approach, with many researchers strongly arguing for a mono-methods approach (Onwuegbuzie & Leech, 2005), it is the researcher's belief that a pragmatist philosophy should be adopted by more researchers so that methodologies are designed based on the most appropriate strategies for a particular set of circumstances (Morgan, 2014). This is the only way that social sciences and sport psychology research in particular will not be hindered by researchers' precious or protective views of one particular philosophy.

Chapter 4.0

Study one

An exploration of cricket batter's gaze behaviour while batting against spin, medium paced, and fast paced bowling.

4.1 Introduction

The majority of research studying the advance visual information utilised by cricket batters has adopted an occlusion paradigm. Here, research on expert visual anticipation (Abernethy & Russell, 1984; Müller et al., 2006; Penrose & Roach 1995; Renshaw & Fairweather, 2000) has consistently highlighted that experts athletes are superior to non-experts at using early visual information prior to the flight of an object to predict the future location of that object. Temporal occlusion studies have highlighted the importance of using advance visual information to guide component phases of the striking skill. It has also been reported that highly skilled cricket batsmen gather pre-delivery visual cues and early ball flight information to anticipate the line and length of the ball (e.g., the balls landing position) (Müller et al., 2009). These highly skilled batters then use this information to make decisions regarding shot selection and how to position their body appropriately for bat-ball interception. In contrast, less skilled batsmen appear unable to gather and act on this early information and are therefore less likely to perform a successful bat-ball interception. The results from previous research studies (Müller & Abernethy, 2012; Müller et al., 2006; Penrose & Roach, 1995; Renshaw & Fairweather, 2000) consistently suggest that the extraction of advance cues is a vital component for cricket batting (McRobert et al., 2009). However, few studies have specifically examined what sources of information are extracted by the batter from the bowler's approach and delivery.

Past cricket eye-tracking studies (Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013) used bowling machines within the experimental design, therefore ignoring the crucial pre-delivery visual cues available to batters. To date, McRobert et al. (2009) is the only study which has specifically investigated what pre-delivery information batters fixate upon by using eye-tracking technology. However, McRobert et al. (2009) only assessed the visual search strategies of batters when facing spin and fast pace bowling. Yet, during the course of a cricket innings, a batter will likely have to intercept deliveries bowled to them at a wide range of different velocities; i.e., slow or spin bowling (72-88 km/h or 20-24 m/s), medium pace bowling (120-128 km/h or 33.5-35m/s), and fast pace bowling (137-145 km/h or 38-42 m/s). Thus, questions still remain about what advance visual cues batters use during pre-delivery when facing medium pace bowling; the most common type of bowling within cricket, specifically amateur cricket. In addition, McRobert et al. (2009) did not tracked the gaze behaviours of batters after the bowler has released the ball when the pre-delivery visual cues were available. Therefore, we do not currently know what strategies batters utilise in order to track ball flight. Combining both pre-delivery and ball flight information (i.e., tracking vision from the start of the run up and through the entire ball flight) seems to be crucial in order to get the 'full picture' of the gaze behaviour of cricket batters.

4.1.1 Aims of the study

The aims of the current study were to investigate the gaze behaviours of cricket batters when presented with video footage of human bowlers of varying speeds and bowling styles. This included conventional off spin bowling (72-88 km/h or 20-24m/s), with spin imparted on that ball which has been neglected by the previous experiments. Medium pace bowling (120-128 km/h or 33-35m/s) and fast paced bowling (129-137 km/h or 36-38 m/s). The current study also examined what information batters fixate upon during the crucial pre-delivery phase for all three types of bowling. In order to achieve this, the batters gaze patterns were tracked from the start of the bowlers run up and throughout the entire ball flight. Finally, this study examined how batters tracked the ball during flight, something that has previously been neglected for fast pace and spin bowling. Therefore, the batters gaze behaviours were tracked from the start of the bowlers run up and throughout the entire the ball flight.

4.2 Methodology

4.2.1 Research question and hypotheses

5. What eye-movements (fixations, fixation location and fixation duration) do batters produce prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) when presented with video footage of human spin, medium pace, and fast paced bowlers?
    - It was hypothesised that batters will fixate on different aspects of the bowler's body including, the wrist, the hand and the head of the bowler. It

is also hypothesised that the batter will fixate on the ball and the point of release, as suggested by McRobert et al. (2009) and Müller et al. (2006).

6. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) when presented with video footage of human spin, medium pace, and fast bowlers?
    - It was hypothesised that batters will fixate on different aspects and segments of the bowlers' body when facing spin compared to facing medium pace or fast bowlers as suggested by McRobert et al. (2009).
7. Do batters use predictive saccades or smooth pursuits in order to follow the ball during its flight when viewing video footage of human bowlers of varying velocities (i.e., spin bowling, medium pace bowling, and fast paced bowling)?
    - Batters will try to utilise smooth pursuit for all/the majority of the ball flight when facing spin bowling, as the balls velocity will be slower enough to track throughout its flight.
    - Batmen will not pursuit track the ball through the entire flight when facing medium paced or fast bowlers, instead they will make a predictive saccade as suggested in the previous research (Croft et al., 2011; Land & McLeod, 2010; Mann et al., 2013).
8. Do batters use a difference strategy (i.e. predictive saccade vs. smooth pursuit) to follow the ball during its flight when viewing video footage of spin bowling compared to medium pace or fast pace bowling?
    - There will be a significant different in the way batters follow/track the ball during its flight, when facing bowlers of varying speeds.

4.2.2 Participants

Participants were recruited with the help of the coaching staff at a professional (elite) cricket club in the United Kingdom. The participants were seven male (*Mean age =* 18.4, *SD* = 0.3) cricket batters who were, at the time of participation, contracted to the academy at their first-class county cricket club (division one) in England. All batters were regular top order batsmen (i.e. regularly bat in the top 6 positions within their respective team). As determined by their club coaches, batters represent the most talented and successful young players within their county squads, and it is expected that a number of these players will progress to gain a full professional contract either at their current county, or elsewhere in England. When defining elite participants within research studies, it is important to have a clear, valid and reliable understanding of what the term elite means. Swann et al. (2015), found that definitions of elite or expert athlete within the literature range from Olympic gold medallist to regional and university athletes. Swann and colleagues suggest a model that can be used to classify athletes. In accordance with the models and definitions recommended by Swann et al. (2015) the batters within this study can be defined as semi-elite. Semi-elite athletes are athletes whose highest level of participation is below the top standard possible in their sport (e.g., in talent-development programs, or athletes at a second-tier standard). Previous studies using eye-tracking within cricket have used very small sample sizes of 3 and 2 respectively (Land & McLeod 2000; Mann et al., 2013). This study conformed to more normal practice within eye-tracking research (Amazeen, Amazeen, & Beek, 2001; Rodrigues et al., 2002; Savelsberg et al., 2002; Savelsberg, Hanns, Kooijman, & Kampen, 2010; Singer et al., 1998; Vickers 1996; Williams et al., 2002) and use a larger sampling size of seven participants.

Inclusion criterion for batters within the study was as follows: all batters (at the time of the study) had a professional or academy contract at a first-class cricket county. The batters were healthy, fully fit, and not struggling with any injury that might affect their performance, vision or decision-making within the experiment. No batters were included within this research if they had any visual defects either corrected or otherwise, therefore no participants wore glasses or contact lenses. This information was gained through conversations with the participants prior to data collection; no formal vision test took place. Batters had all played at least one competitive game of cricket within the past six months and were all participating in regular cricket practice with their current club or county. Prior to the experiment the researcher met with each batter to double check that their level of expertise and experiences within cricket meet the criteria for the study.

4.2.3 Procedure

The study took place within a laboratory setting, using a table-mounted eye tracker made by SR Research Ltd; The EyeLink 1000. Using a table mounted eye tracker allowed the researcher to have greater control over the environment and associated variables, and therefore generate more accurate eye-tracking data (compared to mobile systems). At the time of data collection, the EyeLink 1000 (alongside the SMI iView HiSpeed) was considered one of the two best table mounted eye-tracking systems in the world (Holmqvist et al., 2011). The table mounted system also offers extremely higher sample rates (up to 1000 frames per second) compared to the head mounted systems (rates of up to 50 frames per second at the time of writing). This means that the data collected was comprehensively more accurate, when compared to a head mounted system and therefore the amount of unknown data was reduced (Holmqvist et al., 2011). The eye-tracking laboratory was set up in accordance with the extensive advice and guidelines presented by Holmqvist et al. (2011).

The participants were presented with video clips of both academy and professional bowlers. In accordance with the recommendations of Müller, Brenton and Rosalie (2015), the batters in this task were not familiar with the bowlers recorded for the experiment. The video footage used in this study was collected from a first-class professional cricket club in the United Kingdom. The bowlers videoed as part of this study included an off-spin bowler (who had an academy contract with the club), a medium paced bowler (who had a professional contract with the club) and a fast-paced bowler (who also had a professional contract with the club). The off-spin bowler was described by the academy director as a consistent bowler who imparts a lot of spin on the ball. The spin bowler consistently delivers the ball between 72-88 km/h or 20-24 m/s. The medium paced bowler was an all-round cricketer (a batter as well as a bowler) and at the time of recording the footage had just been offered a professional contract with the club (however had yet to make a first team appearance). This bowler was described as an away swing bowler (moves the ball away from the batter in the air) and consistently bowled the ball between 120-128 km/h or 33.5-35m/s. The fast pace bowler had recently become a first team regular (during the same season) and consistently reached bowling speeds between 129-137 km/h or 36-38m/s. At the time of recording, the fast pace bowler had made 87 appearances for his county 1st XI.

The bowlers recorded for the study were deemed to have a 'regular' bowling action by the coach at the professional county (a UK level four cricket coach) and the author (a UK level two cricket coach). This meant that the bowlers had a traditional side on action, a high/straight bowling arm, and released the ball from a high point above their shoulder. Definition of a regular bowling action was considered to be someone that did not have a wildly different bowling action to the norm, or the traditional action described in coaching manuals. For example, players such as Lasith Malinga, Shaun Tait or Muttiah Muralitharan who all have irregular actions would not have been used within this experiment. The video footage was collected from the point of view of the batter, showing the full bowling action from run up through to full ball flight. The video footage was collected via a high Definition Panasonic camcorder (Panasonic HC-V100), which was positioned on a tripod at head height (5ft 9inches) on the popping crease (i.e., the position where the batter would stand). The camera was position at 5ft 9inches high in line with the middle stump in order to replicate as accurately as possible, the point of view of the batter. The camera had an unobstructed view of the bowler and the full delivery. The tripod legs were marked with masking tape to ensure that the tripod could be reposition should the bowler strike the tripod or the camera with the ball. This was not needed during the recording. Each bowler was asked to delivery two overs (12 deliveries) during the recording of the video. This ensured that there were enough video clips to create the final video as well at the acclimatisation video without the need to reuse any deliveries. If at any stage the bowler delivered an illegal delivery (i.e. a wide or a no-ball) they were asked to bowl this delivery again.

Each batter was shown six video clips from the spin bowler, the medium pace bowler and the fast bowler. The batters were presented with two overs of random video clips before any data is recorded. This allowed the participants to acclimatise to the laboratory setting, get use to the lighting in the room, the eye-tracking technology, and the correct way to respond to the delivery seen on the screen. If the participant requested, they would have been offered the opportunity to repeat this process until they felt comfortable enough to start data collection. No batters asked for more time to acclimatise. Only when the participant had confirmed that they were comfortable with the procedure did any data collection take place.

Before the data collection took place, the batters were presented with and asked to read a brief explaining a common ‘game scenario’. This brief can be seen later in the chapter (see section 3.2.4). The batters were asked to make a decision as to what shot they would hypothetically play after viewing each separate delivery. Tapping the desk with either their right or left hand made this decision. The batters were asked to select from two simple options: attack or defend. If the participant believed that it was correct to play an attacking shot to the delivery, then they were asked to tap the desk with his left hand. If they believed that the correct option was to defend the ball then he was required to tap the desk with his right hand. The decision-making aspect of the task was included so the batters would view the clip in a more ecological way. Cricket is a game where decision-making is of paramount importance. For each passage of play (ball that is bowled) the batter needs to make a decision about the shot that is going to be played (Cotterill, 2014). Batters have a split second to decide whether to attack or defend. By including a brief and a decision element (a decision that batters make every ball) it was hoped that the batters would view the video as if it was a real game scenario. The exercise therefore becomes more than just watching video clips of bowlers. There was no right or wrong answer to the question defend or attack the ball, and the results of the decision-making task were not evaluated or included in the data analysis.

4.2.4 Brief

The batters were presented with the following brief: Please imagine that you have just arrived at the crease ready to bat during the first innings of a 50 over match. Please do you best to think and act as you would if you were batting for your county team. You are playing on your home ground, the wicket is very flat, and the weather conditions are all in your favour. The sun is out and it is currently excellent conditions for batting. Each participant was then presented with the game scenario based on where they usually bat in the batting order. They were told what the current score was, how many wickets are down, and who is coming on to bowl next, i.e. spin bowler, medium pace, or fast bowler. The scores given to the players are based on what was deemed an average first innings total by the researcher (Who is an ECB level two cricket coach) 275/9 in 50 overs at 5.5 runs per over. The following scores were presented: Opener: 0-0, Number 3: 30-1 (8 overs), Number 4: 95-2 (18 overs), Number 5: 134-3 (25 overs), Number 6: 199-4 (36 overs), Number 7: 228-5 (40 overs), Number 8: 238-6 (42 overs), Number 9: 249-7 (44 overs), Number 10: 251-8 (45 overs), Number 11: 260-9 (47 0vers), Total: 275/9 (50 overs).

4.2.5 Calibration and validation

Following the brief and the acclimatisation, the researcher took each participant through the calibration and validation phase. It is important that each participant goes through calibration and validation for numerous reasons (e.g., differences in eye size, eye position, seating position height etc.) all of which will have an effect on the quality of data recorded (Holmqvist et al., 2011). The researcher used a nine-point calibration (consider the gold standard for eye-tracking research) and the calibration and validation was only accepted when the degree of variance (between the batters gaze, and the calibration marker) for each of the nine points was below 0.50**°** (Holmqvist et al., 2011) (See figure 4.1 for an example of an accepted and rejected calibration and validation). The average accuracy values for each of the batters were: participant one: 0.24°, participant two: 0.30°, participant three 0.33°, participant four: 0.27°, participant five: 0.32°, participant six: 0.33°, participant seven: 0.23°.

Figure 4.1: Picture on the left represents and accepted calibration and validation. Picture on the right represents a rejected calibration and validation; this participant would have been taken through the procedure again.

4.2.6 Measures

During the experiment the fixations, fixation duration, fixation location, saccades and smooth pursuits of each of the participant were recorded. The fixation location and fixation duration of the batters' gaze pre-delivery (before the ball is released) were recorded and analysed. A fixation was defined as the period of time (80ms or greater) when the eye remained stationary within 2° of movement tolerance (Carpenter, 1988; Holmqvist et al., 2011; William & Davids 1998). The fixations, saccades and smooth pursuits of the batters were recorded after the release of the ball. Therefore, the point-of-gaze of each participant was recorded from the beginning of the clip, through the entire run up, the bowling action and release, and through the entire ball flight. How the participant pursuit tracks/follows the ball during delivery (ball flight) was analysed and assessed to see, for example, if the participant made a predicted saccade (Land & McLeod, 2000; Croft et al., 2010) or if the participant could pursuit track the ball throughout the whole ball flight. The ball flight was analysed up to the point of the ball bounce. Some previous research has claimed that it is possible to track the ball all the way through to bat-ball contact (Mann et al., 2013), whereas other researchers have claimed that this might not be possible (Land & McLeod, 2000). Without any bat-ball contact in the current experiment and without the possibility for batters to rotate their head downwards to track the final stages of ball flight, making claims as to how the batters tracked the ball post bounce seemed to be obsolete.

The independent variable for the experiment was the initial ball velocity (the bowling style: spin, medium-paced or fast bowling). The dependent variables included: the gaze behaviour of the participant, the fixation duration and fixation location prior to ball release (during the bowlers run up) and the method for tracking the ball after the bowlers' release: I.e. predictive saccade vs. smooth pursuit. All of the individual pre-delivery fixation locations were analysed, however, in order to provide an overview of the results, the author collated the individual locations into 4 distinct categories: the upper body, the lower body, the ball/bowling hand and the point of release (see figure 4.2 for a diagram of how the body was divided). Grouping body locations into categories in a similar manner to previous eye-tracking studies (e.g. McRobert et al., 2009) and occlusion studies (e.g. Muller et al., 2006) provides a clear overview as to what region of the body and visual scene the participants fixate upon for the longest period of time. It was hoped that, alongside the specific body location, having a clear overview of what region batters fixate upon the most may be useful in the applied field and when developing a visual training programme. A number of researchers have advocated for less explicit instruction and a move towards guided visual discovery (Abernethy et al., 2012; Jackson & Farrow, 2005; Masters et al., 1999; Milazzo et al., 2016; Smeeton et al., 2005). These researchers have suggested that the vision of the trainee should be directed to information rich areas and they should discover for themselves what specific cues within this area are important (Williams et al., 2003). Therefore, gaining information about what region of the body or visual scene are fixated upon batters could be extremely useful information for coaches, researchers and psychologists wanting to develop a guided visual discovery training programme. Participant's gaze behaviour data was collected at a rate of 1000 frames per second and was subjected to a frame-by-frame analysis using the SR research's DataViewer.

4.2.7 Data analysis

The participant's pre-delivery fixation locations (i.e., ball/bowling hand, head, point of release, chest, right knee, right foot, left knee, left hip, left shoulder, right shoulder, left foot, left side, left arm/elbow, right thigh, right arm/elbow and right hip) and fixation duration at each location were analysed manually frame-by-frame using the SR Research DataViewer software.

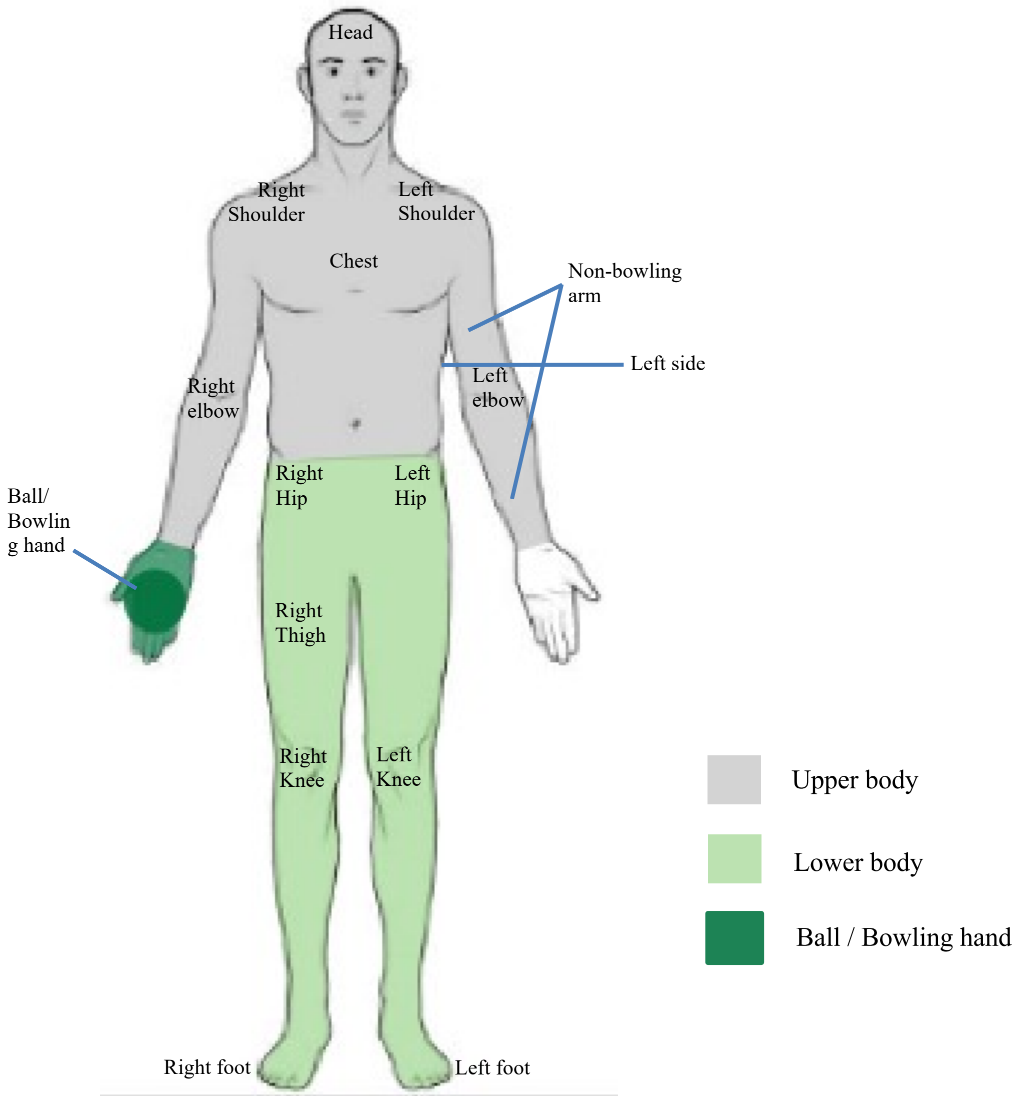

Figure 4.2: A visual representation of the body locations where the participants fixated pre-delivery. The diagram also highlights how the body was divided into upper body, lower body and ball/bowling hand.

Tests were conducted in SPSS (version 22.0.0.1) to determine if there was a significant difference between the amount of time fixating on upper body, lower body, the ball, as well as the point of release across the three conditions of spin, medium and fast pace bowling, with an alpha value set at $p < .05$. Non-parametric Friedman tests were also conducted to determine if there was a significant difference in the fixation duration across each of the body locations (i.e., where batters fixated during the pre-delivery). Post hoc analysis consisted of Wilcoxon Signed Rank Tests using a Bonferroni adjusted alpha value to control for Type I error (with the alpha level adjusted to $p = .025$).

Fixations, pursuits tracking, and saccades were also analysed frame-by-frame in SR Research DataViewer to explore the batter's gaze behaviour during ball flight. Footage from the Eye-Link 1000 camera was digitised in the SR Research DataViewer software to determine two different spatial locations in each frame of video footage: 1) the ball, 2) location of gaze. These reference points were used to calculate the distance between the direction of gaze and the ball. In accordance with Croft et al., (2010), tracking was defined as the proportion of time where gaze-ball discrepancy was less than 2° visual angle. The raw data was assessed manually frame-by-frame in the animation view of the SR Research DataViewer software. The animation view aligns the gaze position (represented by the gaze cursor) with the video footage presented to the participant and includes a concurrent time code displaying the time from the start of trial recording. The gaze cursor diameter was set to represent 2° visual angle in pixels; calculated using the screen resolution (in pixels), the screen dimensions (in mm) and the recording distance to the screen. This allowed the researcher to progress through each trail frame-by-frame to note the period of time that the participant's gaze (as represented by the gaze cursor in the DataViewer software) stayed aligned with the ball throughout the delivery. This information was then used to determine the percentage of ball flight the participants' gaze stayed aligned with the ball and thus was successfully tracked. Due to the restriction of head movement within the study, only pre-bounce ball flight was assessed during this study. Following the frame-by-frame analysis for each of the trials, the percentage of total ball flight tracked before making a predictive saccade to the landing location was calculated for each participant. Saccadic eye movements were recorded automatically via the event detection algorithm in SR Research DataViewer software. The saccadic eye movements were, however, double checked and manually coded by the researcher during the frame-by-frame analysis. A one-way repeated measures ANOVA (with the alpha value set at $p < .05$) was conducted to compare the amount of time the batters tried to pursuit track the ball across the three conditions of spin, medium pace, and fast pace bowling. Post hoc test consisted of pairwise comparisons using a Bonferroni adjusted alpha level.

4.2.8 Ethical considerations

The University of Winchester (postgraduate research ethics panel) provided ethical clearance for this study. However, before any data collection took place each participant was provided with an information sheet explaining the purpose of the study (see appendix A). The information sheet clearly explained the batter's rights, including their right to withdraw at any stage should they wish. The information sheet also highlighted how the data and information collected would be used and explained that the individuals' participation within the study would be kept completely confidential. All batters then sign informed consent (see appendix B). The data collected was stored on a private password-protected computer and placed in a password-protected folder. Only the researcher, supervising director of studies, and supervisory team has had access to these files.

The health and safety of the batters was of paramount importance to the researcher. In order to ensure that the batters experience no harm either physically or psychologically, the study was structured around the guidelines of Holmqvist et al. (2011). These guidelines comprehensively describe best practice, gold standards, and the correct procedures to follow when conducting eye-tracking research in a laboratory setting. The comfort of the participant was also considered, and all efforts were taken to make sure that taking part in the experiment did not impact on the batters' comfort or happiness.

4.3 Results

In order to answer the four research questions, the data analysis was broken down into two parts. The first section examines the gaze behaviours of the batters prior to the release of the ball i.e. from the initiation of the run up through to ball release. The second half of the data analysis examines the gaze behaviours of the batters after the ball had been released and through the ball flight. This results chapter is therefore broken down into two separate sections: pre-delivery results and ball flight results.

4.3.1 Pre-delivery results

Initial pre-delivery gaze results showed that as well as fixating on the ball, the batters in the experiment directed their gaze and fixated upon 16 different bodily locations: 14 locations when facing fast bowling, 13 locations when facing medium pace, and 14 locations when facing spin (see tables 4.1, 4.2, 4.3 & 4.4). As well as the bodily locations, the batters also positioned their gaze ahead of the ball towards the location of release (point of release) before the ball reached that location (i.e. the batters fixated on the point from where they predicted the ball would be released before the ball reached this area). The author collated the above data from the 16 bodily locations and placed this data into four categories: upper body, lower body, ball, and point of release (see figure 4.3).

Analysis were administered to determine the amount of time the batters fixated on the ball, the point of release, the upper body and the lower body. After checking the normality of the data, the results revealed that the data was not normally distributed. After provisionally assessing the Skewness and Kurtosis statistics, and dividing each by the standard error as suggested by Pallant (2011), it was found that the data representing, lower body for medium pace, and point of release for medium pace all exceed the ±1.96 limit, suggesting that the data is not normally distributed. After running a number of subsequent descriptive tests to confirm these findings, the results of the Shapiro-Wilk test indicate that the data representing lower body for spin $p = .002$, lower body medium pace $p = .023$, and the point of release for medium pace $p = .006$ all violate the assumption of normality. Non-parametric Friedman tests were therefore administered to determine if there was a significant difference between the amount of time fixating on the lower body, and the amount of time fixating on the point of release across the three conditions of spin, medium and pace bowling. The results from the Shapiro-Wilk test suggests that the data representing the amount of time fixating on the upper body and the amount of time fixating on the ball was normally distributed, therefore, a one-way repeated measures ANOVA was conducted to analyse these areas.

Results from the Friedman tests revealed that there were no statistically significant difference in the percentage of time spent fixating on the point of release between conditions χ^2 (2, n = 7) = 2.000, p = .368. Although the result approached significance, there was no statistically significant difference in the amount of time spent fixating on the lower body across the three conditions χ^2 (2, n = 7) = 5.846, p = .054. The results from the one-way repeated measures ANOVAs suggested that there was no statistically significant difference in the percentage of time spent fixating on the upper body between conditions of spin, medium-pace and fast-pace bowling Wilks' Lambda = .764, F (2, 5) = .773, p = .510. There was also no statistically significant difference in the percentage of time spent fixating on the ball across the three conditions of spin, medium-pace and fast-pace bowling Wilks' Lambda = .993, F (2, 5) = .019, p = .981.

Table 4.1. Overview of the pre-delivery results for fast, medium and spin bowling.

	Fast	Medium	Spin
Number of fixation locations	14	12	13
Number of upper body fixation locations	7	7	6
Number of lower body fixation location	6	4	6
Total time fixating on upper body (ms)	62396	69418	47920
Average percentage of pre-delivery fixating on upper body per delivery (ms)	38.4%	48%	35.7%
Total time fixating on lower body time (ms)	16558	3342	9088
Average percentage of pre-delivery fixating on lower body per delivery (ms)	10.5%	2.2%	7.3%
Total time fixating on the ball (ms)	59716	51612	48315
Average percentage of pre-delivery fixating on the ball per delivery (ms)	35%	36.4%	34.9%
Total time fixating on the point of release (ms)	28070	19908	29558
Average percentage of pre-delivery fixating on the point of release per delivery (ms)	16.1%	13.3%	22%

Table 4.2. Areas fixated upon pre-delivery when facing fast bowling, number of batters who fixated on each area, total time fixated upon and average percentage of pre-delivery fixated up each location.

Fast Bowling			
	No of batters	**Total fixation duration for all batters**	**Average percentage of pre-delivery fixation on each location (%)**
Ball/ Bowling hand	7	59717	35
Head	7	37629	21.5
Point of release	7	28070	16.1
Chest	5	13312	9.9
Right knee	5	3049	2
Right foot	5	2209	1.3
Left knee	4	5663	3.6
Left hip	4	4160	2.6
Left shoulder	3	5330	3.3
Right shoulder	3	3162	1.9
Left foot	2	1121	0.8
Left side	2	999	0.7
Left arm/elbow	1	1354	0.8
Right thigh	1	356	0.1

Table 4.3. Areas fixated upon pre-delivery when facing medium pace bowling, number of batters who fixated on each area, total time fixated upon and average percentage of pre-delivery fixated up each location.

Medium Pace			
	No of batters	**Total fixation duration for all batters**	**Average percentage of pre-delivery fixation on each location (%)**
Ball/bowling hand	7	51612	36.4
Point of release	7	19908	13.3
Head	6	36603	25.2
Chest	4	12096	8.7
Left shoulder	4	7331	5.1
Right foot	3	692	0.6
Right shoulder	2	8068	5.5
Left arm/elbow	1	2654	1.7
Right elbow/arm	1	1392	1
Left hip	1	1290	0.8
Right knee	1	878	0.6
Right hip	1	482	0.3

Table 4.4 Areas fixated upon pre-delivery when facing spin bowling, number of batters who fixated on each area, total time fixated upon and average percentage of pre-delivery fixated up each location.

Spin bowling			
	No of batters	**Total fixation duration for all batters**	**Average percentage of pre-delivery fixation on each location (%)**
Ball/Bowling hand	7	48315	34.9
Point of release	7	29558	22
Head	6	26394	18.1

Right shoulder	6	11886	9.1
Left shoulder	4	4112	3.2
Right hip	3	2323	1.9
Right knee	2	1625	1.3
Chest	2	4389	4.1
Left hip	2	1005	0.9
Left arm/elbow	2	675	0.6
Right arm/elbow	2	464	0.4
Right foot	1	2458	1.7
Left foot	1	959	1
Left knee	1	718	0.5

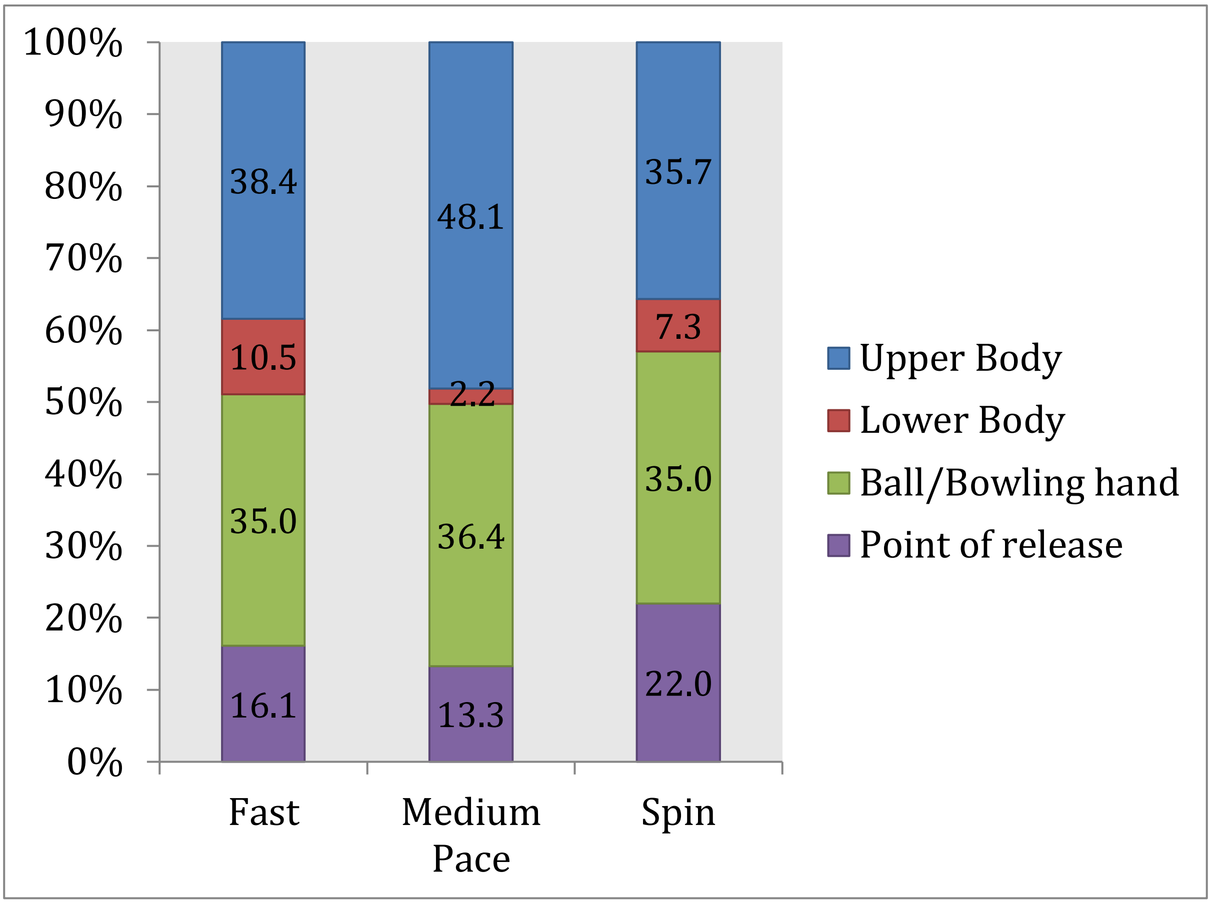

Figure 4.3: Percentage of pre-delivery time spent fixating on upper body, lower body, ball/bowling hand, and point of release across the three conditions.

4.3.2 Pre-delivery locations

Friedman tests were also conducted to determine if there was any statistically significant difference between the amount of time spent fixating at the 16 bodily locations across the three conditions of spin, medium pace and fast bowling. Results revealed that there was only one location where any statistically significant difference was found; the right shoulder χ^2 (2, n = 7) = 7.524, p < .023. Wilcoxon Signed Rank Tests (using a Bonferroni adjusted alpha value) to control for Type 1 error I (with the alpha level adjusted to .025) revealed no statistically significant difference across the three conditions. The amount of time spent fixating on the shoulder between pace and spin almost achieved significance, z = –2.201, p = .028, with a large effect size (r = .59), however failed to reach statistically significant levels with the adjusted alpha level.

No statistically significant difference was found at the other bodily locations across the three locations of spin, medium pace and fast pace bowling. Head χ^2 (2, n = 7) = 1.143, p = .565. Left shoulder χ^2 (2, n = 7) = 3.500, p = .174. Right Hip χ^2 (2, n = 7) = 5.600, p = .061. Right Knee χ^2 (2, n = 7) = 3.900, p = .142. Chest χ^2 (2, n = 7) = 2.800, p = .247. Left Hip χ^2 (2, n = 7) = 1.733, p = .420. Left arm/elbow χ^2 (2, n = 7) = .200, p = .905. Right arm/elbow χ^2 (2, n = 7) = 2.000, p = .368. Right foot χ^2 (2, n = 7) = 1.810, p = .405. Left foot χ^2 (2, n = 7) = 2.000, p = .368. Left Knee χ^2 (2, n = 7) = 4.769, p = .092. Right thigh χ^2 (2, n = 7) = 2.000, p = .368. Left side χ^2 (2, n = 7) = 4.000, p = .135.

4.3.3 Ball flight results

All batters produced a predictive saccade, moving their gaze to the location of the predicted ball bounce. Two of the seven batters (Batters 3 & 7) kept the gaze still, i.e. fixated on the point of release and did not try to pursuit track the ball, before they made the predictive saccade across the three conditions of spin, medium and fast bowling. The other five batters (batters 1, 2, 4, 5 & 6) all pursuit tracked the ball during the initial sections of ball flight before making a predictive saccade to the predicted location of ball bounce for the three different types of bowling (timings of the predictive saccade can be seen in figure 4.4 A, B & C).

The average ball flight time (before bounce) for the spin bowler was 701ms, the average saccade was initiated after 440.3ms or 62.8% of ball flight. The average ball flight time (before bounce) for the medium-paced bowler was 511ms with the saccade made on average after 302.4ms or 59.2% of ball flight. The average ball flight time (before bounce) for the fast bowler was 395ms with the initiation of the predictive saccade taking place on average after 179.1ms or 45.3% of the ball flight. The means and standard deviations are presented in Tables 4.5 and 4.6. A one-way repeated measures ANOVA was conducted to compare the amount of time that elapsed before making a predictive saccade (i.e. the amount of time the batters either kept their vision stationary on the point of release, or pursuit tracked the ball) across the three conditions of spin, medium pace, and fast bowling. The results show that there was a statistically significant difference in the amount of time before the participant's made a predictive saccade across the three conditions; Wilks' Lambda = .090, F (2, 5) = 25.261, p = .002, Partial eta squared effect size = 0.657.

Table 4.5. Descriptive statistics for the amount of time (ms) batters tracked the ball before making a predictive saccade across each condition (spin, medium pace and fast bowling).

	Mean	Std. Deviation
Spin	440.3	±99.4
Medium	302.4	±44.6
Fast	179.1	±32.6

Post hoc pairwise comparisons (using a Bonferroni adjustment) of the ball flight data revealed that there was a statistically significant difference in the amount of time before batters made a predictive saccade between all three conditions. Between spin (*M*= 440.3, *SD*= 99.4) and fast bowling (*M*= 179.1, *SD*= 32.6) p = .001, between medium (*M*= 302.4, *SD*= 44.6) and fast bowling (*M*= 179.1, *SD*= 32.6) p = .001, and between spin (*M*= 440.3, *SD*= 99.4) and medium paced bowling (*M*= 302.4, *SD*= 44.6) p =.003.

A one-way repeated measures ANOVA was conducted to compare the percentage of ball flight that elapsed across the three conditions of spin, medium pace, and fast bowling before a predictive saccade was made (descriptive statistics are presented in Table 4.6). There was a statistically significant difference in the percentage of ball flight before which batters made a predictive saccade across the three conditions: Wilks' Lambda = .2.94, F (2, 5) = 5.992, p = .047, Partial eta squared effect size = .706. Post hoc pairwise comparisons (using a Bonferroni adjustment) revealed that there was a significant difference in the percentage of ball flight prior to a predictive saccade between the pace (*M*= 45.3, *SD*= 8.2) and medium pace (*M*= 59.2, *SD*= 8.8) *p = .028,* and between pace (*M*= 45.3, *SD*= 8.2) and spin bowling (*M*= 62.8, *SD*= 14.2) p = .037. This suggests that the batters either pursuit tracked the ball for a longer percentage of ball flight, or kept their vision fixated on the point of release for a longer percentage of ball flight, when viewing medium pace and spin bowling compared to fast bowling. There was no significant difference in the percentage of ball flight that elapsed before the predictive saccade was made, when participants viewed the spin bowling compared to medium pace bowling.

Table 4.6. The percentage of ball flight batters' pursuit tracked the ball for before making a predictive saccade across the three conditions (spin, medium and fast bowling).

	% of ball flight tracked	Std. Deviation
Spin	62.8%	±14.2 %
Medium	59.2%	±8.8 %
Fast	45.3%	±8.2 %

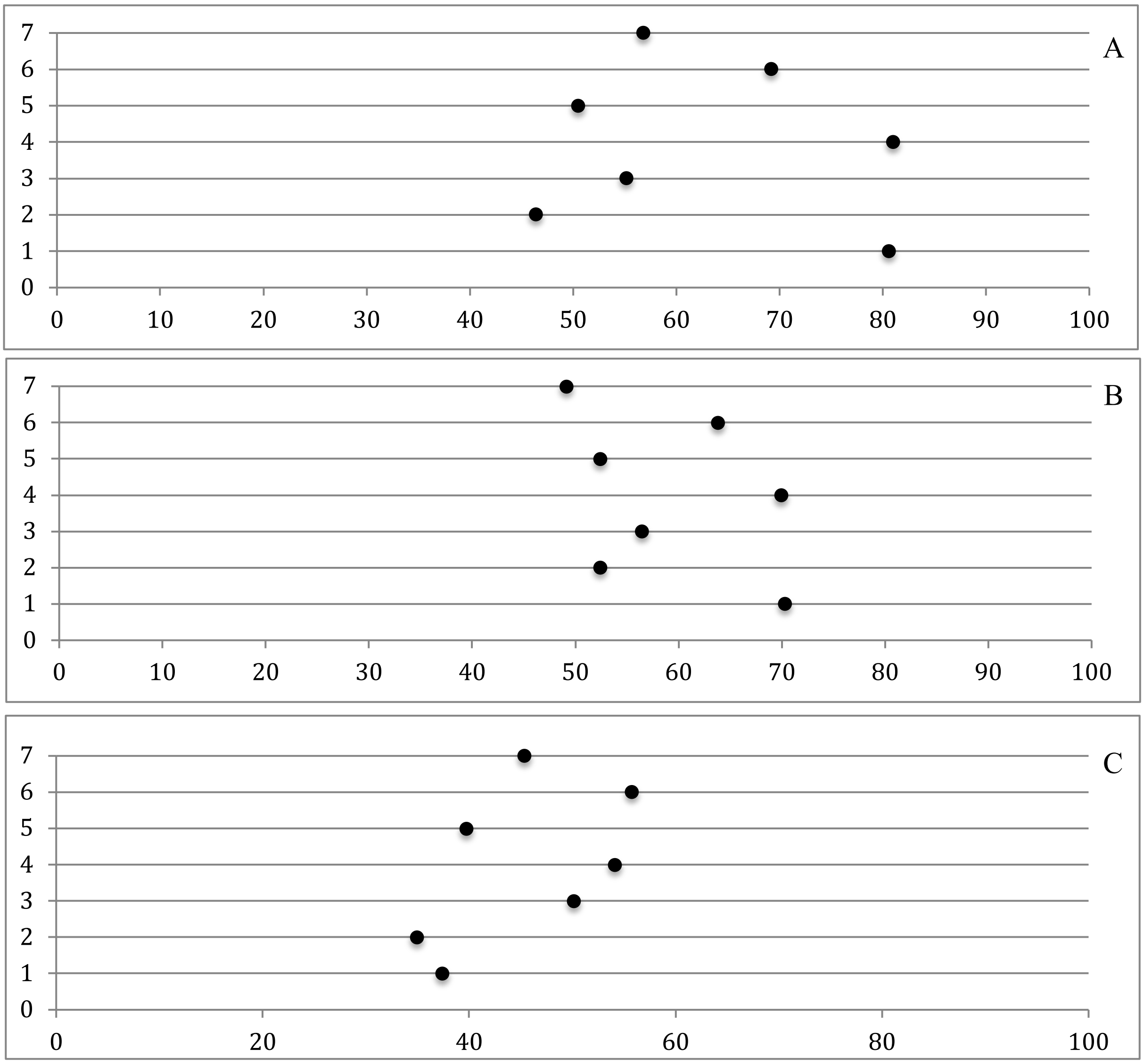

Figure 4.4. Timing of predictive saccades. The horizontal lines represent the 100% of the flight time of the ball. The dots represent the average timing of the predictive saccade for each participant (1-7). Figure 3.3A represents spin bowling, figure 3.3B represents medium pace bowling, and figure 3.3C represents fast bowling.

4.4 Discussion

4.4.1 Pre-delivery

The results provided crucial insight regarding the fixation locations used by batters in order to gather crucial pre-delivery information when facing varying bowling styles. The results from the pre-delivery data analysis reveal that the batters fixated upon the ball/bowling hand, 16 different bodily locations, and where the batters predicted the ball would be released (i.e. point of release). The analysis showed that batters did not have strict gaze behaviour when viewing the same bowling type, or indeed different bowlers. While there were some differences in the eye movements of the participants, a number of patterns did emerge. For example, the most fixated upon areas were consistently the ball/bowling hand, the head, and the point of release. However, inter-individual differences were noted with some batters purely watching the ball prior to moving to the point of release, while others fixated upon several body locations before moving to the point of release.

4.4.2 Different bowling types

When comparing the differences in gaze behaviours across conditions, the results revealed that there was no statistically significant difference in the amount of pre-delivery the batters spent fixating on the ball/bowling hand, the point of release, or the upper body across the three conditions of spin, medium pace, and fast bowling. This suggests that the batters in this experiment used very similar search strategies when viewing the footage of the three different bowling types. This contradicts the previous research of McRobert et al. (2009) who found that that all batters altered their gaze behaviours as a function of observing fast and spin bowlers. McRobert and colleagues' results suggest that when viewing spin bowling, batters would use longer fixations and spend more time extracting information from the ball-hand location compared to when viewing fast bowlers. In comparison, when viewing fast bowling McRobert and colleagues suggest that batters would spend more time fixating on the on the ball-hand and central body locations (i.e. head–shoulders, trunk–hips). The results from the current study revealed that there was no significant difference in the amount of time spent fixating on the upper body, ball/bowling hand, or the point of release across the three conditions. Indeed, the gaze behaviours for spin compared to fast bowling were remarkably similar (see figure 4.3), with only small variations noted in gaze behaviours when viewing the medium paced bowler. While not statistically significant, the result for the amount of time spent fixating on the lower body between the medium pace and fast bowling conditions approached significance, which will be discussed later. These findings suggest that the bowling hand and ball, alongside additional information gained from fixating on the upper body, are the primary sources of information gathered by batters when facing a range of different type of bowling i.e. spin, medium pace, and fast bowling. The findings also suggest that batters tended to fixate upon the same locations when viewing spin, medium pace and fast bowlers.

4.4.3 Lower body

As mentioned above, analysis revealed that the percentage of ball flight the batters in this experiment fixated upon the lower body across the three conditions of spin, medium pace and fast bowling approached significance. Batters spent a longer percentage of the pre-delivery fixating on the lower body when viewing video footage of the fast bowler compared to medium paced bowling. Logic might suggest that the fast-paced bowler has a longer run-up when compared to the medium paced bowler, affording more opportunity for the batter to view the lower body. This line of thinking falls short, however, if you compare the fixations of the batters when viewing spin compared to medium pace bowling. Indeed, the medium pace bowler in this experiment had a longer run up compared to the spin bowler, yet the batters fixated upon the lower body for an average of 7.3% of pre-delivery when viewing the spin bowler, compared to an average of 2.2% of pre-delivery when viewing the medium pace bowler.

Previous occlusion studies (Müller et al., 2006) suggest that batters might not consider viewing the lower body of a bowler important when batting. For instance, having occluded the lower body, Müller and colleagues reported that there was no significant reduction in the ability to predict the line and length of the ball that was about to be bowled. In fact, they found that for lower-skilled players, occluding the lower body resulted in an improvement in prediction performance. This suggests that watching the lower body of the bowler may actually impede their performance, most likely through distraction. The current study supports these findings from Müller et al's study. The results clearly suggest (see figure 4.3), that the across the three conditions, batters spent less time fixating on the lower body compared to the ball, upper body and point of release. While this experiment fails to highlight the significant of batters viewing the lower body, it does nonetheless identify that the lower body seems to offer less important information to the batters compared to other areas of the bowler's body (upper body, bowling hand/ball and point of release). When facing fast bowlers, however, the batters fixated on the lower body for a longer period of time compared to medium pace and spin bowling, the reason for this is unknown.

4.4.4 Ball/bowling hand

Across the three conditions, the ball and the bowling hand appear to be the most important area for the batters to focus on. Indeed, participants spent longer fixating here than any other area, with similar findings also reported by McRobert et al. (2009). This finding suggests that batter consider it important to fixate upon the ball and bowling hand during the run up when viewing spin, medium and fast bowling. In addition, occlusion studies (Müller et al., 2006; Regan, 1997; Tayler & McRobert, 2004) have previously reported decrements in the ability to predict the ball (type of delivery) that is about to be bowled for both elite and amateur batters when the bowling arm and ball were occluded. For example, Müller and colleagues suggested that for any advance pick-up of information to occur when batting, the bowling arm and the bowling hand need to simultaneously be present. It therefore seems crucial to 'pay close attention' to the bowling hand/ball in order to predict the characteristics (e.g., line and length) of the delivery. In contrast, deception (i.e. the purposeful presentation of false visual cues) and disguise (i.e. delaying the onset of an informative cue) are important techniques used by skilled bowlers to minimise batters ability to anticipate the delivery and increase the chances of inducing a mistake in batters (Brault, Bideau, Craig, & Kulpa, 2010; Jackson, Warren, & Abernethy, 2006). In cricket, bowlers often achieve this outcome by hiding the ball, or disguising the type of delivery (in or away swing, slower ball, etc.) that they are preparing to bowl. Therefore, in order to anticipate the type of ball delivered by the bowler, cricket batters need to extract information from the bowling hand/ball. The ball/hand is considered a pertinent cue area for cricket batters because it provides information on how the bowler grips the ball, as well as the position of the seam (which dictates the amount and type of movement that is produced) and the type of ball that will be bowled (McRobert et al., 2009).

The findings reported here support anecdotal evidence from some of the best batters in the history of the game (Bradman, 2011; Gooch & Murphy, 1980). For example, Donald Bradman (considered by many to be the greatest batter in the history of the sport) argues that all batters should understand the subtleties of the bowler's grip and hand position because during their run up "It is often an easy matter to gain at least some idea of what type he (the bowler) inters the delivery to be" (Bradman, 2011, p. 39). Graham Gooch, one the most successful batters in England cricket's history and current England batting coach, also advocates watching the ball and the bowler closely on their approach to the crease: "concentrate on looking at the bowler as he runs in, look at the arm, then look at the ball" (Gooch & Murphy, 1980, p.15). Indeed, when you listen to most of the top batters speak about the game, they often cite watching the ball during the bowler's run up as vitally important for batting. It might seem obvious, but these results highlight that vital cues are gathered from the ball and bowling hand during the run up and batters spend more time fixating on the ball/bowling hand compared to any other area of the visual scene.

4.4.5 Head

The second most attended to area across the three conditions was the head. While previous research has suggested that skilled batters fixated more on the head/shoulders compared to less-skilled batters when viewing fast bowling (McRobert et al., 2009), the same research also suggests that this area is considered less important when facing spin. The results from this experiment show that on average the batters spent slightly longer viewing the head when facing fast and medium paced bowling (average 896ms and 872ms per delivery respectively) compared to spin (average 629ms per delivery), but the difference was not statistically significant. The importance of viewing the head is not currently known. One suggestion is that when viewing the head, batters are anchoring their vision centrally and using their peripheral vision to extract information (Ripoll et al., 1995; Williams & Davids, 1997; Williams and Elliott, 1997). While it is not fully understood why batters fixate their vision at the head, the results from this study show that batters spend a vast amount of the bowlers run up fixating upon this location.

4.4.6 Point of release

One interesting finding was that all batters positioned their gaze towards the point of release ahead of the ball, i.e. batters moved their gaze to a location above the right shoulder of the bowler (i.e. their delivery arm) in anticipation of the ball release, before the ball reached this point. Every participant made this fixation towards the point of release for each condition of spin, medium pace and fast bowling. There was no significant difference in the amount of time the batters kept their gaze at this location across the conditions, suggesting that this strategy and the timing of this strategy is similar for all types of bowling. The data does suggest that this fixation was on average made slightly earlier when facing spin bowling compared to medium pace and fast bowling.

This finding supports research conducted in other sports; for example tennis, where players have been shown to make a predictive saccade to the anticipated contact point of a tennis serve (Singer et al., 1998); and Shank and Haywood (1987) suggested that batters position their gaze at the anticipated ‘release zone’ of the baseball pitcher.

McRobert et al. (2009) also found that skilled batters spent more time fixating on the predicted ball release area when compared to less skilled batters. One explanation is that this strategy enables the batter to position their vision 'ahead' of the ball, allowing the ball to come into the location of their gaze. This strategy also allows the batters to make sure their vision is stationary when the ball is released. This early positioning of the fixation at the point of release is important as during a saccadic eye movement information cannot be taken in and visual processing cannot occur. It therefore appears crucial that batters have their eyes fixated upon the point of release before the ball.

4.4.7 Summary of pre-delivery

The results reveal certain interesting patterns and show that batters consistently fixate on the ball/bowling hand, the head, and the point of release, for a longer period of time compared to other body parts across all three conditions. There are numerous perspectives about how and why the batters would have found these locations more important than others. Scene-schemas (Friedman, 1979) provide semantic, spatial and generic knowledge about a particular type of scene or environment. The schemas include a wide amount of information including information about the location of object which are typically found in the situation as well as their likely spatial location (Williams et al., 2011). Once the batters identify a scene, an appropriate scene-schema is retrieved extremely rapidly from our long-term memory, in order to guide the individuals fixations and help them identify areas of potential interest (Henderson, 2003). Episodic scene knowledge (Henderson & Ferreira, 2004), i.e. knowledge and information regarding a specific scene, which has been gathered either recently (i.e. short-term episodic scene knowledge) or via numerous past exposures to a related scene (long-term episodic scene knowledge) is also believed to guide the gaze and vision of batters (Williams et al., 2011).

The batters within this experiment, i.e. semi-elite cricketers, are likely to have acquired these scene-schemas and episodic scene knowledge as well as a vast amount of task specific knowledge through many hours and years of deliberate and purposeful practice (Ward, Hodges, Williams, & Starkes, 2004). These knowledge structures thus direct their gaze towards more informative and the most important areas of the display when viewing spin, medium pace and fast bowling. The location of each fixation is therefore presumed to indicate an area of interest, while the duration of each fixation reflects the relative importance or complexity of the area (Williams et a., 2011). Therefore, we can conclude that the ball/bowling hand, the head and the point of release are considered vitally important by the batter when trying to anticipate and predict the type of delivery that the bowler will bowl.

4.4.8 Ball flight discussion

The results show that all seven batters made a predictive saccade to move their gaze to the estimated point where the ball would bounce. These results are supportive of previous eye-tracking in cricket studies (Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013; McRobert et al., 2009), all of which report batters making a predictive saccade to the estimated point of ball bounce. The predictive saccade allowed the batters to ‘get ahead’ of the ball and wait for it to come into their visual field, rather than trying to pursuit track the ball and potentially run the risk of their gaze lagging behind the ball, thus not being able to ‘see’ the ball at bounce. Studies have also shown that this strategy is utilised by skilled baseball, tennis players, as well as table tennis players (Bahill & LaRitz, 1984; Ripoll & Fleurance, 1988; Williams et al., 2004),

4.4.9 Different strategies employed to track the ball

While all batters produced a predictive saccade to position their gaze at the location of ball bounce, one interesting finding was that two of the batters did not try to track the initial phase of ball flight. Instead, they kept their gaze fixated upon the point of release before making the predictive saccade towards the bounce location. Therefore, the batters in this experiment utilised two distinct strategies for tracking the ball during the ball flight. Batters 3 and 7 kept their gaze stationary following ball release (i.e. kept fixating on the point of release and did not pursuit track the initial ball flight) before making a predictive saccade to the bounce location. This strategy was consistent across the different bowling conditions of spin, medium and fast paced bowling, i.e. batters 3 and 7 used this strategy when facing spin, medium and fast bowling. The other five batters (1, 2,4,5 and 6) all pursuit tracked the initial stages of ball flight for varying durations, before making the predictive saccade.

One explanation for the lack of pursuit tracking from batters 3 and 7 is that the artificial design of the task and the fact that the batters could not move their head while viewing the video footage. Mann et al. (2013) highlight that for successful batting performance it is important to coupling head movement with the ball. Removing this ability to move the head (due to the desk mounted eye-tracker) might have adversely impacted upon normal visual strategy of the batters. Another possible explanation is that the batters used their peripheral vision to 'pick up' and process enough information from their initial location of ball release. The batters might have fixated their gaze centrally (at the point of release) and use their peripheral vision to gain information regarding the ball's speed and location (Haywood, 1984; Williams et al., 2004).

4.4.10 Different bowling types

The results revealed that there was a significant difference in the amount of time the batters either tracked the ball or kept their fixations stationary before making a predictive saccade across the three conditions of spin, medium pace and fast bowling. Post hoc analysis revealed that there was a significant difference across all three conditions. Between spin and medium pace, between Spin and fast bowling, and between and fast bowling. The fast bowler has a significantly shorter ball flight (due to the faster velocity) compared to the medium pace and the spin bowler, which probably accounts for the shorter amount of time before the predictive saccade.

When comparing the percentage of ball flight before the predictive saccades, the results show that, on average, when facing spin the batters pursuit tracked or kept their gaze stationary for 62.8% of ball flight, when facing medium pace they pursuit tracked or kept their gaze stationary for 59.2% of ball flight and when facing fast bowling they pursuit tracked or kept their gaze stationary for 45.3% of the ball flight. The statistical analysis revealed that the participants either pursuit tracked the ball for a significantly longer percentage of ball flight or kept their vision fixated on the point of release for a longer percentage of ball flight when viewing medium pace and spin bowling compared to fast pace bowling. In contrast, the data suggests that there was no difference in the percentage of ball flight tracked before the predictive saccade when batters viewed spin bowling compared to medium pace bowling

Land and McLeod (2000) reported that cricket batters facing what they described as medium pace deliveries (90km/h or 25 m/s, similar to the velocities used in the current study to represent the spin bowler) typically pursuit tracked the ball for between 50% and 80% of ball flight, before producing a predictive saccade to the expected bounce point. Croft et al. (2010) reported similar results when facing speeds of between 61.2–90km/h or 17–25 m/s (again, similar speeds to spin bowling in the current experiment), with typical durations of pursuit tracking prior to a saccade between 63% and 71%. The percentage of ball flight pursuit tracked (i.e., between 45.3% and 62.8%) in the current study is similar to previous research, however, these findings highlight how increasing the speed from spin bowling (72-88 km/h or 20-24m/s) to fast bowling (129-137 km/h or 36-38m/s) the percentage of ball flight that is pursuit tracked significantly reduces.

The work by Croft and colleagues (2010) suggests that a change in ball velocity does not directly alter the gaze behaviour of the batters during ball flight. One of the possible reasons for their finding might be the small variance of ball speed used within their study (61.2–90km/h or 17–25 m/s). Another possible explanation might be that Croft et al. (2010) randomised the ball speed between trials. This left the batters with little knowledge about what the speed would be for the next delivery. The use of a bowling machine within their research design meant that the batter would gain no pre-delivery information to help predict the type and speed of the ball that would likely be bowled. Yet, in a real-world setting, it is extremely likely that the cricketer would gain some information about the type of ball and possible speed of delivery from the length of bowler run up. When presented with this information (i.e., when viewing video footage of a run-up through to ball flight), it seems the bowling velocity changes the gaze patterns of batters when pursuit tracking the ball. Indeed, batters typically pursuit track the ball for longer periods of ball flight when the ball velocity is slower and for a shorter percentage of ball flight when facing fast bowlers.

4.4.11 Limitations and future research

One of the most obvious limitations with the experimental design of the study is the artificial nature of the task. In order to have the most control over the experiment and to achieve the most accurate eye-tracking data possible, the experiment took place in a laboratory setting using a table mounted eye tracker. While this increases the accuracy and reliability of the eye-tracking results, it obviously reduced the ecological validity of the findings. Also, it is not clear whether the search strategies observed under artificial laboratory conditions provide an accurate reflection of subjects' visual behaviour within realistic field-based situations, where motivation, anxiety, fatigue, and emotion may affect performance (Abernethy 1987; Williams et al., 2004). For example, Vickers, Williams, Rodrigues, Hillis, and Coyne (1999), suggest that fatigue can impact upon gaze behaviour and report a reduction of quiet eye during for shooters who were experience fatigue. Research also suggests that high levels of anxiety lead to a narrowing of the perceptual field, thus effectively impairing the possibility of information pick-up via peripheral vision (Bacon, 1974; Janelle, Singer & Williams, 1999; Landers, Wang & Courtet, 1985; Murray & Janelle, 2003; Williams & Elliott, 1999). Theoretically, if the ability to extract information via the periphery is reduced the importance of foveal vision may be increased, thus elevating fixation rates and producing different findings when compared to the laboratory setting. Subsequent follow up experiments should be conducted to see if the results transfer and can be replicated in a ‘real-world’ setting, where batters face and are able to intercept a cricket ball being delivered by a real bowler. These experiments will only be possible outside of the laboratory using head mounted eye-tracking technology.

Another aspect of the experimental design that could limit the ecological findings of the study was presenting video footage on a standard size (17 inch) computer monitor. Although studies using dynamic film tasks have many advantages over picture-based protocols and provide more control than field research, there are still several limitations. For example, it is not particularly clear what effect the reduction in image size and dimensionality has on visual performance (Williams et al., 2000). There have been very few attempts within the literature to compare athletes gaze behaviour strategies in sporting tasks when presented with dynamic, life-sized, three-dimensional models compared to the two-dimensional images presented on small monitors (Williams et al., 2000).

The need for the batters to keep their head still throughout the experiment is also another limitation. Cricket batters are often coached from a young age to move their head towards the line of the ball and are traditionally instructed to rotate their head downwards so that the ball is ‘under their nose’ when they make contact (Mann et al., 2013). This coupling of the position of the head in relation to the to the ball, has been found to be very precise in elite batters and Mann and colleagues suggest that this ability appears to be an important hallmark of expertise in batting. The use of a table mounted eye tracker did not allow for any rotation or movement of the head and the removal of this could have altered the batters’ gaze behaviour. The absence of head movement also meant that assessing the method batters employed to track or view the ball post bounce was not possible.

The experiment only presented the batters with bowling that was considered a “full” or a “good-full length” balls, i.e. video clips of the bowler only contained balls that pitched relatively close (less that 6 metres) to the batter. There was no short-pitched bowling presented to the batters in the experiment. While fast bowlers commonly used short pitch bowling and bouncers (i.e. bowling that pitches further away from the batter and achieves a higher bounce) to try and dismiss the batter, this strategy is less common for medium pace bowlers and virtually never utilised by spin bowlers. Indeed, it is usually considered a poor delivery if a spin bowler pitches the ball short. Because short bowling is so uncommon when facing spin and medium pace bowing when playing cricket at a high standard, the decision was made to only include full or good-full length deliveries in the experiment for all the conditions. Further experiments are therefore needed to determine what strategies batters used when facing human bowlers of varying speed who pitch the ball short. This will provide a more comprehensive overview of how the ball is tracked when facing bowling of varying speeds, specifically when facing fast paced bowling.

Finally, this study utilised a small sample size and as such, the results should be interpreted with caution. Indeed, while offering an important insight to the fixation locations and gaze behaviours of cricketers, the findings from the present study cannot be generalised beyond the current sample. Given that this exploratory study was the first of its kind in a contemporary area of research, further studies should look to incorporate a larger sample size in order to determine whether these findings can be generalised to the wider population. In doing so, researchers need to consider the amount of time required for frame-by-frame data analysis. For instance, participants in this study were presented with 6 video clips of each bowling condition (medium pace, fast pace, spin bowling), with both pre-delivery and ball flight data analysed, resulting in a substantial amount of frame-by-frame data analysis per participant. Thus, the painstaking nature of 'real world' frame-by-frame eye-tracking research continues to be one of the main drawbacks of the field.

More research is however still needed if we are to fully understand the gaze strategies and search behaviours of cricket batters in a real cricketing environment. The second study within this research project will take place in situ (a real-world cricket practice session) using mobile eye-tracking technology. It will be the first study to track the gaze of batters when facing human bowling. The second study will be the most ecological eye-tracking cricket study conducted and will provide the first insight of the gaze behaviours and search strategies of batters in their natural context. The participants will perform in their regular environment, will be wearing their own cricket equipment, and will bat (perform) in accordance to their own style and tactics. Critically, this studies design allows for the actual movements of the batter to occur, i.e. for the batter to intercept the ball and make bat-to-ball contact, thus addressing one of the major criticisms within the literature: the dissociation of perception and action (Van der Kamp, Rivas, van Doorn & Savelsbergh 2008). The aim of study two is therefore to investigate the gaze behaviours of cricket batters in situ, while facing human bowlers of varying velocities and bowling styles.

4.4.12 Conclusion

While there might be some limitations with the controlled nature of the study, the results provide us with a clearer understanding of how cricket batters track the ball during its flight, and the location of their gaze pre-delivery. While there have been a number of studies that have used eye-tracking technology in cricket previously (Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013; McRobert et al., 2009) none of these studies have tracked the gaze of batters all the way from run-up through ball flight.

The pre-delivery analysis shows that batters fixated upon 16 bodily locations spending more time fixating upon the bowlers' hand/ball, the head of the bowler and the point of release. These locations (bowling hand/ball, head and point of release) are therefore presumed to indicate an area of interest for the batters and, due to the longer the duration of each fixation, we conclude that the ball/bowling hand, the head and the point of release are considered the most important areas by the batters when trying to anticipate and predict the type of delivery that the bowler will bowl. There were no noticeable differences in the way batters viewed the different types of bowling, with the exception of batters fixating on the lower body more when viewing fast bowling compared to medium pace bowling.

The ball flight analysis is similar to the previous research (Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013) and shows that the batters made a predictive saccade to the predicted location of the ball bounce. The predictive saccade allows batters to position their gaze ahead of the ball and wait for it to come into their visual field, rather than trying to pursuit track and falling behind. Our results contradict those of Croft and colleagues who found no difference in the tracking behaviour of batters when viewing different bowling velocities. When viewing fast bowling the batters in our experiment pursuit tracked the ball for less of its flight (45.3%) compared to spin (62.8%) and medium pace bowling (59.2%). This suggests that when the bowling velocity is slower batters will pursuit track the ball for a longer duration.

Chapter 5.0
Study Two

An exploration of cricketers' gaze behaviours while batting against spin and medium-paced bowling.

5.1 Introduction

While numerous studies have investigated the vision of sports performers, few have conducted the research in naturalistic or real sporting environments. Instead, the majority of these studies have used video footage on a computer screen or projected the footage onto a laboratory wall (e.g. McRobert et al., 2009). While these previous laboratory-based studies have increased and advanced our knowledge within the fields of anticipation, decision-making and visual-search, the viewing of pictures and videos presented via a display still constitutes a somewhat artificial task (Duchowski, 2002). Video displays offer the researcher complete control over a broad range of variables and trials to be completed within the experiment. However, while increasing control and providing methodological convenience, video displays are limited when trying to accurately simulate and represent ballistic movement in the natural environment. Some information is inevitably diminished or lost through the recordings (even with modern high definition footage) and the 2D format inhibits the ability for participants to utilise three-dimensional information which can be crucial in aiding depth perception (Mann et al., 2010). Eye-tracking technology has advanced greatly over the past 20 years. Current eye-tracking technology is cheaper, faster, more accurate and easier to use than the previous desk-mounted and early head-mounted systems. This rapid improvement in technology has allowed research to be conducted away from the laboratory. This advancement in technology offers greater ecological validity through context specific field-based research, and significant potential for dynamic movement domains such as sport and exercise (Discombe & Cotterill, 2015).

Due to widely incorporated laboratory-based methodologies of much of the perceptual-motor expertise research, it has received a valid criticism of consistently dissociated perception and action. The dual-pathway theory of vision, otherwise known as the two-streams hypothesis, advocated by Milner, Goodale and colleagues (Goodale et al., 1991; Milner & Goodale, 1995) is often cited to be neuropsychological evidence for the need to preserve the perception–action coupling that occurs naturally in real world tasks

(Mann et al., 2010). Within this framework, visual information reaching the neural cortex travels along two parallel pathways or streams depending on the intended use of that information (Mann et al., 2010). The ventral pathway or 'vision-for-perception' pathway, is highly conscious and is used to produce a perceptual interpretation of our environment. In contrast, the dorsal pathway or the 'vision-for-action' pathway, appears to subconsciously produce online visually controlled movements (Mann et al., 2010). As a result, it is often referred to as the visual-motor pathway. Van der Kamp et al. (2008) argue that most existing studies of within the domain of perceptual-motor expertise, have unintentionally studied the ventral 'visual-for-perception' pathway and not activated the dorsal 'vision-for-action' pathway that is most likely to be heavily relied upon in real sporting tasks. Van der Kamp and colleagues propose that due to the flaws within the literature i.e. the fact that realistic and natural movement do not occur, much of the current research and existing knowledge is misunderstood, limited, and biased.

To address the disassociation of perception-action, a number of studies have incorporated simplified movements in their testing paradigms (e.g., Savelsbergh et al., 2002; Williams et al., 1995; McRobert et al., 2009). However, these simplified movements typically fail to afford the participant an opportunity for to produce a realistic sporting movement, for example intercepting a moving object. The majority of these simplified movement tasks require the participant to make a shadow or fake response to simulate intercepting a moving object. However, as Króliczak et al. (2006) suggested, this shadow or fake movement may not be sufficient to activate the 'vision-for-action' pathway. Further fMRI evidence from Króliczak et al. (2007) demonstrated that real interceptive actions (e.g. hitting a cricket ball) were mediated by different neural processes when compared to shadowed movements (e.g. pretending to hit a cricket ball). These finding highlights that a shadowed interceptive action will not necessarily activate the same areas of the brain which is typically activated by a real interceptive action (Mann et al., 2010). The results from the Króliczak et al. study suggest that simplified responses fall short of testing the dorsal (vision-for-action) visual pathway, and, as a result, they are likely to misrepresent the true ability of skilled performers. Research exploring perceptual-motor skills should therefore when possible, allow the participant to complete the real sporting activity (e.g. actually intercept the moving object), in order to elicit responses of the dorsal visual pathway (Mann et al., 2010).

Perceptual-motor performance has specifically been defined as "a complex product of cognitive knowledge about the current situation and past events, combined with a player's ability to produce the sport skill(s) required" (p.259). This definition emphasises the important role decision-making plays within sports performance and highlights two important components of decision-making: cognitive knowledge (what the decision is); and motor, response execution (is the decision effectively executed) (Gutierrez Diaz del Campo et al., 2011). Due to time constraints, in some sports, athletes are required to process both a decision and a movement in quick succession (Bard et al., 1994; Poolton et al., 2006). In some ball sports (such as cricket, tennis, basketball, squash, and hockey) the time constraints impacting upon perception and action are severe (Müller et al., 2006) and can push the performer to the limits of human performance. Successful decision-making and anticipation are therefore crucial for success and there is substantial evidence of a significant relationship between athlete skill level and anticipation ability (McRobert & Tayler, 2005; Penrose & Roach, 1995; Renshaw & Fairweather, 2000). Because decision-making plays such a vital role in successful sporting performance, understanding the processes behind successful decision-making might afford us the opportunity to develop strategies to improve decision-making performance. To date, no study has utilised eye-tracking technology to investigate the impact that gaze behaviour has on decision-making within cricket. Understanding whether the gaze behaviour of an athlete can impact the success of an athlete is therefore vitally important.

5.1.2 Aims of the Study

The aim of study two was to investigate the gaze behaviours of cricket batsmen in ecologically valid environments, while facing human bowlers of varying velocities and bowling styles. This will include slow bowling/conventional off spin bowling and medium-paced bowling. The secondary aim of the study was to investigate whether there is a change in gaze behaviour between correct and incorrect decision-making and shot execution.

5.1.3 Research question and hypotheses

1. Do participants consider the ball and the upper body of the bowler the most important environmental cues and will they spend more time fixating on these locations prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) when facing human spin and medium-paced bowlers in situ?
    - It is hypothesised that batsmen will fixate on varying aspects of the bowler's body (mainly upper body) and according to study one will spend

more time fixating on the bowlers' hand/ball, the head of the bowler and the point of release.

2. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowler's run up) when facing human spin and medium-paced bowlers in situ?
    - In line with the results from study one, it is hypothesised that there will be no noticeable differences in the way batters viewed the different types of bowling.
3. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowler's run up) when batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
    - It is hypothesised that there will be a significant difference in the fixation locations prior to ball release (fixations, fixation duration and fixation location) when batters make a correct decision compared to an incorrect decision.
4. Do batters use predictive saccades or smooth pursuits in order to follow the ball during its flight when facing human bowlers of varying velocities (i.e., spin bowling and medium-paced bowling)?
    - In line with the results from study one, it is hypothesised that batters will produce predictive saccades when facing all types of bowling (spin, medium and fast).
    - Batters will pursuit track the ball for a longer period (before making a predictive saccade) when facing spin compared to medium-paced bowling.
5. Is there a significant difference in the method for tracking the ball (the percentage of ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post bounce ball flight tracked, and the percentage of ball flight participants fail to track) when facing human spin compared to medium-paced bowlers?
    - In accordance with study one, it is hypothesised that there will be a difference in gaze behaviour when facing spin bowling compared to medium-paced bowling.

6. Is there a significant difference in the method for tracking the ball (the percentage of ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post bounce ball flight tracked, and the percentage of ball flight participants fail to track) when batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
    - There will be a significant difference in the method of tracking the ball (the percentage of ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post bounce ball flight tracked, and the percentage of ball flight participants fail to track) when the participant made a correct decision compared to an incorrect decision.

5.2 Methodology

5.2.1 Participants

Typically, due to the painstaking nature of 'real world' frame-by-frame eye-tracking research (Lappi, 2015), eye-tracking studies in sport have used smaller samples sizes. Indeed, previous studies using eye-tracking within cricket have utilised very small sample sizes of 3 and 2 participants respectively (Land & McLeod 2000; Mann et al., 2013). This study will conform to normal practice within eye-tracking research (Amazeen et al., 2001; Rodrigues & Vickers, 2002; Savelsberg et al., 2002; Savelsberg et al., 2010; Singer et al., 1998; Vickers 1996; Williams et al., 2002) and use a medium-large sampling size of 7 participants. The participants in the current study were male amateur cricketers (*Mean age* = 22.3, *SD*= 4.5) who played local first XI league club cricket (WEPL Gloucestershire league) with an average of 13 years (*SD*= 4.8) of cricketing experience. All participants were considered top order batters or batting all-rounders and regularly batted in the top six positions for their team. The regular batting position of the participants were as follows: participant one: opener, participant two: number 3, participant three: number 4 or 5, participant 4: number 5, participant 5: number 6 or 7, participant 6: opener or number 3, participant 7: number 6 or 7.

Selection criterion for the study included the following: participants having at least 5 years playing experience; the participants are healthy and not struggling with any injury that might affect their performance, vision, or decision-making within the experiment.; and had also played at least one competitive game of cricket (either indoor or outdoor) within the month prior to testing and had been regularly (a minimum of one session per week) participating in practice with their cricket club. The participants within this study had no visual defects corrected or otherwise i.e. none of the participants within this study wore glasses or contact lenses. This information was obtained through conversations with the participant prior to data collection; no formal eye test or vision test was conducted. Prior to the experiment the researcher met with each participant to make sure that their level of expertise and experiences within cricket met the criteria for the study.

5.2.2 Procedure

In order to maintain the highest level of ecological validity and to activate the dorsal (vision-for-action) visual pathway, this study took place during a real indoor cricket net (practice) environment; an environment that is familiar to the participants as they regularly train in this type of environment. The participants performed in their regular training environment, wore their own cricket equipment and batted (performed) in accordance to their own style and tactics. Critically, this studies design allowed for the actual movements of the batsmen to occur, i.e. for the batsmen to intercept the ball and make bat-to-ball contact (hit the ball that is being delivered towards them). The participants wore the SensoMotoric Instruments (SMI) 2.0 ETG head mounted eye-tracking equipment, which records gaze behaviour at 60Hz per second. The participants were in full cricket equipment, including cricket helmet, and faced human bowlers of varying speed, including spin and medium-paced bowlers. The eye-movements (fixations, fixation duration, fixation location, saccades, and smooth pursuits) of the participants were tracked using the SMI 2.0 ETG eye tracker. The bowlers for this experiment were two amateur players who have both played a high standard of club cricket (local premier-league). Both bowlers (spin and medium-paced) were deemed to have a 'regular' bowling action by the author (a level two cricket coach). Definition of a regular bowling action was considered to be someone that did not have a wildly different bowling action to the norm (for example, the bowling action of Lasith Malinga, Shaun Tait or Muttiah Muralitharan). Müller, Brenton and Rosalie, (2015) suggest that having familiarity with the opposition (in this case the bowler) increases the ability of the participant to predict and anticipate their actions. Müller and colleagues recommend that wherever possible, participants should not be familiar with the oppositions. However, logistically this was not possible within this study. The bowlers used within this study were from another local club and while they do not regularly play against or train with the each other, the batters were familiar with the bowlers within this experiment.

Before any testing took place, the researcher took each participant through the calibration and validation phase. It is important that each participant goes through calibration and validation for numerous reasons (e.g. differences in eye size, eye position, variation between glasses etc.) all of which will have an effect on the quality of data recorded (Holmqvist et al., 2011). The researcher used a three-point calibration technique as it is considered to be more robust when compared to the standard one-point calibration that is available on the SMI ETG 2.0 eye-tracking technology. Before the data collection took place, the participant was presented with, and read, a brief explaining a common 'game scenario' (see section 4.2.3). The participants were instructed to imagine that they have just arrived at the crease ready to bat in the first innings of a 50 over match (equivalent to a one-day international match and commonplace club cricket). They were informed that the pitch they are playing on is excellent for batting, the weather conditions are also in their favour, and will be encouraged to act and think accordingly.

It is important to account for individual differences when studying decision-making. For example, what might be considered a risky or inappropriate shot selection for one batter would be considered normal or effective for another. One person might play the sweep shot extremely well whereas another might have cut this out of their game, therefore making it a risky shot when they do play it. Therefore, in order to determine whether the shot selection and decision-making was correct, it is important to gain the view of the batter himself and not rely on observations or coach's assessments. To determine if the batter felt they made the correct decision regarding shot selection, the researcher asked the following questions after each delivery: 'Yes or no, do you believe you made the correct decision in terms of shot selection?' The researcher also asked the following question: 'Yes or no, do you feel you successfully executed the shot?'

5.2.3 Measures and variables

The pre-delivery eye-movements of each participant was recorded and analysed. The pre-delivery analysis started when the bowler started his run up and finished at the point of ball release. The fixation duration and fixation location of the participants pre-delivery were recorded and analysed. All of the individual fixation locations were analysed. The author also categorised the participants fixations into five categories: upper body, lower body, ball/bowling hand, point of release and non-relevant locations (see section 4.2.3, and figure 4.2 for more information). After the release of the ball the participants' vision continued to be tracked. The ball flight was assess to determine how the participant tracks/follows the ball during delivery (ball flight) and, for example, if the participant made a predicted saccade (e.g. Land & McLeod, 2000; Croft et al., 2010; Mann et al., 2013) or if the participant pursuit tracked the ball throughout the whole ball flight. After the bounce of the ball, recording continued until bat-ball contact or the ball passed the batter. Therefore, during the experiment, the fixations, fixation duration, fixation location, saccades and smooth pursuits of each of the participant were recorded for the whole delivery, from the beginning of the run-up, through the bowling action and the full ball flight.

The independent variable for the experiment was the initial ball velocity (the bowling style: spin or medium-paced bowling). The dependent variables included: the gaze behaviour of the participant, the fixation duration and fixation location prior to ball release (during the bowlers run up), and the method for tracking the ball after the bowlers' release. Participants' vision was recorded at a rate of 60 frames per second and subjected to manual a frame-by-frame analysis within the SMI BeGaze software.

5.2.4 Data analysis

In order to assess what the participants fixated on, the participants' vision was recorded at a rate of 60Hz (60 frames per second) and subjected to a frame-by-frame analysis using SMI BeGaze eye-tracking analysis software. Data was analysed as two separate sets of data, 1) The gaze and eye movement of the batsmen prior to ball release, and 2) How the batsmen tracked the ball during the flight.

5.2.4.1 Pre-delivery data analysis

Footage from the Mobile Eye camera was digitised to determine the areas and locations that the batsmen fixated on prior to ball release. The fixation location and the fixations durations were calculated for each participant during each trial. Analysis assessed the mean fixation duration for each location the participant fixated upon pre-delivery. These locations were also collated and placed in the following categories; upper body, lower body, non-relevant, ball and point of release for each condition of spin and medium-paced bowling. Paired Sample T-tests or Wilcoxon Signed Rank test were administered to determine if there was a statistical difference between the two conditions of spin and medium-paced or between correct and incorrect decisions.

5.2.4.2 Ball-flight data analysis

In order to see a moving object clearly during pursuit tracking, the object must be aligned with the direction of gaze. Accurately distinguishing between fixations and smooth pursuits is still a major challenge within dynamic eye-tracking footage (Larsson, Nyström, Ardö; Aström, Stridh, 2016). During real world eye-tracking studies, the participant moves freely and therefore critical spatial locations or areas of interest are not specified in advance but instead defined by the gaze behaviour of the participant. In order to analyse the data from these real work studies, it is therefore necessary to use a frame-by-frame coding (Larsson et al., 2016). Footage from the SMI 2.0 Mobile Eye-tracker camera was digitised in the SMI BeGaze software to determine two different spatial locations in each frame of video footage: 1) the ball and 2) location of gaze. These reference points were used to calculate how long the direction of gaze aligned with the ball. In accordance with Croft et al., (2010), tracking was defined as the proportion of time where gaze-ball discrepancy was less than 2° visual angle. The raw data was assessed manually frame-by-frame in the BeGaze Bee Swarm function. The Bee Swarm function of the BeGaze software shows the raw data of each participant's gaze plotted over the recorded video footage from the eye tracker, which shows the position of the ball. The SMI eye tracking glasses record the gaze position at an accuracy of approximately 0.5° visual angle over all distances (SensoMotoric Instruments, 2016). The gaze cursor in the Bee Swarm function was therefore increased accordingly to represent approximately 2° visual angle. This allows the researcher to progress through the video overlay one frame at a time and note the position of gaze in relation to the position of the ball. This information was then used to determine the percentage of ball flight that the participant's gaze (as represented by the gaze cursor in BeGaze software) stayed aligned with the ball throughout the delivery. If the gaze cursor and the ball were aligned, this was coded as 'successful tracking'. If the gaze cursor and the ball did not align at any stage of the ball flight, then this was coded as 'ball flight attempted but failed to track accurately'. Saccadic eye movements were generated by algorithm within the BeGaze software, however, saccades were double checked and coded manually by the researcher. Following the manual frame-by-frame analysis, the percentage of the total ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post bounce ball flight tracked, and the percentage of ball flight attempted but failed to track was calculated for each delivery. The analysis of the direction of gaze relative to the position of the ball, (i.e. the percentage of the total ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post bounce ball flight tracked, and the percentage of ball flight attempted but failed to track), across each of the conditions (spin and medium-paced) was conducted separately and assessed via a Paired Sample T-tests or Wilcoxon Signed Rank tests.

5.2.5 Ethical Considerations

The University of Winchester provided ethical approval for this study; however, before any data collection took place, each participant was provided with an information sheet explaining the purpose of the study (see appendix C). The information sheet explained the participants' rights, including their right to withdraw at any stage should they wish. The information sheet also explained how the data was used and participants were informed that their results and identities would be kept completely confidential. All participants then signed informed consent (see appendix D). The data was stored on a private password-protected computer and placed in a password-protected folder. Only the researcher and supervising team had access to the data.

The health and safety of the participants is paramount. In order to ensure that the participants experience no harm either physically or mentally, the study was structured around the guidelines of Holmqvist et al. (2011). These guidelines comprehensively describe best practice, and the correct procedures to follow when conducting eye-tracking research. While it is not expected that there would be any harm to the participants, in the sport of cricket there is often numerous body to ball contacts (i.e. the hard cricket ball hits the batter) resulting in potential injuries. Therefore, there was a medic (qualified first aider) on standby during all testing. While the participant was used to facing these types of bowlers, the addition of eye-tracking glasses, might have affected their movements, vision, and potentially performance. Therefore, each participant was allowed as long as they wished to practice against a coach providing throw downs at a slower speed (throw downs are considered move accurate and easier to control). This afforded each participant a chance to "get their eye in", a procedure that is often used by cricketers at both a professional and amateur level, and make sure they feel comfortable before facing the human bowlers.

5.3 Results

In order to answer the six research questions for this study, the data analysis was split into three distinct sections. The first section of the data analysis focused on the gaze behaviours of the participant prior to the release of the ball. With the data analysis starting from the initiation of the bowlers run up, through to ball release. The second section of the data analysis evaluated the gaze behaviours of the batters after the ball had been released and through the entire ball flight. The final section of the data analysis explored the differences in gaze behaviour pre-delivery and through the ball flight when comparing correct decision-making vs. incorrect decision-making. As a result, the results section for this study is therefore broken down into three separate sections: pre-delivery results, ball flight results and the impact of gaze behaviour on decision-making.

5.3.1 Pre-delivery results (all participants)

The participants' pre-delivery fixations, fixation location and fixation duration were analysed manually frame-by-frame using the SMI BGaze software. Initial pre-delivery analysis revealed that, when facing both spin and medium-paced bowling, the participants fixated on 12 different locations. The locations included the ball/bowling hand, the point of release, the landing location (pitch), non-relevant locations, as well as four upper body locations and four lower body locations (see tables 5.1, 5.2 & 5.3). All of the data from the pre-delivery locations was collated and placed into one of five categories: upper body, lower body, ball, point of release, and non-relevant locations (see figure 5.1).

A number of different locations were analysed including: the time the batters spent fixating on the ball, the upper body, the lower body, the point of release and non-relevant locations. Shapiro-Wilk tests were administered in order to determine whether the data was normally distributed. Results from the Shapiro-Wilk test revealed that the data representing the time fixated on the ball for spin bowling $p = .546$, and ball for medium-paced bowling $p = .592$, were normally distributed. Therefore, Paired-Samples T-tests were administered to determine if there was a difference in the time spent fixating on this location when facing spin compared to medium-paced bowling. The data representing the time spent fixating on the upper body medium-paced $p = .005$, lower body medium-paced $p < .001$, point of release spin $p < .001$, point of release medium-paced $p < .001$ and non-relevant spin $p < .001$ and non-relevant medium-paced $p < .001$ all violate the assumptions of normality. Therefore, to test if there was a difference in time spent fixating on these locations (upper body, lower body, point of release & non-relevant location) when facing spin compared to medium-paced bowling, Wilcoxon Signed Rank tests were administered.

The results from the Paired Samples T-tests and the Wilcoxon Signed Rank tests revealed that there was only one significant difference in the percentage of time spent fixating on any of the collated pre-delivery locations when facing spin compared to medium-paced bowling. There was a significant difference between the percentage of time spent fixating on the point of release z = -2.057, p = .040, between spin (M= 8%, SD= 5.7%) and medium-paced bowling (M= 6.1%, SD= 4.1%) with a medium effect size (r= .32). The results from the Paired Samples T-tests revealed that there was no significant difference in the percentage of time spent fixating on the ball, t (41) = -1.598, p = .118, between the two condition of spin (M= 51 %, SD= 14.9%) and medium-paced bowling (M= 46.5%, SD= 16.7%). The results from the Wilcoxon Signed Rank Tests also revealed that there was no significant difference in the percentage of time spent fixating on the upper body z = -.894, p = .371, between spin (M= 19.9%, SD= 10.4%) and medium-paced bowling (M= 22.5%, SD= 14.3%). There was no significant difference between the percentage of time spent fixating on the lower body z = -.019, p = .985, between spin (M= 5.61%, SD= 9%) and medium-paced bowling (M= 5.2%, SD= 6.9%). There was also no significant difference between the amount of time spent fixating on the non-relevant locations z = -1.124, p = .261, between the two condition of spin (M= 13.6%, SD= 13%) and medium-paced bowling (M= 16.8%, SD= 15.4%).

5.3.2 Pre-delivery results all locations (all participants)

Shapiro-Wilk tests were also administered on the nine other locations across the two conditions of spin and medium-paced bowling. Results revealed that all of the data representing the following locations: head, chest, right foot, right knee, right shoulder, hips, left foot, non-bowling arm, landing location (non-body) for both spin and medium-paced bowling; were not normally distributed (all p < .001).

Wilcoxon Signed Rank tests revealed that there was a significant difference at two locations between the two conditions of spin and medium-paced bowling. There was a significant difference between spin (M= 12.7%, SD= 10.8%) and medium-paced bowling (M= 17.5%, SD= 14.7%) for the percentage of time spent fixating at the head z = -2.648, p = .008, with a medium effect size (r= .40). There was also a significant difference between spin bowling (M= 2.7%, SD= 3.1%) and medium-paced bowling (M= 0.9%, SD= 1.9%) for time spent fixating at the non-bowling arm z = -2.839, p= .005, with a medium effect size (r= .44.). There was no significant difference in time spent fixating across any of the remaining seven locations between spin and medium-paced. Chest z = -1.033, p = .301, right foot z = -1.287, p = .198, right knee z = -1.013, p = .311, right shoulder z = -.840, p = .401, hips z = -.944, p = .345, left foot z = -.730, p = .465, landing location z = -1.156, p = .248.

Table 5.1. Overview of pre-delivery results.

	Spin	Medium-paced
Number of fixation locations	11	12
Number of upper body fixation locations	4	4
Number of lower body fixation locations	3	4
Total time fixating on upper body (ms)	26487	33120
Mean and SD for percentage of time fixating on upper body per delivery (%)	19.9 ± 10.4	22.5 ± 14.3
Total time fixating on lower body (ms)	8600	9115
Mean and SD for percentage of time fixating on lower body per delivery (%)	5.6 ± 9	5.2 ± 6.9
Total time fixating on the ball (ms)	69845	74065
Mean and SD for percentage of time fixating on the ball per delivery (%)	51 ± 14.9	46.5 ± 16.7
Total time fixating on the point of release (ms)	10124	9152
Mean and SD for percentage of time fixating on the point of release per delivery (%)	8 ± 5.7	6.1 ± 4.1
Total time fixating on non-relevant cues	18887	28361
Mean and SD for percentage of time fixating on non-relevant cues per delivery (%)	13.5 ± 13	16.8 ± 15.4

Table 5.2. Areas fixated upon pre-delivery when facing spin bowling, number of batters who fixated on each area, total time fixated upon and mean and standard deviation of percentage of time fixated upon each location.

Spin Bowling			
	Number of Batters	Total fixation duration for all batters (ms)	Average and SD of percentage of time spent fixating on each location (%)
Ball	7	69845	51 ± 14.9
Non-relevant	7	18887	13.6 ± 13
Head	7	16755	12.7 ± 10.8
POR	7	10124	8 ± 5.7
Chest	6	4765	3.6 ± 4.3
Right Foot	5	3894	2.5 ± 4.2
Non-Bowling Arm	5	3647	2.7 ± 3.1
Right Knee	5	2838	1.9 ± 4.2
Pitch (Non-body)	2	2579	1.9 ± 5.3
Right Shoulder	2	1320	0.9 ± 2.8
Hips	1	1585	1 ± 4.6

Table 5.3. Areas fixated upon pre-delivery when facing medium-paced bowling, number of batters who fixated on each area, total time fixated upon and mean and standard deviation of percentage of time fixated upon each location

Medium-paced bowling			
	Number of Batters	Total fixation duration for all batters (ms)	Average and SD of percentage of time spent fixating on each location (%)
Ball	7	74065	46.5 ± 16.7
Non-relevant	7	28361	16.8 ± 15.4
Head	7	26055	17.5 ± 14.7
POR	7	9152	6.1 ± 4.1
Right Foot	7	5607	3.4 ± 3.9
Chest	6	4627	2.8 ± 4.3
Pitch (Non-body)	2	5437	3.5 ± 9.1

Right Knee	2	2045	1.1 ± 3.7
Non-Bowling Arm	2	1454	1 ± 1.9
Right Shoulder	2	902	0.4 ± 1.4
Hips	1	738	0.3 ± 1.6
Left Foot	1	725	0.3 ± 1.3

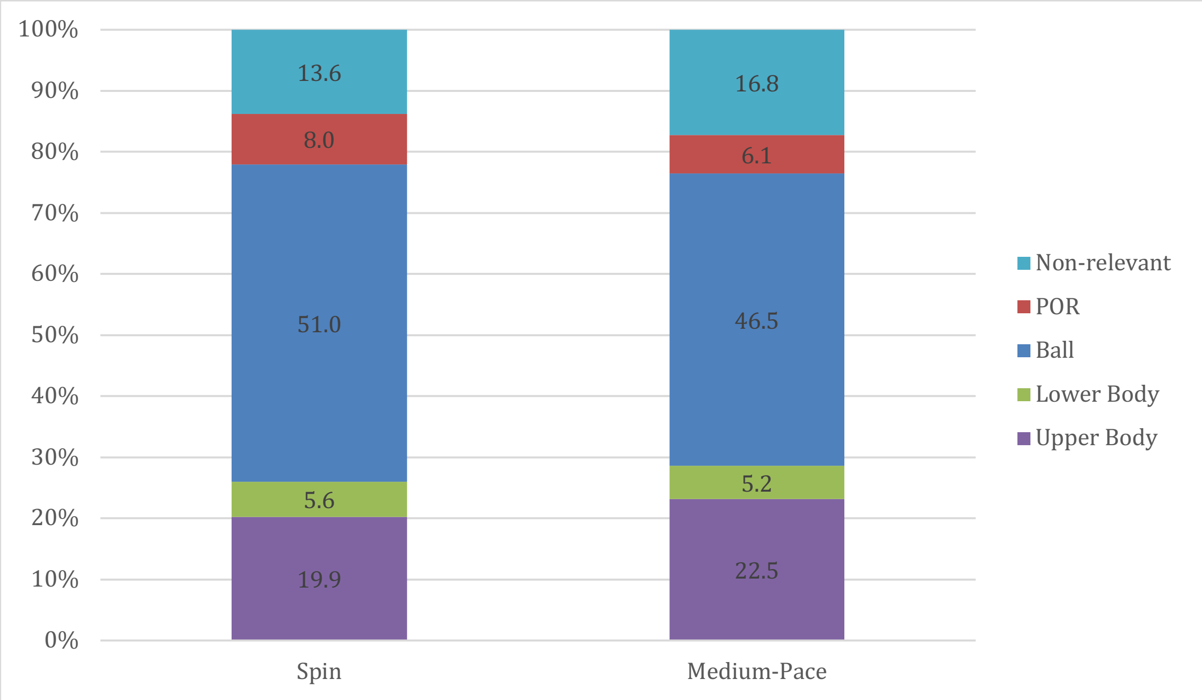

Figure 5.1. Percentage of pre-delivery time spent fixating on upper body, lower body, ball/bowling hand, point of release and non-relevant areas across the two conditions of spin and medium-paced.

5.3.3. Pre-delivery results (individual participants)

All participants produced varying eye movements when viewing spin and medium-paced bowling. While some players had more of a structured and fixed search strategy, other players' strategies changed ball to ball. While no noticeable differences were found when comparing the data as a whole, when assessing each participant individually significant differences were found in the pre-ball release gaze behaviour for three of the seven participants between the two condition of spin and medium-paced bowling (participants one, two and four).

Participant 1

Paired Samples T-tests were administered and revealed that there was a significant difference in gaze behaviour of participant one when facing spin compared to medium-paced bowling. There was a significant difference between the percentage of time spent fixating on the ball between spin (*M*= 59.2%, *SD*= 12.3%) and medium-paced (*M*= 39.9%, *SD*= 12.6%), *t* (5) = 3.694, *p* = .014. There was no significant difference between the percentage of time spend fixating on non-relevant locations between spin (*M*= 3.6%, *SD*= 4.3%) and medium-paced bowling (*M*= 16.1%, *SD*= 19.4%), *t* (5) = -1.536, *p* = .185. There was no significant difference between the percentage of time spent fixating on the point of release between spin (*M*= 9.5%, *SD*= 12.3%) and medium-paced bowling (*M*= 12.6, *SD*= 5.1), *t* (5) = -1.345, *p* = .236. There was no significant difference between the percentage of time spent fixating on the upper body between spin (*M*= 9.7%, *SD*= 5.7%) and medium-paced bowling (*M*= 13.8%, *SD*= 13.9%), *t* (5) = -.845, *p* = .437. There was no significant difference between the percentage of time spent fixating on the lower body between spin (*M*= 7.5%, *SD*= 7.5%) and medium-paced bowling (*M*= 1.9%, *SD*= 2.3%), *t* (5) = 1.907, *p* = .115.

Participant 2

Wilcoxon Signed Rank tests and Paired-Samples T-tests were administered and revealed that there was a significant difference in the gaze behaviour of participant two when facing spin compared to medium-paced bowling. The results suggest that the participant spent significantly longer percentage of pre-delivery fixating on the ball when facing medium-paced bowling (*M*= 64.5%, *SD*= 9.82) compared to spin bowling (*M*= 46.6%, *SD*= 17.1%), *t* (5) = -2.721, *p* = .042. The eta squared statistic (0.52) suggests a small to moderate effect size (Cohen, 1988). There were no differences in gaze behaviour across the other locations.

There was no significant difference between the percentage of time spent fixating on non-relevant locations between spin (*M*= 15.3%, *SD*= 10%) and medium-paced (*M*= 9.7%, *SD*= 5.8%), *t* (5) = 1.544, *p* = .183. There was no significant difference between the percentage of time spent fixating on the point of release between spin (*M*= 6.3%, *SD*= 1.3%) and medium-paced (*M*= 5.2%, *SD*= 2%), *t* (5) = 1.021, *p* = .354. There was no significant difference between the percentage of time spent fixating on the upper body between spin (*M*= 23.6%, *SD*= 12.9%) and medium-paced bowling (*M*= 18.3%, *SD*= 9.9%), *t* (5) = 1.102, *p* = .321. There was no significant difference between the percentage of time spent fixating on the lower body between spin (*M*=8.1%, *SD*= 13.7%) and medium-paced bowling (*M*= 2.3%, *SD*= 3.8%), *z* = -.730, *p* = .465.

Participant 3

Paired Samples T-tests and Wilcoxon Signed Rank tests were administered and revealed that there were no significant differences between any of the pre-delivery locations when facing spin and medium-paced bowling for participant three. There was no significant difference between the percentage of pre-delivery spent fixating on the ball between spin (*M*= 46.2%, *SD*= 12%) and medium-paced (*M*= 46.7%, *SD*= 7.3%), *t* (5) = .085, *p* = .935. There was no significant difference between the percentage of time spent fixating on non-relevant locations between spin (*M*= 15.3%, *SD*= 10%) and medium-paced (*M*= 20%, *SD*= 10.7%), *t* (5) = -1.774, *p* = .136. There was no significant difference between the percentage of time spent fixating on the point of release between spin (*M*= 4.8%, *SD*= 1.4%) and medium-paced (*M*= 2.9%, *SD*= 1.3%), *t* (5) = 2.682, *p* = .063. There was no significant difference between the percentage of time spent fixating on the lower body between spin (*M*= 10.7%, *SD*= 15.3%) and medium-paced bowling (*M*= 13.7%, *SD*= 11.8%), *t* (5) = 2.317, *p* = .654. There was no significant difference between the percentage of time spent fixating on the upper body between spin (*M*= 23.1, *SD*= 9.1%) and medium-paced bowling (*M*= 13.8%, *SD*= 7.5%), *z* = -524, *p* = .600.

Participant 4

Wilcoxon Signed Rank tests and Paired-Samples T-tests were administered and revealed that there was a significant difference in the gaze behaviour of participant four when viewing spin compared to medium-paced bowling. The results suggest that the participant spent significantly longer fixating on the point of release when facing spin bowling (*M*= 19.3%, *SD*= 6.9%) compared to medium-paced bowling (*M*= 6.6%, *SD*= 4.5%), *t* (5) = 3.9, *p* = .014. The eta squared statistic (0.75) suggests a large effect size (Cohen, 1988). Participant four spent a significantly longer percentage of time fixating on the upper body when facing medium-paced (*M*= 45.8%, *SD*= 10.9%) compared to spin bowling (*M*= 26.5%, *SD*= 10%), *t* (5) = -2.913, *p* = .033. The eta squared statistic (0.63) suggests a large effect size (Cohen, 1988). Participant four also spent a significantly longer percentage of pre-delivery fixating on the ball when facing spin (*M*= 39.2%, *SD*= 8%) compared to medium-paced (*M*= 21.2%, *SD*= 8.3%), *t* (5) = 4.414, *p* = .007, with a large effect size (0.8) (Cohen, 1988). There were no significant differences in gaze behaviour across the other locations. There was no significant difference between the percentage time spent fixating on non-relevant locations between spin (*M*= 14.9%, *SD*= 6.1%) and medium-paced (*M*= 21.8%, *SD*= 14.5%), *t* (5) = -1.012, *p* = .358. There was no significant difference between the percentage of time spent fixating on the lower body between spin (*M*= 0, *SD*= 0) and medium-paced bowling (*M*= 4.7%, *SD*= 5.3%), *z* = -1.604, *p* = .109.

Participant 5

Paired Sample T-tests were administered and revealed that there were no significant differences between any of the pre-delivery locations when facing spin and medium-paced bowling for participant five. There was no significant difference between the percentage of time spent fixating on the ball between spin (*M*= 40.8%, *SD*= 8.3%) and medium-paced bowling (*M*= 43%, *SD*= 12.1%), *t* (5) = -.272, *p* = .797. There was no significant difference between the percentage of time spent fixating on non-relevant locations between spin (*M*= 28.5%, *SD*= 17.2%) and medium-paced (*M*= 25%, *SD*= 20.9), *t* (5) = .298, *p* = .778. There was no significant difference between the percentage of time spent fixating on the point of release between spin (*M*= 5.1%, *SD*= 1.8%) and medium-paced (*M*= 5.4%, *SD*= 3.2%), *t* (5) = -.168, *p*= .873. There was no significant difference between the percentage of time spent fixating on the lower body between spin (*M*= 4.7%, *SD*= 4.7%) and medium-paced bowling (*M*= 3.4%, *SD*= 4.4%), *t* (5) = .542, *p* = .611. There was no difference in the percentage of time spent fixating on the upper body between spin (*M*= 18.4%, *SD*= 9.6%) and medium-paced bowling (*M*= 19.2%, *SD*= 16.2%), *t* (5) = -.184, *p* = .861.

Participant 6

Paired Sample T-tests were administered and revealed that there were no significant differences between any of the pre-delivery locations when facing spin and medium-paced bowling for participant six. There was no difference between the percentage of time spent fixating on the ball between spin (*M*= 55.7%, *SD*= 10.9%) and medium-paced (*M*= 46.1%, *SD*= 9.2%), *t* (5) = 1.289, *p* = .254. There was no significant difference between the percentage of time spent fixating on non-relevant locations between spin (*M*= 16.1%, *SD*= 15.2%) and medium-paced (*M*= 20%, *SD*= 14.1%), *t* (5) = -1.822 *p* = .128. There was no significant difference between the percentage of time spent fixated on the point of release between spin (*M*= 5.3%, *SD*= 1.7%) and medium-paced (*M*= 4.4%, *SD*= 1.9%), *t* (5) = 1.052, *p* = .341. There was no significant difference between percentage of time spent fixating on the lower body between spin (*M*= 8.4%, *SD*= 5.7%) and medium-paced bowling (*M*= 8.9%, *SD*= 6.1%), *t* (5) = -.155, *p* = .883. There was no significant difference between percentage of time spent fixating on the upper body between spin (*M*= 14.5%, *SD*= 5%) and medium-paced bowling (*M*= 20.6, *SD*= 7.2%), *t* (5) = -1.822, *p* = .128.

Participant 7

Wilcoxon Signed Rank tests and Paired Samples T-tests were administered and revealed that there were no significant differences between any of the pre-delivery locations when facing spin and medium-paced bowling for participant seven. There was no significant difference between the percentage of time spent fixating on the ball between spin (*M*= 69.4%, *SD*= 11%) and medium-paced (*M*= 65.4%, *SD*= 5.2%), *t* (5) = 1.084, *p* = .328. There was no significant difference between the percentage of time spent fixating on the point of release between spin (*M*= 5.9%, *SD*= 0.9%) and medium-paced (*M*= 5.8%, *SD*= 1.5%), *t* (5) = .193, *p* = .855. There was no significant difference between the percentage of time spent fixating on the upper body between spin (*M*= 23.5%, *SD*= 10.5%) and medium-paced bowling (*M*= 26.2%, *SD*= 4.1%), *t* (5) =- .710, *p* = .509. There was no significant difference between the percentage of time spent fixating on non-relevant locations between spin (*M*= 1.2%, *SD*= 1.8%) and medium-paced (*M*= 0.7%, *SD*= 1.8%), *z*= 0.00, *p* = 1.000. There was no significant difference between the percentage of tine spent fixating on the lower body between spin (*M*=0%, *SD*= 0%) and medium-paced bowling (*M*= 1.9%, *SD*= 1.6%), *z* = -1.826, *p* = .068.

5.3.4 Ball flight results (all participants)

Ball flight data was analysed to determine if there was a difference in the methods batters used to track the ball when facing spin or medium-paced deliveries. The average ball flight times can be seen in table 5.4. The percentages of ball flight tracked can be seen in table 5.5. Shapiro-Wilk tests were administered to determine if the ball flight data was normally distributed. The data representing that the total time tracking the whole delivery for spin *p* = .276, total time tracking the whole delivery medium-paced *p* = .757, the total time tracking pre-bounce for spin *p*=0.603, the total time tracking pre-bounce medium-paced *p* = .069, total time attempted/failed tracking spin *p* = .138 and total time attempted tracking medium-paced p = .163 were all normally distributed. Therefore, Paired Samples T-tests were run to determine if there was a difference across the conditions. The data representing the total time tracking the ball post bounce for spin $p < .001$ and total time tracking the ball post bounce for medium-paced $p = .001$ violated the assumption of normality. Therefore, a Wilcoxon Signed Rank test was run to determine if there was a difference across the two conditions of spin and medium-paced bowling.

Table 5.4. Mean and SD of total ball flight time, release to bounce time and bounce to contact time across the two conditions of spin and medium-paced bowling.

	Mean and SD of time release to contact (ms).	Mean and SD of time release to bounce (ms).	Mean and SD of time bounce to bat contact (ms).
Spin	*M*= 916.4, *SD*= 39.9	*M*= 768, *SD*= 41	*M*= 153.4, *SD*= 52.1
Medium-paced	*M*= 646.7, *SD*= 57.3	*M*= 435, *SD*= 63.2	*M*= 211.9, *SD*= 75.6

Table 5.5. Mean and SD percentages of total ball flight tracked (release to contact), pre-bounce ball flight (release to bounce), post bounce ball flight (bounce to contact) and time attempted to track and failed across the two conditions of spin and medium-paced bowling.

	Mean and SD % of total ball flight tracked.	Mean and SD % of pre-bounce ball flight tracked.	Mean and SD % of post bounce ball flight tracked.	Mean and SD % of ball flight attempted/failed to track
Spin	*M*= 79.1, *SD*= 7.7	*M*= 86, *SD=7.7*	*M*=31.6, *SD*= 30.7	*M*= 14.2, *SD*= 7.9
Medium-paced	*M*= 65.9, *SD*= 9.7	*M*= 71.9, *SD*= 15.9	*M*= 39.3, *SD*= 30.5	*M*= 20.2, *SD*= 12.4

The results from the Paired Samples T-tests suggest that there was a significant difference in the percentage of time the participants spent tracking the ball through the entire flight between spin (*M*= 79.1, *SD*= 7.7) and medium-paced bowling (*M*=65.9, *SD*=9.7), *t* (41) = 6.495, *p* < .001. The eta squared statistic (0.51) indicates a large effect size (Cohen, 1988). There was a significant difference in the percentage of time the participants spent tracking the ball pre-bounce when facing spin (*M*= 86, *SD*= 7.7) compared to medium-paced bowling (*M*= 71.9, *SD*= 15.9), *t* (41) = 4.874, *p* < .001. The eta squared statistic (0.37) indicates a medium effect size (Cohen, 1988). There was also a significant difference in the percentage of ball flight the participants attempted and failed to track between spin (*M*= 14.2, *SD*= 7.9) and medium-paced bowling (*M*= 20.2, *SD*= 12.4), *t* (41) = -2.969, *p* = .005. The eta square statistic (0.18) indicates a small effect size (Cohen, 1988). The results from the Wilcoxon Signed Rank test reveal that there was no significant difference between the percentage of ball flight tracked post bounce between the two conditions of spin (*M*= 31.6, *SD*= 30.7), and medium-paced bowling (*M*=39.3 *SD*= 30.5), *z*= -1.116, *p* = .265.

5.3.5 Ball flight results (individual participants)

The group analysis of the ball flight (see section 5.3.4) showed that there was a significant difference in the percentage of total ball flight, the percentage of ball flight tracked pre-bounce and the percentage of ball flight failed to track between the two conditions of spin and medium-paced bowling. There was no difference in the percentage of ball flight tracked post-bounce. In order to gain a greater understanding of the difference between participants, the ball flight data was also analysed individually. The individual results (see below) suggest that five of the seven participants used different methods to track the ball during ball flight when facing spin compared to medium-paced bowling.

Participant 1

Wilcoxon Signed Rank tests and Paired Samples T-tests were administered to determine if there was a difference in the way the participant tracked the ball when facing spin compared to medium-paced bowling. The results suggest that participant 1 tracked the ball for a significantly longer percentage of time pre-bounce when facing spin (*M*= 90.5, *SD*= 5.1) compared to medium-paced bowling (*M*=77.3, *SD*= 9.5), *t* (5) = 2.765, *p* = .040. The eta squared statistic (0.6) suggests a large effect size (Cohen, 1988). The results also suggest that participants failed to track the ball for a significantly larger percentage of ball flight when facing medium-paced bowling (*M*= 28.5, *SD*= 14.4) compared to spin bowling (*M*= 10, *SD*= 4.9), *t* (5) = -2.725, *p* = .042. The eta squared statistic (0.6) suggests a large effect size (Cohen, 1988).

The results revealed that there was no significant difference in the percentage of total ball flight tracked between spin (*M*= 84.5, *SD*= 3.9) and medium-paced bowling (*M*= 68, *SD*= 14.2), *z* = -1.782, *p* = .075. The results revealed that there was no significant difference in the percentage of post bounce ball flight tracked between spin (*M*= 22.6, *SD*= 35.1) and medium-paced bowling (*M*= 15, *SD*= 23.5) *z*= -0.365, *p* = .715.

Participant 2

Wilcoxon Signed Rank tests and Paired Samples T-tests were administered to determine if there was a difference in the way the participant tracked the ball when facing spin compared to medium-paced bowling. The results suggest that there was no significant difference in the way participant 2 tracked the ball during its flight between spin and medium-paced bowling. There was no significant difference in the percentage of total ball flight tracked between spin (*M*= 74.8, *SD*= 3.6) and medium-paced bowling (*M*= 73.8, *SD*= 6.4), *t* (5) = 0.347, *p* = .743. There was no significant difference in the percentage of pre-bounce ball flight tracked between spin (*M*= 82.2, *SD*= 4.2) and medium-paced bowling (*M*= 82.3, *SD*= 5.2) *t* (5) = -0.062, *p* = .953. There was no significant difference in the percentage of ball flight the participant failed to track between spin (*M*= 23.8, *SD*= 4.6) and medium-paced bowling (*M*= 25.4, *SD*= 7.4), *t* (5) = -0.516, *p* = .628. There was no significant difference in the percentage of post bounce ball flight tracked between spin (*M*= 17.2, *SD*= 13.3) and medium-paced bowling (*M*= 40.3, *SD*= 19), z= -1.572, *p* = .112.

Participant 3

Wilcoxon Signed Rank tests and Paired Samples T-tests were administered to determine if there was a difference in the way the participant tracked the ball when facing spin compared to medium-paced bowling. The results suggest that there was a significant difference in the way participant 3 tracked the ball post bounce between spin and medium-paced bowling. The results reveal that participant three tracked the ball for a significantly longer percentage of post bounce ball flight when facing medium-paced (*M*= 61.5, *SD*= 32.1) compared to spin bowling (*M*= 16.8, *SD*= 21.2) z= -1.992, *p* = .046, with a large effect size (*r*= 0.8) (Cohen, 1988).

There was no significant difference in the percentage of total ball flight tracked between spin (*M*= 77.5, *SD*= 8.7) and medium-paced bowling (*M*= 68, *SD*= 12.3), *t* (5) = 1.231, *p* = .273. There was no significant difference in the percentage of pre-bounce ball flight tracked between spin (*M*= 83.9, *SD*= 3.3) and medium-paced bowling (*M*= 63.1, *SD*= 20.4) *t* (5) = 2.387, *p* = .063. There was no significant difference in the percentage of ball flight the participant failed to track between spin (*M*= 8.9, *SD*= 4.2) and medium-paced bowling (*M*= 9.5, *SD*= 4.8), *z*= -0.734, *p* = .463.

Participant 4

Wilcoxon Signed Rank tests and Paired Samples T-tests were administered to determine if there was a difference in the way the participant tracked the ball when facing spin compared to medium-paced bowling. The results suggest that participant 4 tracked the ball for a significantly longer percentage of time pre-bounce when facing spin bowling (*M*= 87.8, *SD*= 8.1) compared to medium-paced bowling (*M*= 75.2, *SD*= 8.5), *t* (5) = 2.868, *p* = .035. The eta squared statistic (0.6) suggests a large effect size (Cohen, 1988). The results also reveal that participant four tracked a significantly larger percentage of the total ball flight when facing spin (M= 79.7, SD= 4.5) compared to medium-paced (M= 57.9, SD= 7.2), *t* (5) = 11.188, *p* = .00. The eta squared statistic (0.96) suggests a large effect size (Cohen, 1988).

The results revealed that there was no significant difference in the percentage of ball flight the participant failed to track between spin (*M*=15.4, *SD*= 6.1) and medium-paced bowling (*M*= 26.6, *SD*= 21.7), *t* (5) = -1.464, *p* = .203. There was no significant difference in the percentage of post bounce ball flight tracked between spin (*M*= 43.2, *SD*= 27) and medium-paced bowling (*M*= 12.7, *SD*= 20.9), z= -1.363 *p* = .173.

Participant 5

Paired Samples T-tests were administered to determine if there was a difference in the way the participant tracked the ball when facing spin compared to medium-paced bowling. The results suggest that participant 5 tracked the ball for a significantly longer percentage of time pre-bounce when facing spin bowling (*M*= 95.1, *SD*= 4.1) compared to medium-paced bowling (*M*= 64.2, *SD*= 21.4), *t* (5) = 3.702, *p* = .014. The eta squared statistic (0.7) suggests a large effect size (Cohen, 1988). The results also reveal that participant five tracked a significantly larger percentage of the total ball flight when facing spin (M= 85.6, SD= 5.2) compared to medium-paced (M= 64.9, SD= 5.2), *t* (5) = 5.540, *p* = .003. The eta squared statistic (0.86) suggests a very large effect size (Cohen, 1988).

The results revealed that there was no significant difference in the percentage of ball flight the participant failed to track between spin (*M*=12.6, *SD*= 5.1) and medium-paced bowling (*M*= 17.6, *SD*= 7.3), *t* (5) = -1.452, *p* = .206. There was no significant difference in the percentage of post bounce ball flight tracked between spin (*M*= 51, *SD*= 23) and medium-paced bowling (*M*= 57.3, *SD*= 22), *t* (5) = -0.502, *p* = .637.

Participant 6

Paired Samples T-tests were administered to determine if there was a difference in the way the participant tracked the ball when facing spin compared to medium-paced bowling. The results suggest that there was no significant difference in the way participant 6 tracked the ball during its flight between spin and medium-paced bowling. There was no significant difference in the percentage of total ball flight tracked between spin (*M*= 72.7, *SD*= 11.4) and medium-paced bowling (*M*= 63.7, *SD*= 9.7), *t* (5) = 1.624, *p* = .165. There was no significant difference in the percentage of pre-bounce ball flight tracked between spin (*M*= 81.8, *SD*= 5) and medium-paced bowling (*M*= 66, *SD*= 17.8) *t* (5) = 0.716, *p* = .506. There was no significant difference in the percentage of ball flight the participant failed to track between spin (*M*= 18.9, *SD*= 8) and medium-paced bowling (*M*= 18.4, *SD*= 7.1), *t* (5) = 0.787, *p* = .467. There was also no significant difference in the percentage of post bounce ball flight tracked between spin (*M*= 36.8, *SD*= 37.5) and medium-paced bowling (*M*= 48.9, *SD*= 37.5), *t* (5) = -0.903, *p* = .408.

Participant 7

Paired Samples T-tests and Wilcoxon Signed Rank tests were administered to determine if there was a difference in the way the participant tracked the ball when facing spin compared to medium-paced bowling. The results reveal that participant 7 tracked a significantly larger percentage of the total ball flight when facing spin (*M*= 80.1, *SD*= 5.7) compared to medium-paced (*M*= 64, *SD*= 6.2), *t* (5) = 3.674, *p* = .014. The eta squared statistic (0.7) suggests a very large effect size (Cohen, 1988).

The results revealed that there was no significant difference in the percentage of pre-bounce ball flight tracked when facing spin bowling (*M*= 83.9, *SD*= 7.7) compared to medium-paced bowling (*M*= 69.8, *SD*= 15.3), *t* (5) = 1.776, *p* = .136. There was no significant difference in the percentage of ball flight the participant failed to track between spin (*M*=

7.8, *SD*= 5.6) and medium-paced bowling (*M*= 15.3, *SD*= 7.8), *t* (5) = -1.460, *p* = .204. There was no significant difference in the percentage of post bounce ball flight tracked between spin (*M*= 40, *SD*= 44.1) and medium-paced bowling (*M*= 37.7, *SD*= 32.7), *z*= -2.201, *p*= 0.917

5.3.6 Correct vs. incorrect decision-making

The data was also analysed to determine if there was a difference in gaze behaviour when batters made what they believed to be a correct vs. incorrect decision. The analysis was again split into two sections, pre-delivery and ball flight. Table 5.6 shows the number of incorrect decisions made by the amateur batters while facing spin and medium-paced bowling. Due to the small number of incorrect decisions made compared to correct decisions, there was not enough data to assess the impact of changes in gaze behaviour on decision making at an individual level. Therefore, data analysis was only conducted at a group level to assess the impact of gaze behaviour on decision making. The results reveal that the gaze behaviour either pre-delivery or during ball flight did not change when the batter made an incorrect decision compared to a correct decision when facing spin or medium-paced bowling.

Table 5.6. Number of incorrect decisions made by the participants when facing spin and medium-paced bowling.

	Number of incorrect decisions made	
	Spin bowling	**Medium-paced bowling**
Participant 1	0	1
Participant 2	1	2
Participant 3	1	1
Participant 4	2	2
Participant 5	1	3
Participant 6	3	2
Participant 7	2	3
Total	10/42	14/42

5.3.7 Pre-delivery: correct vs. incorrect decision-making

Shapiro-Wilk tests were administered to determine if the ball flight data was normally distributed. Results from the Shapiro-Wilk test revealed that the time spent fixating at the ball, upper-body and non-relevant locations for were normally distributed. Results from the Shapiro-Wilk test also revealed that the following locations for both spin bowling violated the assumption of normality: lower-body and point of release. All the data for the medium-paced bowling apart from the data for the percentage of time spent fixating on the point of release was normally distributed. To compare the difference for the normally distributed data, Paired Samples T-tests were administered, and the non-parametric Wilcoxon Signed Rank test was administered for the data which was not normally distributed.

The results revealed that there was no significant difference in gaze behaviour pre-delivery when a correct decision was made compared to an incorrect decision for spin bowling. There was no significant difference between the percentage of time spent fixating on the ball for a correct (*M*= 52.5%, *SD*= 10.7%) compared to an incorrect decision (*M*= 40.4%, *SD*= 20.6%), *t* (5) = 1.790, *p* = .133. There was no significant difference in the percentage of time spent fixating on the non-relevant locations between correct (*M*= 15.6%, *SD*= 11.5%) and incorrect decisions (*M*= 15.4%, *SD*= 11.9%), *t* (5) = -.045, *p* = .966. There was no significant difference in the amount of time spent fixating on the upper body for correct (*M*= 19%, *SD*= 5.9%) compared to incorrect decisions (*M*= 24.2%, *SD*= 16.2%) *t* (5) = -.850, *p* = .434. There was no significant difference the percentage of time spent fixating on the lower body for correct (*M*= 5.1%, *SD*= 5.2%) compared to incorrect decisions (*M*= 1.1%, *SD*= 2.7%) *z*= -1.826, *p* = .068. There was no significant difference in the percentage of time spent fixating at the point of release for correct (*M*= 7.7%, *SD*= 4.8%) compared to incorrect decisions (*M*= 8.3%, *SD*= 6%) *z*=-1.153, *p* = .249.

The results also revealed that there was no significant difference in gaze behaviour pre-delivery when a correct decision was made compared to an incorrect decision for medium-paced bowling. There was no significant difference between the percentage of time spent fixating on the ball for a correct (*M*= 49%, *SD*= 21.5%) compared to an incorrect decision (*M*= 48.9%, *SD*= 22%), *t* (5) = -.031, *p* = .976. There was no significant difference in the percentage of time spent fixating on the non-relevant locations between correct (*M*= 15.6%, *SD*= 10.2%) vs. incorrect decisions (*M*= 21.6%, *SD*= 7.6%), *t* (5) = .873, *p* = .422. There was no significant difference the percentage of time spent fixating on the lower body for correct (*M*= 3%, *SD*= 2.3%) compared to incorrect decisions (*M*= 3.6%, *SD*= 2.3%), *t* (5) = .473, *p* = .656. There was no significant difference in the percentage of time spent fixating on the upper body for correct (*M*= 22.9%, *SD*= 13.6%) compared to incorrect decisions (*M*= 22.1%, *SD*= 10.5) *t* (5)= -.400, *p* = .706. There was no significant difference in the time spent fixating at the point of release for correct (*M*= 6.8%, *SD*= 4.2%) compared to incorrect decisions (*M*= 5.2%, *SD*= 2.5%) *z*= -.736, *p* = .461.

5.3.8 Ball flight: correct vs. incorrect decision-making

Shapiro-Wilk tests were administered to determine if the ball flight data was normally distributed. All of the data representing both correct and incorrect decisions when facing spin and medium-paced bowling was above alpha level of 0.05 indicating normality. Therefore, Paired Samples T-tests were run to determine if there was a difference between the two sets of data. When facing spin bowling, there was no significant difference in the percentage of the entire ball flight tracked for correct decision (*M*= 79, *SD*= 5.2) and incorrect decisions (*M*=76.5, *SD*= 4.5), *t* (5) = 1.630, *p* = .164. There was no significant difference in the amount of time the participants tracked the ball before the bounce between correct (*M*= 85.4, *SD*= 6.6) and incorrect decisions (*M*= 85.3, *SD*= 3.4), *t* (5) = 0.052, *p* = .961. There was no significant difference between the amount of time the participants tracked the ball post bounce between correct (*M*= 39.5, *SD*= 20.16) and incorrect decisions (*M*= 28.8, *SD*= 20.4), *t* (5) = 0.824, *p* = .447. There was also no significant difference in the amount of time the participants attempted and failed to track the ball for correct (*M*= 14.1, *SD*= 7) and incorrect decisions (*M*= 15.7, *SD*= 6.5), *t* (5) = -0.644, *p* = .548.

Similar results were seen when facing medium-paced bowling with no significant difference found in gaze behaviour and tracking between correct and incorrect decision-making. There was no significant difference in the percentage of the entire ball flight tracked for correct decision (*M*= 67.2, *SD*= 5.9) and incorrect decisions (*M*=61.2, *SD*= 5.9), *t* (6) = 1.842, *p* = .115. There was no significant difference in the amount of time the participants tracked the ball before the bounced between correct (*M*= 74.3, *SD*= 8.8) and incorrect decisions (*M*= 66.4, *SD*= 10.6), *t* (6) = -1.628, *p* = .155. There was no significant difference between the amount of time the participants tracked the ball post bounce between correct (*M*= 37, *SD*= 18.8) and incorrect decisions (*M*= 41.5, *SD*= 26.1), *t* (6) = 0.649, *p* = .540. There was also no significant difference in the amount of time the participants attempted and failed to track the ball for correct (*M*= 20.2, *SD*= 7.4) and incorrect decisions (*M*= 22.7, *SD*= 10.7), *t* (6) = 0.632, *p* = .551.

5.4. Discussion

The aim of this study was to investigate the gaze behaviours of cricket batsmen in ecologically valid environments, while facing human bowlers of varying velocities and bowling styles. A secondary aim of the study was to investigate whether there is a change in gaze behaviour between correct and incorrect decision-making and shot execution. The result (which will be discussed in the following section), represents the first 'real world' eye-tracking in cricket data and provide crucial insight as to how the batters track the ball during flight and what visual cues they utilise before the ball is released.

5.4.1 Pre-delivery most attended to locations

Across both conditions of spin and medium-paced bowling, the ball was by far the most attended to location with participants spending longer fixating on that part of the visual field than any other area. These finding are both intuitive and in line with the findings from study one in the current programme of research. The results also provide additional support for the findings of McRobert et al. (2009), who found that more time was spent fixating on the ball-hand compared to any other fixation locations. Previous occlusions studies (Müller et al., 2006; Tayler & McRobert, 2004) have also suggested that the removal of visual information relating to the bowling hand and ball reduced the ability of both novice and elite batters to predict the bounce location of the ball. We know that deception (i.e. the purposeful presentation of false visual cues) and disguise (i.e. delaying the onset of an informative cue) are important techniques used by skilled bowlers to minimise batters ability to anticipate the delivery and increase the chances of inducing a mistake in batters (Brault et al., 2010; Jackson et al., 2006). Therefore, the finding that batters fixated on the ball and bowling hand is not surprising. The findings in this area are pretty conclusive; batters deem it vital to generate information from the ball and bowling hand of the bowler when facing a range of different bowling types.

Another body location that received a lot of attention was the head. In study one, on average the batters spent slightly longer viewing the head when facing fast and medium bowling compared to spin, but the difference was not statistically significant. In the current study, however, there was a significant difference in the amount of time batters fixated on the head during the run up. When viewing spin on average the batters viewed the head for an average of 12.7% of pre-delivery compared to an average of 17.5% of pre-delivery when viewing medium-paced bowling. Previous laboratory-based research has suggested that skilled batters will fixate more on the head/shoulders compared to less-skilled batters when viewing fast bowling (McRobert et al., 2009). These findings suggest that in a 'real world' cricket scenario this is also true. The reason the participants within this study viewed fixated upon the head is not currently known, however, is in line with past real-world research from other sporting contexts. This research (e.g., Williams et al., 2002) highlights the importance of central body locations for advance visual cues.

In accordance with study one, and previous eye-tracking research (e.g., Shank & Haywood, 1987; Singer et al., 1998; McRobert et al., 2009), all batters positioned their gaze towards the point of release ahead of the ball, i.e. batters moved their gaze to a location above the bowler's right shoulder (the point of release) in anticipation of the ball release, before the ball reached this point. Every participant made this fixation towards the point of release for both the condition of spin and medium-paced bowling. There was no significant difference in the amount of time the batters kept their gaze at this location across the conditions, suggesting that this strategy and the timing of this strategy is similar for all types of bowling. This 'real world' finding provides more support for the idea that cricket batters use this strategy to enable the participant to get their vision 'ahead' of the ball, allowing the ball to come into their vision. Humans cannot process information during a saccadic eye movement, a term knows as saccadic suppression (Ditchburn 1973; Festinger 1971; Massaro 1975). Therefore, in order to process information during the vital ball release phase, vision needs to be stationary. It is hypothesised that the saccade to the point of release allows the batters to make sure their vision is stationary and saccadic suppression does not occur at the point of ball release.

One of the surprising findings from the current study was the amount of time participants spent fixating on non-relevant information. Locations were deemed non-relevant if they were fixated upon following the start of the bowlers run up but did not directly involve visual information needed to execute the skill of batting. Non-relevant fixations were defined as fixations made to locations away from the bowler (or the bowler's immediate vicinity), ball, or the playing surface. The non-relevant locations were deemed by the researcher not to have any direct relationship to the delivery of the cricket ball. Typical non-relevant locations observed during this study were fixations towards the stumps at the bowler's end, items left of the floor outside of the net (e.g., kits bags, other people's kit, cricket balls), other teammates, advertising boards, signs around the facility, and the fire exit. The participants could not have gained any meaningful information that could impact the execution of their batting performance from these locations, however, all seven participants attended to non-relevant locations during the experiments. Taking into account the skill level of the participants (amateur), future research should look to investigate whether elite athletes also attend to non-relevant locations when batting. In the laboratory-based study (study one of the research programme) semi-elite batters did not attend to non-relevant location, real-world research should be completed to see if this is the case in a natural environment. The locations and the condition of the experimental setting (a training environment) might also have had an impact here. It would be interesting to discover if the findings from the current study, that amateur batter fixate on non-relevant locations, are replicated in a real match scenario, or whether the batters only fixate on non-relevant information during training. This finding could highlight an error in the training approach of amateur players and by highlighting and addressing this issue, might afford amateur players an opportunity to improve and enhance the validity of their training.

5.4.2 Pre-delivery spin vs. medium-paced bowling

When analysing the collated results of all participants, the results revealed that the batters use very similar fixation locations when viewing medium-paced and spin bowling. In accordance with study one and as hypothesised, the result suggests that there was no statistically significant difference in the amount of time the batters spent fixating on the ball, upper body, lower body, across the two condition of spin vs. medium-paced. Non-relevant fixations were also assessed and again no differences were found between the conditions. There was, however, a significant difference in the percentage of time batters fixated upon the point of release between spin and medium pace. Batters spent a significantly longer percentage of the pre-deliver fixating on the point of release when facing spin compared to medium-paced bowling. These ‘real world’ findings support the findings from the laboratory-based study conducted previously. The use of video-based paradigms has been heavily criticised within the fields of decision-making and eye-tracking due to the lack of ecological validity and not allowing for the activation of the dorsal visual pathway (Van der Kamp et al., 2008). However, the result from this and the previous study (study one) suggest that there may not be a big difference in gaze behaviour of batters when viewing video footage compared to facing a real bowler.

The finding that there was only one statistically significant difference in fixation location when viewing spin compared to medium-paced bowling contradicts previous research within the field (McRobert et al., 2009). McRobert and colleagues found that that batters altered their visual search strategy as a function of observing fast and spin bowlers. McRobert and colleagues argued that when viewing spin bowling, batters would use longer fixations and spend more time extracting information from the ball-hand location compared to fast bowlers. In comparison, when viewing fast bowling McRobert and colleagues suggested that batters would spend more time fixating on the on the ball-hand and central body locations. The results from the current study contradict this and suggests that participants tended to use the same or very similar gaze behaviour when facing spin and medium-paced bowlers. Indeed, even when assessing each participant's pre-delivery results individually, very few differences in gaze behaviour were found when facing spin and medium-paced on pre-delivery locations. Significant differences were only found in the gaze behaviour when facing spin and medium-paced bowling for three of the seven participants. These were participant 1 (who spent a longer percentage of pre-delivery fixating on ball when facing spin bowling compared to medium-paced bowling), participant 2 (who spent longer fixating on the ball when facing medium-paced vs. spin bowling) and participant 4 (who spent longer fixating upon the point of release when facing spin compared to paced). This suggests that the same body locations were considered important and demanded the attention of the participant regardless of the bowling style.

5.4.3 Ball flight

The most interesting findings from this study related to the ball flight data. There was a significant difference in the percentage of time the participants tracked the ball when facing spin compared to medium-paced bowling. Participants tracked the ball for a significantly longer period of time when facing spin bowling compared to medium-paced bowling. Participants tracked the ball for a significantly longer period of the pre-bounce ball flight when facing spin compared to medium-paced bowling. Participants also, attempted to track the ball but failed for a higher percentage of ball flight when facing medium-paced bowling compared to spin bowling.

The total percentage of ball flight tracked by the participants in the current study is similar to previous research within the field. When facing slow bowling in Land and McLeod's (2000) study, participants tracked the ball for between 50% and 80% of the ball flight. Croft et al. (2010) report similar results when facing speeds of between 61.2–90km/h or 17–25 m/s (similar speeds which represent spin bowling in the current experiment) typically pursuit track between 63% and 71% of the ball flight. When facing spin bowling in the current study, participants' pursuit tracked on average 79% of the ball flight. While the results when facing spin are similar to the previous research, they contradict Croft et al.'s. (2010) findings that changing the bowling velocity did not impact on how participants tracked the ball. The findings from this study and study one, suggest that when viewing medium-paced bowling participants tracked the ball for a significantly shorter duration of the ball flight - on average 65% of ball flight when viewing medium-paced bowling, compared to an average of 79% when viewing spin bowling.

One of the possible explanations for the differences in the findings from both study one and the current study and Croft and colleagues' work, might be the small variance of ball speed used within Croft et al's. study (61.2–90km/h or 17–25 m/s). Another possible explanation might be that Croft et al. (2010) used a bowling machine and randomised the ball speed between trials. This left the batters with little knowledge about what the speed (ball velocity) would be for the next delivery. The use of a bowling machine within their research design meant that the batter would gain no pre-delivery information to help predict the type and speed of the ball that would likely be bowled. In a real-world setting (such as the one created within this experiment), the batters were able to gain information about the type of ball and speed of the delivery from the pre-delivery information. Batters could see the bowler and were aware whether they would bowl spin or medium-paced. When presented with advance information, it seems batters changed their strategies and method for tracking the ball. In real world situations, batters typically pursuit track the ball for longer periods of ball flight when the ball velocity is slower and for a shorter percentage of ball flight when facing a faster bowler.

5.4.4 Pre-delivery: correct vs. incorrect decisions

Due to the extreme time constraints in sport such as cricket, batters are required to process information and make decisions about how to respond in time periods which push the limits of human performance (Cotterill & Discombe, 2016). Therefore, successful performance can be attributed to the effectiveness of an athlete's DM. The eye-mind hypothesis (Just & Carpenter, 1984) states that there is a strong correlation between where an individual is looking and what that person is thinking about. Indeed, it is believed that fixations allow attention to be directed to specific details from the scene, in order to guide decision-making or motor control skills (Panchuk et al., 2015) and that eye-tracking data can serve as an assessment of decision-making (Vachon & Tremblay, 2014). Due to the important role that eye-movements play in the decision-making process, it was hypothesised that the participants within this study would have displayed differences in eye-movements when they made what they considered a correct decision compared to an incorrect decision. However, contrary to the hypothesis, the results reveal that the gaze behaviour, both pre-delivery and during ball flight, did not change when the batter made a correct decision compared to an incorrect decision when facing spin or medium-paced bowling.

It is assumed that skilled players' superior anticipation and decision-making ability is underpinned by more efficient gaze behaviour involving more fixations to a greater number of information rich locations (Campbell & Moran, 2014; Williams et al., 1994; Roca et al., 2018). Vickers (1992) suggests that more experienced athletes, coaches, and referees, make less saccades when compared to their less successful counterparts. It is also assumed that successful decision-makers used more goal-oriented search strategies and fixate their gaze on key elements for longer, which resulted in superior performance, faster decision times and greater response accuracy (Vaeyens et al., 2007; Moreno et al., 2002; Piras, 2009, 2010; Lee, 2010, Hancock & Ste-Marie, 2013). One explanation for these findings is the suggestion within eye-tracking research that there is a dramatic decline in visual sensitivity during saccades known as saccadic suppression (Ditchburn 1973; Festinger 1971; Massaro 1975). This essentially means that during a saccade we are technically blind and cannot process any information. Theoretically then, due to saccadic suppression, a visual search strategy that involves fewer fixations (therefore less saccades) is assumed to be more effective (Williams et al. 1994). A more efficient search strategy involves fewer fixations of longer duration enabling more time to be spent analysing the important stimuli and gaining more information rather than using saccadic eye-movements to search through a display (Williams et al. 2000). While we have a strong theoretical understanding of how eye-movements can distinguish between elite and amateur athletes and between successful and unsuccessful decision makers, the results from the current study suggest that there is no difference in the gaze behaviour of cricket batters when they make correct vs. incorrect decisions. Further research should explore this in greater detail and determine whether this is the case for both elite and amateur batters.

5.4.5 Conclusion

Due to the artificial nature of previous studies (the use of bowling machines and laboratory-based studies [e.g., Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013; McRobert et al., 2009]), no previous study had tracked the gaze of batters all the way from run-up through ball flight. The results from the present study therefore provide a clearer understanding of how cricket batters track the ball during its flight and the location of their gaze pre-delivery in a 'real world' environment. The pre-delivery results suggest that the most fixated upon locations for both spin and medium-paced bowling was the ball, non-relevant locations, the head, and the POR. There was no significant difference in time spent fixating on the ball, the upper body, lower body, non-relevant locations between the spin and medium-paced conditions. Indeed, the only significant differences in percentage of time spent fixating on pre-delivery location between the two conditions was found at the point of release (participants spent longer fixating here when facing spin compared to medium-paced bowling), the head (participants spent a longer percentage of pre-delivery fixating here longer when facing medium-paced compared to spin bowling) and the non-bowling arm (participant spent more of the pre-delivery fixating on the non-bowling arm when facing spin compared to medium-paced bowling). When analysing the participants' data individually, very few differences were found when facing spin and medium-paced on pre-delivery locations. This suggest that the pre-delivery gaze behaviour strategies of cricketers in real world environments is very similar and batters gain important pre-delivery cues from the same locations of both spin and medium-paced bowlers.

The ball flight analysis revealed that there was a significant difference in the total time the participants track the ball when facing spin compared to medium-paced bowling. When facing spin bowling, participants tracked a significant longer percentage of total ball flight and pre-bounce ball flight. Participants also attempted but failed to track the ball for a significantly longer percentage of ball flight when facing medium-paced bowling compared to spin bowling. When assessing the participants' data individually, it became apparent that five of the seven participants used different methods to track the ball when facing spin compared to paced. The group and the individual analysis of the ball flight suggest that when the bowling velocities increase the percentage of ball flight tracked decreases. The results reveal that the gaze behaviour either pre-delivery or during ball flight did not change when the batters made an incorrect decision compared to a correct decision when facing spin or medium-paced bowling.

This research has provided us with a good understanding of what visual cues batters find important and how batters track the ball in 'real world' environments. Future research should look to investigate whether there is a difference between gaze behaviour and search strategies of amateur players compared to professionals or elite cricketers. More 'real world' eye-tracking is needed so we can fully understand how the visual strategies are utilised by cricketers of all levels. This information could not only inform us of best coaching methods and practices, but also has the potential to inform effective vision and decision-making training programmes.

Chapter 6.0

Study Three

An exploration of elite and amateur cricketers' gaze behaviours while batting against spin and medium-paced bowling.

6.1 Introduction.

Eye-tracking research within the field of sport psychology has previously relied heavily on the use of video footage projected on to laboratory walls or computer screens. This is particularly the case when it comes to research exploring fast moving objects (e.g., Shank & Haywood, 1987; Savelsbergh et al., 2002; McRobert et al., 2009). The advancement of eye-tracking technology over the past 10-15 years means that research should resist the temptation to use these convenient research methodologies, as they now have the ability to collect more real-world data (Discombe & Cotterill, 2015). One real world eye-tracking approach that is starting to receive more attention in the literature is comparing elite and amateur athletes' vision. Whether out of admiration, envy, or scientific curiosity, people and researchers have had a long-standing fascination with the extraordinary skills of elite level athletes (Eklund & Tenenbaum, 2014). This interest in elite performance has led researchers to design methodologies in order to better understand how athletes can achieve incredible feats of sporting skill under severe time constraints. There is now a wide range of research studies demonstrating that experts use different visual behaviours and advanced cues when extracting information from their visual field, compared to amateurs (Williams & Ford, 2008). While it is generally accepted that there are some common differences between elite and amateur athletes such as differences in the number, location and duration of fixations made (e.g., Vaeyens et al., 2007), most differences found in the literature are extremely sport specific (Williams & Ford, 2008). Therefore, sport specific research needs to be carried out in order to gain a full understanding of the gaze behaviour of experts in any given sport (e.g., cricket).

Study two was the first real-world cricket study to track the batters' gaze patterns from the start of the bowler's run up and throughout the entire ball flight. The findings from study two provide the first real insight into how cricket batters track the ball during its flight and the location of their gaze pre-delivery in a 'real world' environment. The results from study two suggest that the pre-delivery gaze behaviour of amateur cricketers are very similar when facing both spin and medium-paced bowlers. However, when assessing how amateur batters tracked the ball during the ball flight, clear differences were seen in the method for tracking deliveries when facing spin compared to medium-paced bowling. When facing spin bowling, participants tracked a significantly longer percentage of total ball flight and pre-bounce ball flight. Participants also attempted but failed to track the ball for a significantly longer percentage of ball flight when facing medium-paced bowling compared to spin bowling. Study two provided the first insights into amateur cricketers' gaze behaviours, however, we do not know whether elite cricketers use similar strategies.

The current study seeks to compare elite vs. amateur cricketers' gaze behaviours in a real-world setting. The study seeks to answer specific questions relating to vision, gaze and cricket batting including: do elite players fixate on the same locations when compared to those of less skilled batters during the bowler's pre-delivery phase? Do they fixate upon the same locations when facing spin and medium-paced bowling? How do elite players compare to amateurs track the ball during the ball flight? It is hoped that this information can provide vital information which can be used to help coach and improve amateur batters' vision and batting performance in the future. There are not only clear empirical reasons to research differences between elite and non-elite performers, but also this field of research also has numerous applied implications (Eklund & Tenenbaum, 2014). This type of research is considered by many to be a vital area and a "hot topic" in psychology (Swann et al., 2015) and sport offers the ideal platform for this form of study. Information gained from this research can highlight the difference and mechanics involved in sport performance, which underpins experts' superior performance when compared to novices. This information can also provide the platform for a vision-based cricket training programme, giving young aspiring cricketers the best possible chance of fulfilling their potential.

6.1.2 Aims of the study

The aim of study three is to investigate and compare the gaze behaviours of elite and amateur cricket batsmen in a real practice environment, while facing human bowlers of varying velocities and bowling styles. The bowling styles included conventional off spin bowling and medium-paced bowling. The secondary aim of the study is to investigate whether there is a change in gaze behaviour between correct and incorrect decision-making.

6.1.3 Research question and hypotheses

1. What eye-movements (fixations, fixation location and fixation duration) do elite and amateur batters produce prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) when facing spin and medium-paced bowlers?
    - In line with the previous literature (e.g., Müller et al., 2006; McRobert et al., 2009) and findings from study one and two, and previous literature it is hypothesised that batsmen will fixate on varying aspects of the bowler's upper body, more specifically, the bowlers' hand/ball and the head of the bowler, as well as the point of release.
2. Do elite and amateur batters produce different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowlers' run up) when facing spin bowling compared to medium-paced bowlers?
    - In line with the results from study one and two, it is hypothesised that there will be no noticeable differences in the gaze behaviour of the batters when they face the different types of bowling.
3. Is there a significant difference in eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) between the elite and amateur batters?
    - According to the literature (e.g. Vaeyens et al., 2007; Williams & Ford, 2008) it is hypothesised that there will be a significant difference in the eye-movements of elite compared to amateur batters. It is expected that the elite players will have more consistent search strategies when compared to amateur batters.
4. Do batters produce significantly different eye-movements (fixations, fixation duration and fixation location) prior to the release of the ball (i.e., during the preparatory phase and bowlers run up) when they make a correct decision regarding shot selection, compared to when they make an incorrect decision regarding shot selection?
    - In accordance with study two, there will be no significant differences in the batters' gaze behaviour prior to ball release (fixations, fixation duration and fixation location) when both elite and amateur batters make a correct decision compared to an incorrect decision.

5. Do elite and amateur batters use different methods to track the ball during its flight when facing spin compared to medium-paced bowling?
    - Batters will pursuit track the ball for a longer period when facing spin compared to medium-paced bowling.
6. Is there a significant difference in the method for tracking the ball (percentage of ball flight tracked), when elite and amateur batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
    - There will be a significant difference in the method of tracking the ball, specifically the duration of pursuit tracking, between correct decision-making and incorrect decision-making.
7. Is there a significant difference in the method for tracking the ball during its flight (percentage of ball flight tracked) between elite and amateur batters?
    - It is hypothesised that elite batters will pursuit track a significantly high percentage of ball flight compared to amateur batters.

6.2 Methodology

6.2.1 Participants

Typically, eye-tracking studies tend to use small sample sizes, especially when conducted in the real world (Amazeen et al., 2001; Rodrigues & Vickers, 2002; Savelsberg et al., 2002; Savelsberg et al., 2010; Singer et al., 1998; Vickers 1996; Williams et al., 2002). For example, previous research within cricket (Land & McLeod 2000; Mann et al., 2013) has used very small sample sizes of 3 and 2 respectively. This study however, used a larger sample size of 12 participants. The participants consisted of six male amateur cricketers and six male elite players. The amateur cricketers (*Mean age*= 26.2, *SD*= 4.5) played local league club cricket (WEPL Gloucestershire league) with an average 13.8 years (*SD*= 4.1) of cricketing experience. The amateur batters were the regular top six batters for their club's first XI. None of the amateur batters had any visual defects or wore any corrective aids (i.e. glasses or contact lenses). The six elite cricketers (*Mean age*= 27.5, *SD*= 6.3) had an average of 7 years professional experience (*SD*= 5.7) and average of 17.2 years of cricketing experience (*SD*= 6.7). The six elite players were all, at the time of data collection, contracted and playing first class cricket for their professional club. None of the elite participants had any visual defects or wore any corrective aids (i.e. glasses or contact lenses). The batting positions for the six elite batters were as follows; Participant 1: opener, participant two: opener, participant 3: number 3 or 4, participant 4: number 5 or 6, participant 5 number 3, participant 6: number 3, 4 or 5. Three of the six elite participants had played full international cricket for their respective country. At the time of data collection, the elite cricketers had a combined 128 international test matches, 170 one-day internationals and 10 Twenty20 international appearances. They also had a total of 609 first class, 530 List A and 262 Twenty20 professional appearances.

Selection of the amateur cricketers for the study included the following criterion: participants had at least 5 years' playing experience. The participants were healthy and not struggling with any injury that would have impacted their performance, vision, or decision-making within the experiment. The participants must have played at least one competitive game of cricket (either indoor or outdoor) at least one month prior to taking part in the study and were all regularly (a minimum of one session per week) participating in practice with their current club. Prior to any data collection, the researcher met with each participant to discuss the study and check their level of expertise and experiences within cricket met the criteria for the study.

6.2.2 Procedure

This study took place in two locations. Both were the regular training facilities for each of the two groups of participants. The first location, where data was collected with the elite batters, was a large indoor cricket school/practice net. This environment was very familiar to the participants as they trained within this environment on a daily basis. The second location, where the data collected for the amateur batters, was an outdoor cricket net at the local cricket club where the amateur cricketers played and trained. Again, the amateur players were extremely used to practicing and performing within this environment. The participants all wore the SMI 2.0 ETG head mounted eye-trackers, which recorded their gaze behaviour at 60Hz. All participants wore their full batting equipment, including their own pads, gloves, thigh guard and cricket helmet and faced one over (6 deliveries) from two bowlers, a spin bowler and medium-paced bowlers. The eye-movements (fixations, fixation duration, fixation location, saccades, and smooth pursuits) of the participants were all tracked using SMI 2.0 ETG eye tracker.

The bowling speeds within the study varied depending on the level of the participant. Amateur batsmen faced amateur bowlers and elite batsmen faced elite bowlers, therefore the speeds the bowling speeds between groups changed. It is not appropriate, safe or ecologically valid to ask an amateur player to face an elite bowler who delivers the ball at much higher velocities than they are used to. Likewise, asking a professional batsman to face an amateur bowler would dramatically reduce the difficulty of their regular training, thus throw into question the ecological nature of the study. Both the elite and amateur bowlers were deemed to have a 'regular' bowling action by the author (a level two cricket coach). Definition of a regular bowling action was considered to be someone that did not have a wildly different bowling action to the norm (for example the bowling action of Lasith Malinga, Shaun Tait, Jasprit Bumrah, or Muttiah Muralitharan). When conducting research with elite participants, it is important to match the participant to an opponent of a similar skill level (Müller et al., 2016). It was, therefore, not logistically possible to present bowlers who were not familiar to the batters. The bowlers for this study were therefore selected from the same team as the batters and would be familiar with their bowling style and action.

The pre-delivery eye-movements of each participant were analysed. The analysis began when the bowler started his run up and finished at the point of release of the ball. The length of time analysing eye-movements for the pre-delivery differed between the different bowlers, due to the different length of their run up. A spin bowler typically has a shorter run up than a medium-paced bowler. After the release of the ball the participants' vision continued to be tracked. Fixations, saccades and smooth pursuits were all recorded and analysed to investigate how the participants tracked, followed or predicted where the ball bounced.

Before the data collection took place, the participant was presented with, and read, a brief explaining a common 'game scenario'. The participants were instructed to imagine that they have recently arrived at the crease ready to bat in the first innings of a 50-over match (equivalent to a one-day international match and common place in both club and professional cricket). Participants were informed that the pitch they were playing on was excellent for batting, the weather conditions are also in their favour and they were encouraged to act and think accordingly. The full brief can be seen in section 4.2.3.

Before any testing, the researcher took all participants through a calibration and validation phase. It was vital that each participant complete the calibration and validation for numerous reasons (e.g., differences in eye size, eye position, variation between glasses etc.) all of which will have an effect on the quality of data recorded (Holmqvist et al., 2011). The researcher used use a three-point calibration as it is considered more robust when compared to the standard one-point calibration that is available on the SMI ETG 2.0 eye-tracking technology. The calibration was performed at a distance of 22 yards the same length of the cricket wicket and the distance where the ball was released. The author monitored the calibration remotely throughout the experiment via an Acer laptop, which had a remote wireless connection to the SMI eye-trackers. If at any stage throughout the experiment the calibration drifted, the experiment was paused, and the participant was taken through the 3-point calibration again before testing resumed.

It is important to account for individual differences when studying decision-making. For example, what might be considered a risky or inappropriate shot selection for one batter would be considered normal or effective for another. One person might play the sweep shot extremely well whereas another might have cut this out of their game, making it a risky shot when they do play it. Therefore, in order to determine whether the shot selection was correct it is important to gain the view of the batter himself and not rely on observations or coaches' assessments. To determine whether the batter felt they made the correct decision regarding shot selection, the researcher asked the following questions after each delivery. 1. 'What decision did you make to that delivery?' 2. 'Yes or no, do you believe you made the correct decision in terms of shot selection?' The decision-making data was recorded by the researcher via pen and paper and also via the microphone on the SMI Eye-tracking Glasses. The recording was used by the researcher to double-check that the correct information was recorded and analysed.

6.2.3 Measures and variables

During the experiment, the fixations, fixation duration, fixation location, saccades and smooth pursuits of each of the participant were recorded. The fixation duration and fixation location of the participants pre-delivery (before the ball was released) were recorded and analysed. All of the individual fixation locations were analysed. The author also categorised the participants' fixations into five categories: upper body, lower body, ball/bowling hand, point of release and non-relevant locations (see section 4.2.3, and figure 4.2 for more information). The fixations, saccades, smooth pursuit and flight path of the ball were recorded after the release of the ball (i.e. the full bowling action and ball flight). How the participant tracked/followed the ball during delivery (ball flight) was analysed and assessed to see if there were any differences in tracking methods when facing spin compared to medium-paced bowling. The gaze data was also assessed to see if there were any differences in how elite compared to amateur batters tracked the ball. The percentage of total ball flight tracked, pre-bounce ball flight tracked, post bounce ball flight tracked and the percentage of ball flight the participants failed to track were all analysed.

The independent variable for the experiment was the initial ball velocity (the bowling style: spin or medium-paced). The dependent variables included: the gaze behaviour of the participant, the fixation duration and fixation location prior to ball release (during the bowlers' run up), and the method for tracking the ball after the bowlers' release. Participants' gaze behaviour data was collected at a rate of 60 frames per second and subjected to a manual frame-by-frame analysis within the SMI BeGaze software.

6.2.4 Data analysis

Data was analysed in three distinct sections: 1) the gaze and search strategies of the batsmen prior to ball release 2) how the batsmen tracked the ball during the flight 3) the differences in gaze behaviour pre-delivery and through the ball flight when comparing correct decision-making vs. incorrect decision-making.

6.2.4.1 Pre-delivery data analysis

Footage from the Mobile Eye camera was digitised to determine the areas and locations that the batsmen fixated on prior to ball release. The fixation location and the fixation durations were all calculated for each participant during each trial. SPSS analysis assessed the mean fixation duration for each location the participant fixated upon pre-delivery. These locations were also collated and placed in the following categories; upper body, lower body, non-relevant, ball and point of release for each condition of spin and medium-paced bowling. Paired Samples T-Tests or Wilcoxon Signed Ranks Tests were administered to determine if there was a statistical difference between the two conditions of spin and medium-paced for both the elite and the amateur players separately. Independent Samples T-Tests or Mann-Whitney U Tests were administered to determine whether there was a difference in pre-delivery gaze behaviour between the elite and amateur participants.

6.2.4.2 Ball-flight data analysis

Footage from the SMI 2.0 Mobile Eye-tracker camera was digitised in the SMI BeGaze software to determine two different spatial locations in each frame of video footage: 1) the ball and 2) location of gaze. These reference points were used to calculate how long the direction of gaze aligned with the ball. In accordance with Croft et al., (2010), tracking was defined as the proportion of time where gaze-ball discrepancy was less than 2° visual angle. The raw data was assessed manually frame-by-frame in the BeGaze Bee Swarm function. The Bee Swarm function of the BeGaze software shows the raw data of each participant's gaze plotted over the recorded video footage from the eye tracker, which shows the position of the ball. The SMI eye tracking glasses record the gaze position at an accuracy of approximately 0.5° visual angle over all distances (SensoMotoric Instruments, 2016). The gaze cursor in the Bee Swarm function was therefore increased accordingly to represent approximately 2° visual angle. This allows the researcher to progress through the video overlay one frame at a time and note the position of gaze in relation to the position of the ball. This information was then used to determine the percentage of ball flight that the participant's gaze (as represented by the gaze cursor in BeGaze software) stayed aligned with the ball throughout the delivery. If the gaze cursor and the ball were aligned, this was coded as 'successful tracking'. If the gaze cursor and the ball did not align at any stage of the ball flight, then this was coded as 'ball flight attempted but failed to track accurately'. Saccadic eye movements were generated by algorithm within the BeGaze software, however, saccades were double checked and coded manually by the researcher. Following the manual frame-by-frame analysis, the percentage of the total ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post bounce ball flight tracked, and the percentage of ball flight attempted but failed to track was calculated for each delivery. The analysis of the direction of gaze relative to the position of the ball, (i.e. the percentage of the total ball flight tracked, the percentage of pre-bounce ball flight tracked, the percentage of post bounce ball flight tracked, and the percentage of ball flight attempted but failed to track), across each of the conditions (spin and medium-paced) was conducted separately and assessed via a Paired Sample T-tests or Wilcoxon Signed Rank tests.

6.2.4.3 Correct vs. incorrect decision-making

The final stage of data analysis involved splitting the data into two different groups. The first group contained all of the data both (pre-delivery and ball flight) when the participants stated that they made a correct decision. The second set of data (pre-delivery and ball flight) was when the participant stated their decision was not the correct decision. These sets of data were analysed via Independent Samples T-Tests or Mann-Whitney U Tests to determine whether there was a difference in pre-delivery gaze behaviour between the elite and amateur participants.

6.2.5 Ethical considerations

The University of Winchester provided ethical approval for this study; however, before any data collection took place, each participant was provided with an information sheet explaining the purpose of the study (see appendix E). The information sheet explained the participants' rights, including their right to withdraw at any stage should they wish. The information sheet also explained how the data was used and participants were informed that their results and identities would be kept completely confidential. All participants then signed informed consent (see appendix F). The data was stored on a private password-protected computer and placed in a password-protected folder. Only the researcher and supervising team had access to the data.

The health and safety of the participants in the study was of paramount importance. In order to ensure that the participants experienced no harm either physically or mentally, the study was structured around the guidelines of Holmqvist et al. (2011). These guidelines comprehensively describe best practice, and the correct procedures to follow when conducting eye-tracking research. While it is not expected that there would be any harm to the participants, in the sport of cricket there is often numerous body to ball contacts (e.g. batters get hit by the ball) resulting in potential injuries. Therefore, there was a medic (qualified first aider) on standby during all testing. While the participants were used to facing these types of bowlers, the addition of eye-tracking glasses, might affect their movements, vision, and potentially performance. Therefore, each participant was allowed as long as they wished to practice against a coach providing throw downs at a slower speed (throw downs are considered move accurate and easier to control). This afforded them a chance to "get their eye in", a procedure that is often used by cricketers at both a professional and amateur level, and make sure they felt comfortable before facing the human bowlers.

6.3 Results

In order to answer the seven research questions for this study, the data analysis was split into three sections. Section one presents the data analysis for all participants' gaze behaviour prior to the release of the ball (i.e. the pre-delivery). It also presents a comparison between the elite and amateur batters' results. The second section presents the analysis from the ball flight (i.e. from release of the ball to the bat-ball contact for the amateur and elite participants), as well as a comparison between elite and amateur batters. The final section of the data analysis explores the differences in gaze behaviour pre-delivery and through the ball flight when comparing correct decision-making vs. incorrect decision-making for both elite and amateur participants.

6.3.1 Pre-delivery analysis

The participants' pre-delivery fixations, fixation location and fixation duration were analysed manually frame-by-frame using the SMI BGaze software. The results revealed that when facing spin bowlers' amateur players fixated upon 11 locations while elite player fixated upon 10 locations. When viewing medium-paced bowling amateur players fixated upon 9 locations compared to the 10 fixated upon by elite batters. These locations can be viewed in table 6.1, 6.2 and 6.3. The data was also categorised into 5 areas including upper body, lower body, ball, point of release and non-relevant location for both elite and amateur batters (see figure 6.1 and 6.2).

Shapiro-Wilk Tests were administered to check for normality of the data sets. If the data were normally distributed, then a Paired-Samples T-Test was administered and if the data were not normally distributed then a Wilcoxon Signed Ranks Test was administered to determine whether there was a difference in gaze behaviour pre-deliver when facing spin compared to medium-paced bowling. These tests were administered for both elite and amateur batters.

Table 6.1: Overview of the pre-delivery results for both elite and amateur batters.

	Spin Elite	Spin Amateur	Medium-paced Elite	Medium-paced Amateur
Number of fixation locations	10	11	10	9
Number of Upper body fixation locations	3	3	3	2
Number of lower body fixation location	1	3	2	2
Total time fixating on upper body (ms)	20533	14584	22463	11075
Mean and SD of percentage of time fixating on upper body (%)	25 ± 17.4	13 ± 15.9	24.4 ± 15.3	11.3 ± 6.3

Total time fixating on lower body (ms)	750	2220	1199	5656
Mean and SD of percentage of time fixating on lower body (%)	0.8 ± 2.7	6.8 ± 14.7	1.4 ± 3.1	2.6 ± 5.8
Total time fixating on the ball (ms)	52628	56233	53803	68756
Mean and SD of time percentage of time fixating on the ball (%)	61.3 ± 17.8	56.6 ± 16.9	58.3 ± 16.9	62.8 ± 12.9
Total time fixating on the point of release (ms)	5797	5215	5428	4951
Mean and SD of percentage of time fixating on the point of release (%)	7.1 ± 2.7	5.9 ± 4.6	5.9 ± 1.7	4.9 ± 2.7
Total time fixating on non-relevant cues	283	14263	1080	14857
Mean and SD of time percentage of time fixating on non-relevant cues (%)	0.4 ± 2.5	14.5 ± 16.5	0 ± 0	14.5 ± 14.3

Table 6.2. Areas fixated upon pre-delivery when facing spin bowling, number of batters who fixated on each area, percentage of time fixated upon each location with mean and standard deviation per delivery for both amateur and elite batters.

Spin bowling	**Amateur:** Total Number of Batters	**Amateur:** Total fixation duration for all batters (ms)	**Amateur:** Average percentage of time fixated on location (%)	**Elite:** Total Number of Batters	**Elite:** Total fixation duration for all batters (ms)	**Elite:** Average percentage of time fixated on location (%))
Ball	6	56233	56.6±16.8	6	526803	61.3±17.8
Head	6	9808	10±12.4	6	15484	18.7±13.7
POR	6	5215	5.9±4.6	6	5797	7.1±2.7
Non-Relevant	5	14263	14.5±16.5	1	283	0.4±2.5
Right Foot	2	3259	4.4±13.3	1	0	0
Chest	2	3081	3±9.7	3	1511	1.9±4.6
Bat Tap	2	1617	1.6±7.2	1	5316	4.3±11.6
Hips	2	1286	1.4±3.9	0	0	0
Bounce Location	1	1716	1.1±6.8	1	802	1.7±3.8
Right Knee	2	1166	1.1±3.8	1	750	0.8±2.7
Non Bowling Arm	1	4500	0.4±2.5	4	2807	3.4±4.6

Table 6.3. Areas fixated upon pre-delivery when facing medium-paced bowling, number of batters who fixated on each area, percentage of time fixated upon each location with mean and standard deviation per delivery for both amateur and elite batters.

Medium-paced bowling	**Amateur:** Total Number of Batters	**Amateur:** Total fixation duration for all batters (ms)	**Amateur:** Average percentage of time fixated on location (%)	**Elite:** Total Number of Batters	**Elite:** Total fixation duration for all batters (ms)	**Elite:** Average percentage of time fixated on location (%)
Ball	6	68756	62.8±12.9	6	53803	58.3±16.9
Non-Relevant	5	14857	14.5±14.3	1	1080	0±0
Head	6	11670	10.7±6.9	6	16863	18.2±16
POR	6	4951	4.9±2.7	6	5797	5.9±1.7
Right Foot	3	1670	1.9±5.7	3	942	1.1±3.1
Bat Tap	1	2126	1.8±7.8	5	10235	9.1±15.9
Bounce Location	1	1716	1.6±5.2	2	876	0.3±1.2
Right Knee	2	878	1.1±2.7	1	257	0.3±1
Chest	1	3081	0.7±2	2	1067	1.3±4
Non-Bowling Arm	0	0	0	2	2665	3.9±4.6

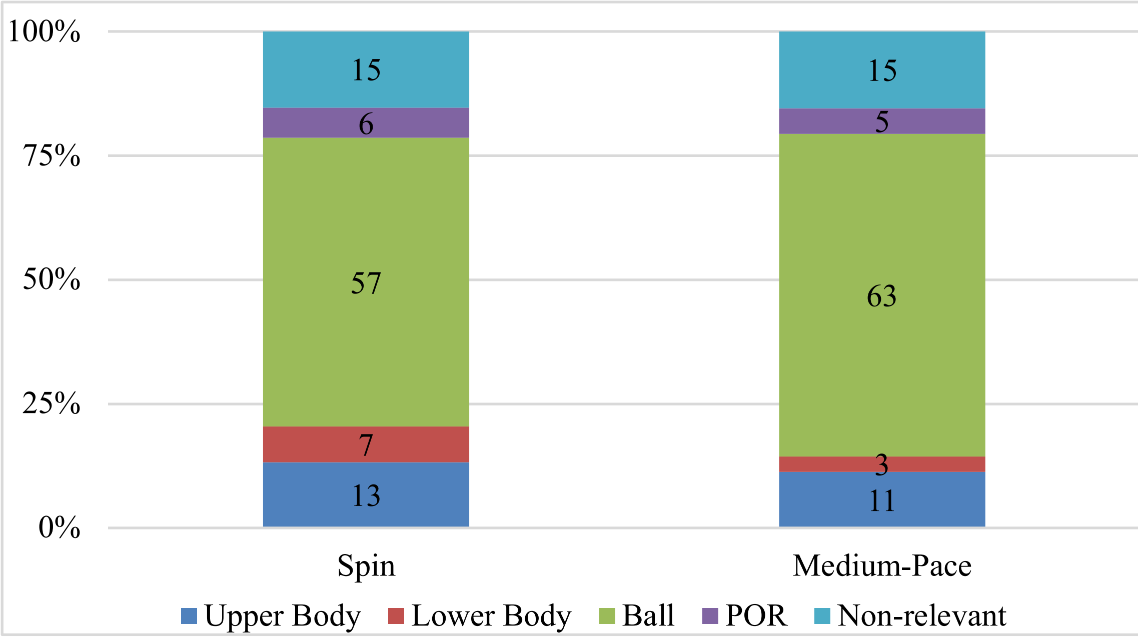

Figure 6.1. Percentage of pre-delivery time spent fixating on upper body, lower body, ball/bowling hand, point of release and non-relevant areas across the two conditions of spin and medium-paced bowling for amateur batters.

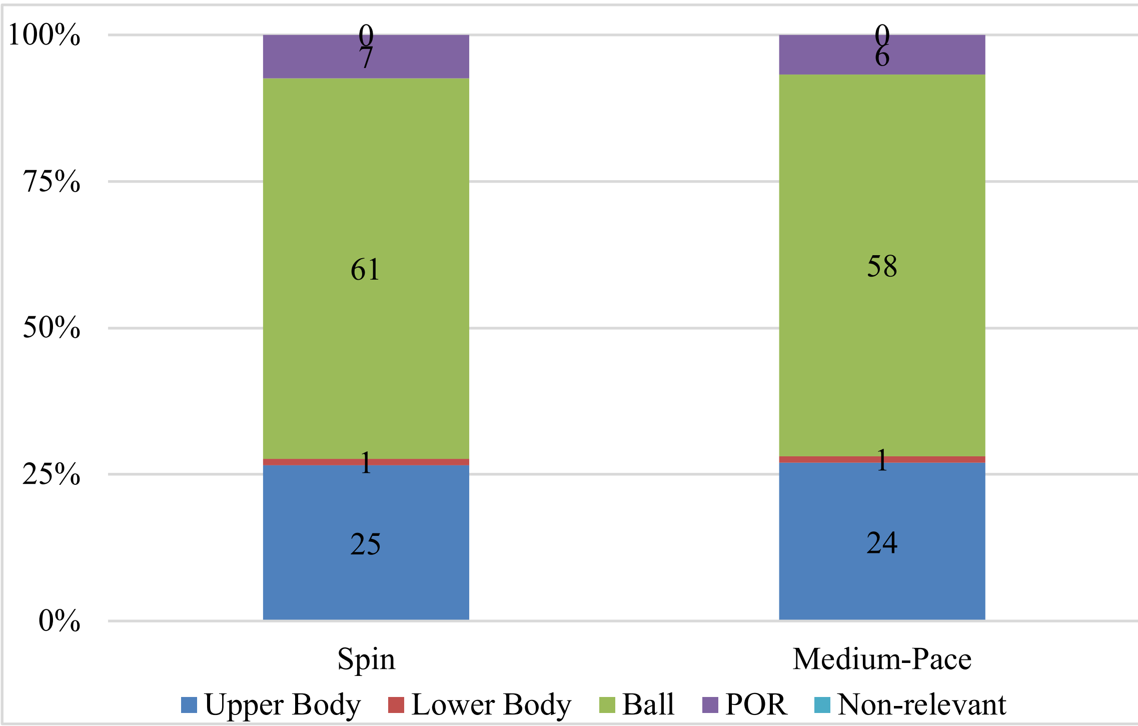

Figure 6.2. Percentage of pre-delivery time spent fixating on upper body, lower body, ball/bowling hand, point of release and non-relevant areas across the two conditions of spin and medium-paced bowling for Elite batters.

6.3.1.2 Pre-delivery amateurs

The results from the Shapiro-Wilk Test showed that the data representing the percentage of time spent fixating on the ball for spin bowling p = .984 and medium-paced bowling p = .064 was normally distributed, therefore, a Paired Samples T-Test was administered. The data representing the percentage of time fixating on the upper body for spin bowling p < .001, point of release (POR) for spin bowling p < .001, non-relevant locations for spin bowling p < .001, non-relevant locations for medium-paced bowling p= .001, lower body spin bowling p < .001, and lower body for medium-paced bowling p < .001, all violated the assumption of normality and therefore Wilcoxon Signed Ranks Tests were administered to assess these locations.

The results from the Paired Samples T-Test revealed that there was no significant difference in the percentage of time amateur batters fixated upon the ball when facing spin bowling (M= 56.6%, SD= 16.8%) compared to medium-paced bowling (M= 62.8%, SD= 12.9%), t (35) = -1.6685, p = .101. The results from the Wilcoxon Signed Ranks Tests revealed that there was not a significant difference between the percentage of time spent fixating on the upper body z= -.009, p = .993, between spin bowling (M= 13%, SD= 15.9%) and medium-paced bowling (M= 11.3%, SD=6.3%). There was not a significant difference in the percentage of time the amateur batters fixated on the lower body z= -1.789, p = .074 between spin bowling (M= 6.8%, SD= 14.7%) and medium-paced bowling (M= 2.6%, SD= 5.8%). There was no significant difference in the percentage of time the batters spent fixating on the point of release (POR) z= -.958, p = .338 between spin bowling (M= 5.9%, SD= 4.6%) and medium-paced bowling (M= 4.9%, SD= 2.7%). There was also no significant difference in the percentage of time the batters spent fixating on non-relevant locations z= -.072, p = .943 between spin bowling (M= 14.5%, SD= 16.5%) and medium-paced bowling (M= 14.5%, SD= 14.3%).

Shapiro-Wilk Tests were also administered on the eight other locations across the two conditions of spin and medium-paced bowling for amateur players. The data representing the amount of time participants fixated on the following locations; head (spin), chest, right foot, right knee, hips, non-bowling arm, landing/bounce location (non-body) and bat tap, for both spin and medium-paced bowling also violated the assumption of normality (all p < .001).

A Wilcoxon Signed Ranked Test revealed that there was a significant difference at only one location, the hips, between the two conditions of spin and medium-paced bowling. There was a significant difference between spin bowling (M= 1.4%, SD= 3.9%) and medium-paced bowling (M= 0, SD= 0) for time spent fixating at the hips, z= -2.201, p = .028, with a medium effect size (*r*= 0.36). There was no significant difference in time spent fixating across any of the remaining seven locations between spin and medium-paced; head *z*= -.627, *p* = .531, chest *z*= -1.245, *p* = .213, right foot *z*= -.866, *p* = .386, right knee *z*= -.169, *p* = .866, non-bowling arm *z*= -1.000, *p* = .317, bounce/landing location *z*= -0.674, *p* = .500, or bat tap *z*= -0.135, *p* = .893.

6.3.1.3 Pre-delivery elite

The results from the Shapiro-Wilk Test showed that the data representing the percentage of time spent fixating on the upper body for medium-paced bowling *p* = .010, ball for medium-paced bowling *p* = .006, POR spin bowling *p* = .002 and POR medium-paced bowling *p* = .004, non-relevant locations for spin bowling *p* < .001, non-relevant locations for medium-paced bowling *p* < .001, lower body spin bowling *p* < .001, and lower body for medium-paced bowling *p* < .001, all violated the assumption of normality and therefore Wilcoxon Signed Ranks Tests were administered to assess these locations. The data representing the percentage of time spent fixating on the ball for spin *p* = .212 and medium-pace bowling *p* = .560 was normally distributed, therefore a paired samples T-Test was administered to asses this location.

The result from the paired sample T-Test revealed that there was no significant difference in the percentage of time spent fixating on the ball, *t* (35) = -.699, *p* = .489, between spin bowling (*M*= 61.3%, *SD*= 17.8%) and medium-paced bowling (*M*= 58.3%, *SD*= 16.9%). The results from the Wilcoxon Signed Ranks Tests revealed that there was no significant difference between the amount of time elite batters spent fixating upon non-relevant locations when facing spin bowling (*M*= 0.4%, *SD*= 2.5%) compared to medium-paced bowling (*M*= 0%, *SD*= 0%), *z*= -1.00, *p* = .317. There was not a significant difference between the percentage of time spent fixating on the upper body *z*= -.503, *p* = .615 between spin bowling (*M*= 25%, *SD*= 17.4%) and medium-paced bowling (*M*= 24.4%, *SD*= 15.3%). There was not a significant difference in the percentage of time the elite batters fixated on the lower body *z*= -.840, *p* = .401, between spin bowling (*M*= 0.8%, *SD*= 2.7%) and medium-paced bowling (*M*= 1.4%, *SD*= 3.1%). There was no significant difference in the percentage of time the elite batters spent fixating on the point of release (POR) *z*= -1.895, *p* = .056 between spin bowling (*M*=7%, *SD*= 2.7%) and medium-paced bowling (*M*= 5.9%, *SD*= 1.7%).

Shapiro-Wilk Tests were also administered on the seven other locations across the two conditions of spin and medium-paced bowling for the elite batters. Results revealed that all of the data representing the percentage of time participants fixated upon the head for spin bowling $p = .014$ and medium-paced bowling $p = .010$ was not normally distributed. The data representing the percentage of time participants fixated on the following locations; chest, right foot, right knee, non-bowling arm, landing/bounce location (non-body) and bat tap (non-body) for both spin and medium-paced bowling also violated the assumption of normality (all $p < .001$).

Wilcoxon Signed Ranked Tests revealed that there was a significant difference at two locations, bat tap and right foot, between the two conditions of spin and medium-paced bowling. There was a significant difference between spin bowling (*M*= 4.3%, *SD*= 11.6%) and medium-paced bowling (*M*= 9.1%, *SD*= 15.9%) for the percentage of time spent fixating at the bat tap location $z= -2.134$, $p = .033$, with a medium effect size ($r= 0.35$). There was also a significant difference in the percentage of time elite batters fixated upon the right foot when facing spin (*M*= 0%, *SD*= 0%) compared to medium-paced bowling (*M*= 1.1%, *SD*= 3.1%), $z= -2.023$, $p = .043$ with a medium effect size ($r= 0.34$). There was no significant difference in time spent fixating across any of the remaining five locations between spin and medium-paced; head $z= -0.360$, $p = .719$, chest $z= -0.663$, $p = .508$, right knee $z= -1.604$, $p = .109$, non-bowling arm $z= -1.185$, $p = .236$, bounce/landing location $z= -.00$, $p = 1.00$.

6.3.1.4 Pre-delivery results elite vs. amateur batters when facing spin

Shapiro-Wilk Tests were administered to determine if the pre-delivery data for the elite and amateur batters when facing spin bowling was normally distributed. The results show that most of the data (the amount of time fixating on the upper body for amateur batters $p < .001$, lower body for amateur batters $p < .001$, lower body for elite batters $p < .001$, non-relevant locations for amateur batters $p < .001$, and non-relevant for elite batters $p < .001$) violated the assumption of normality. The non-parametric Mann Whitney U Tests were therefore administered to assess whether there was a significant difference in gaze behaviour between the two groups. The data representing the amount of time batters fixated upon the ball for amateur batters $p = .984$ and elite batters $p = .213$ was normally distributed; therefore, an Independent Samples T-Test was administered.

The results from the Mann-Whitney U Test revealed that there was a significant difference in the percentage of time the amateur batters (*M*= 13%, *SD*= 15.9%) compared to the elite batters (*M*= 25%, *SD*= 17.4%) fixated upon the upper body when facing spin bowling, $U= 359$, $z= -3.276$, $p = .001$ with a medium effect size ($r= 0.38$). There was a significant difference in the percentage of time the amateur batters (*M*= 14.5%, *SD*= 16.5%) compared to elite batters (*M*= 0.4%, *SD*= 2.5%) fixated upon non-relevant locations when facing spin bowling, *U*= 233, *z*= -5.501, *p* < .001, with a large effect size (*r*= 0.65). There was also a significant difference in the percentage of time that the amateur batters (*M*= 6.8%, *SD*= 14.7%) fixated upon the lower body when compared to the elite batters (*M*= 0.8, *SD*= 2.7%) when facing spin bowling, *U*= 494.5, *z*= -2.502, *p* = .012 with a medium effect size (*r* = 0.3).There was no difference in the percentage of time spent fixating on the point of release between the amateur batters (*M*= 5.9%, *SD*= 7.1%) and the elite batters (*M*= 7.1%, *SD*= 2.7%) when facing spin bowling, *U*= 485, *z*= -1.836, *p* = .0.66. The result from the Independent Samples T-Test revealed that there was no significant difference in the percentage of time amateur batters (*M*= 61.3%, *SD*= 17.7) compared to elite batters fixated upon the ball when facing spin bowling (*M*= 56.6, *SD*= 16.9), *t* (70) = 1.160, *p* = .250, two-tailed.

Shapiro-Wilk Tests were also administered to determine if the pre-delivery data for the elite and amateur batters when facing spin bowling for the other eight locations was normally distributed. The results revealed that the data representing the percentage of time participants fixated on the head for spin *p* = .014 violated normality. The following locations: head (for medium-pace), chest, right foot, right knee, non-bowling arm, hips, landing/bounce location (non-body) and bat tap for both spin and medium-paced bowling also violated the assumption of normality (all *p* < .001). Mann Whitney U Tests were therefore administered to assess these data sets.

The results from the Mann Whitney U Tests revealed that there was a significant difference in the percentage of time amateur batters (*M*= 10%, *SD*= 12.4%) compared to elite batters (*M*= 18.7%, *SD*= 13.7) fixated upon the head when facing spin bowling, *U*= 394, *z*= -2.892, *p* = .004, with a medium effect size (*r*= 0.34). There was a significant difference in the percentage of time amateur batters (*M*= 0.4%, *SD*= 2.5%) compared to elite batters (*M*= 3.4%, *SD*= 4.6%) fixated upon the non-bowling arm, *U*= 394, *z*= -4.155, *p* = .004, with a medium effect size (*r*=0.49). There was a significant difference in the percentage of time amateur batters (*M*= 4.4%, *SD*= 13.3%) compared to elite batters (*M*= 0%, *SD*= 0%) fixated upon the right foot *U*= 522, *z*= -2.760, *p* = .006, with a medium effect size (*r*= 0.3). There was also a significant difference in the percentage of time amateur batters (*M*= 1.4%, *SD*= 3.9%) compared to elite batters (*M*= 0%, *SD*= 0%) fixated upon the hips, *U*= 540, *z*= -2.537, *p* = .011 with a medium effect size (*r*= 0.30). There was no significant difference in percentage of time spent fixating across the other locations between elite and amateur players: chest U= 645.5, z= -.41, p = .967, right knee U= 646, z= -.035, p = .972, bounce/landing location U= 578, z= -1.633, p = .102, or bat tap U= 594, z= -1.260, p= .237.

6.3.1.5 Pre-delivery results elite vs. amateur batters when facing medium-paced bowling

Shapiro-Wilk Tests were administered to determine if the pre-delivery data for the elite and amateur batters when facing medium-paced bowling was normally distributed. The results show that the data representing the percentage of time fixating of the upper body for elite batters p = .010, lower body for amateur batters $p < .001$, lower body for elite batters $p < .001$, non-relevant locations for amateur batters p = .001, non-relevant for elite batters $p < .001$, all violated the assumption of normality. Mann Whitney U Tests were therefore administered to assess this data. The data representing the percentage of time spent fixating on the ball for amateur batters p = .064, and the ball for elite batters p = .558 was normally distributed, therefore an Independent Samples T-Test was administered.

The results revealed that there was a significant difference in the percentage of time spent fixating upon the upper body when facing medium-paced bowling between amateur batters (M= 11.3%, SD= 6.3%) and elite batters (M= 24.4%, SD= 15.3%), U= 313, z= -3.773, $p < .001$, with a medium effect size (r=0.4). There was also a significant difference in the percentage of time amateur batters (M= 14.5%, SD= 14.3%) fixated upon non-relevant location compared to elite batters (M= 0%, SD= 0%), U= 180, z= -3.130, $p < .001$, with a medium effect size (r= 0.37). Finally, there was a significant difference in the percentage of time amateur batters (M= 4.9%, SD= 2.7%) compared to elite batters (M= 5.9%, SD= 1.7%) fixated upon the point of release, U= 439, z= 1.105, p = .019, with a small effect size (r= 0.14). There was no significant difference in the percentage of time amateur batters (M= 62.8%, SD= 12.9%) compared to elite batters (M= 58.3%, SD= 16.9%) fixated upon the ball, t (70) = -1.285, p = .203. There was not a significant difference in the percentage of time amateur batters (M= 2.6%, SD= 5.8%) when compared to elite batters (M= 1.3%, SD= 3.1%) fixated upon the lower body, U= 612, z= -.545, p = .586.

Shapiro-Wilk Tests were also administered on the data from the seven other fixation locations for elite and amateur batters to see if the data was normally distributed. Results revealed that all of the data representing the percentage of time participants fixated upon the head for elite batters p= 0.010 was not normally distributed. The data representing the percentage of time participants fixated) on the following locations: chest, right foot, right knee, non-bowling arm, landing/bounce location (non-body) and bat tap (non-body) for both amateur and elite batters also violated the assumption of normality (all

$p < .001$).

The results from the Mann Whitney U Tests revealed that there was a significant difference in the percentage of time amateur batters (*M*= 0%, *SD*= 0%) compared to elite batters (*M*= 3.9%, *SD*= 4.6%) fixated upon the non-bowling arm *U*= 324, *z*= -4.799, $p < .001$, with a large effect size (*r*= 0.5). There was also a significant difference in the percentage of time amateur batters (*M*= 1.8%, *SD*= 7.8%) compared to elite batters (*M*= 9.1%, *SD*= 15.9%) fixated upon the bat tap location, *U*= 517, *z*= 2.200, *p* = .028, with a small effect size (*r*=0.2). There was no significant difference in percentage of time spent fixating across the other locations between elite and amateur players; head *U*= 513, *z*= -1.518, *p* = .129, chest *U*= 624, *z*= -0.470, *p* = .638, right knee *U*= 587, *z*= -1.196, *p* = .232, right foot *U*= 577, *z*= -1.656, *p* = .098, bounce/landing location *U*= 643, *z*= -0.103, *p* = .918.

6.3.1.6 Pre-delivery individual analysis

Each participant's pre-delivery eye-tracking data for the amount of time fixating on the upper body, lower body, ball, point of review and non-relevant location were analysed individually to determine whether individual participants used similar gaze behaviour pre-delivery when facing spin compared to medium-paced bowling. The results revealed that four of the six amateur players (participants 8, 10, 11 and 12) used different fixation locations pre-delivery when viewing spin bowling compared to medium-paced bowling. Only two of the six elite batters (participants 3 and 5) changed their fixation locations when facing spin compared to medium-paced.

Participant 3 (elite batter 3)

Paired Samples T-Tests revealed that participant three (elite batter three) viewed the POR for a significantly longer percentage of the pre-delivery when facing spin bowling (*M*= 7.7%, *SD*= 2.6%) compared to medium-paced bowling (*M*= 3.5%, *SD*= 1.7%), *t* (5) = 4.100, *p* = .009. The eta squared statistic (0.77) suggests a large effect size (Cohen, 1988). There were no significant differences in gaze behaviour across the other locations of upper body, lower body or ball participant three. Participant three did not fixate on any non-relevant location when facing either spin or medium-paced bowling.

Participant 5 (elite batter 5)

Paired Samples T-Tests revealed that participant five (elite batter five) fixated significantly longer on the upper body when facing spin bowling (*M*= 40.1%, *SD*= 9.9%)

compared to medium-paced bowling (*M*= 16.7%, *SD*= 9.5%), *t* (5) = 3.386, *p* = .020. The eta squared statistic (0.69) suggests a large effect size (Cohen, 1988). Participant five fixated on the ball for significantly longer when facing medium-paced bowling (*M*= 69.2%, *SD*= 13.4%) compared to spin bowling (*M*= 48.6%, *SD*= 11.7%), *t* (5) = -2.937, *p* = .032. The eta squared statistic (0.63) suggests a large effect size (Cohen, 1988). Participant five also fixated upon the point of release for a significantly longer percentage of time when facing spin bowling (*M*= 10.6%, *SD*= 2.2%) compared to medium-paced bowling (*M*= 5.7%, *SD*= 1.9%), *t* (5) = 7.291, *p* = .001. The eta squared statistic (0.9) suggests a large effect size (Cohen, 1988). Participant 5 did not fixate upon the lower body or non-relevant location when facing either spin or medium-paced bowling.

Participant 8 (amateur batter 2)

Paired Samples T-Tests revealed that participant eight (amateur batter two) spent a significantly longer percentage of pre-delivery fixating on the upper body when facing spin bowling (*M*= 20.1%, *SD*= 10.9%) compared to medium-paced bowling (*M*= 9.3%, *SD*= 6.1%), *t* (5) = 3.729, *p* = .014. The eta squared statistic (0.73) suggests a large effect size (Cohen, 1988). Participant eight also spent significantly longer fixating upon the ball when facing medium-paced bowling (*M*= 68.6%, *SD*= 6.3%) compared to spin bowling (*M*= 51%, *SD*= 12.7%) *t* (5) = -2.644, *p* = .046. The eta squared statistic (0.58) suggests a large effect size (Cohen, 1988). There were no significant differences in amount of time fixating on the other locations (lower body, point of release or non-relevant locations) for participant 8.

Participant 10 (amateur batter 4)

The Paired Samples T-Tests revealed that participant ten (amateur batter four) spent significantly longer fixating on the upper body when facing spin bowling (*M*= 34.6%, *SD*= 16.1%) compared to medium-paced bowling (*M*= 17.5%, *SD*= 2.5%), *t* (5) = 2.799, *p* = .038. The eta squared statistic (0.61) suggests a large effect size (Cohen, 1988). There were no significant differences in amount of time fixating on the other locations (lower body, ball, point of release or non-relevant locations) for participant ten.

Participant 11 (amateur batter 5)

Wilcoxon Signed Ranks Tests and Paired-Samples T-Tests revealed that participant eleven (amateur batter five) spent a significantly longer percentage of time fixating on the upper body for medium-paced bowling (*M*= 12.7%, *SD*= 8.7%) compared to spin bowling

(M= 2%, SD= 5%), z= 2.207, p = .028 with a large effect size of (r= 0.9). There were no significant differences in the percentage of time spent fixating on the other locations (lower body, non-relevant locations, ball or point of release) for participant eleven.

Participant 12 (amateur batter 6)

The Paired Samples T-Test revealed that participant twelve (amateur batter six) spent significantly longer fixating on the upper body when facing medium-paced bowling (M= 360, SD= 156) compared to spin bowling (M= 78, SD= 132), t (5) = -2.876, p = .035. The eta squared statistic (0.62) suggests a large effect size (Cohen, 1988). Participant twelve also spent significantly longer fixating on the lower body when facing spin bowling (M= 668, SD= 330) compared to medium-paced bowling (M=150, SD= 181), t (5) = 2.777, p = .039. The eta squared statistic (0.61) suggests a large effect size (Cohen, 1988). There were no significant differences in gaze behaviour across the other locations (ball, point of release and non-relevant locations) for participant twelve.

6.3.2 Ball flight analysis

The ball flight data were analysed to determine whether the batters used differing methods to track the ball when facing spin compared to medium-paced bowling. The percentages the participants tracked the ball for both spin and medium-paced bowling can be seen in table 6.4 for amateur batters and table 6.5 for elite batters.

Table 6.4. Mean and SD percentages of total ball flight tracked by amateur batters (release to contact), pre-bounce ball flight (release to bounce), post bounce ball flight (bounce to

contact) and time attempted to track and failed across the two conditions of spin and medium-paced bowling.

	Mean and SD % of total ball flight tracked.	Mean and SD % of pre-bounce ball flight tracked.	Mean and SD % of post bounce ball flight tracked.	Mean and SD % of ball flight attempted/failed to track
Spin	*M*= 78.8, *SD*= 3.1	*M*= 86.8, *SD*= 4.0	*M*= 29.7, *SD*= 18.0	*M*=16.8, *SD*= 5.3
Medium-paced	*M*= 66.9, *SD*= 7.1	*M*= 81.8, *SD*= 9.3	*M*= 26.0, *SD*= 18.1	*M*= 24.6, *SD*= 5.8

Table 6.5. Mean and SD percentages of total ball flight tracked by elite batters (release to contact), pre-bounce ball flight (release to bounce), post bounce ball flight (bounce to contact) and time attempted to track and failed across the two conditions of spin and medium-paced bowling.

	Mean and SD % of total ball flight tracked.	Mean and SD % of pre-bounce ball flight tracked.	Mean and SD % of post bounce ball flight tracked.	Mean and SD % of ball flight attempted/failed to track
Spin	*M*= 81.8, *SD*= 5.2	*M*= 88.0, *SD*= 7.3	*M*= 33.5, *SD*= 11.4	*M*= 10.5, *SD*= 1.8
Medium-paced	*M*= 70.9, *SD*= 7.4	*M*= 83.0, *SD*= 10.6	*M*= 40.1, *SD*= 18.4	*M*= 16.8, *SD*= 5.3

6.3.2.1 Ball flight analysis: amateur batters

Shapiro-Wilk Tests were administered to determine if the ball flight data were normally distributed and subsequently informed the decision as to whether a Paired Samples T-Test or Wilcoxon Signed Ranks Test was administered. The data representing that the total time tracking the whole delivery for spin $p = .500$, total time tracking the whole delivery paced $p = .137$, the total time attempted/failed tracking for spin bowling $p = .115$ and the total time attempted/failed tracking for medium-paced bowling $p = .052$ were all normally distributed, therefore, Paired Samples T-Tests were administered to determine if there was a difference across the conditions. The data representing the total time tracking pre-bounce for medium-paced bowling $p = .001$, the total time tracking the ball post bounce for spin $p < .001$, and total time tracking the ball post bounce for paced $p < .001$, violated the assumption of normality. Therefore, a Wilcoxon Signed Ranks test was run to determine if there was a difference across the two conditions of spin and medium-paced.

The results from the Paired Samples T-Tests suggest that there was a significant difference in the percentage of time the participants tracked the ball through the entire flight between spin (*M*= 78.9, *SD*= 7.5) and medium-paced bowling (*M*= 66.8, *SD*=12.5), t (35) = 4.542, $p < .001$. The eta squared statistic (0.41) indicates a large effect size (Cohen, 1988). There was also a significant difference in the percentage of ball flight the participants attempted and failed to track between spin (*M*= 16.3, *SD*= 7.4) and medium-paced bowling (*M*= 24.6, *SD*= 11.1), t (35) = -4.076, $p < .001$. The eta square statistic (0.33) indicates a large effect size (Cohen, 1988). The results from the Wilcoxon Signed Ranks Test show that there was not a significant difference in the percentage of time the batters tracked the ball pre-bounce when facing spin (*M*= 87.6, *SD*= 7.5) compared to medium-paced bowling (*M*= 81, *SD*= 15), z= -.713, $p = .087$. There was also no significant difference between the percentage of ball flight tracked post bounce between the two conditions of spin (*M*= 29.3, *SD*= 35.3), and medium-paced bowling (*M*= 28, *SD*= 29.2), z= -227, $p = .820$.

6.3.2.2 Ball flight analysis: elite batters

Shapiro-Wilk Tests were administered to determine if the ball flight data for the elite batters were normally distributed. The results revealed that the data representing the total time attempted/failed tracking for spin bowling $p = .089$ and medium-paced bowling $p = .259$ was normally distributed, therefore a Paired Samples T-Test was administered. The data representing the percentage of time tracking the whole delivery for spin $p < .001$ and medium-paced bowling $p < .001$, the percentage tracking the pre-bounce ball flight for spin $p < .001$ and medium-paced $p < .001$, and the percentage of time tracking the post bounce ball flight for spin $p = .001$ and medium-paced $p = .017$, all violated the assumption of normality, therefore Wilcoxon Signed Ranks Tests were administered to determine whether there was a difference in the way elite batters tracked the ball when facing spin and medium-paced bowling.

The results from the Wilcoxon Signed Ranks Test revealed that there was a significant difference in the percentage of time the participants tracked the ball through the entire flight between spin (*M*= 80.7, *SD*= 10.6) and medium-paced bowling (*M*= 70.2, *SD*= 12), *z*=-3.739, *p* < .001, with a large effect size (*r*= 0.6). There was also a significant difference in the percentage of ball flight the participants attempted and failed to track between spin (*M*= 10.5, *SD*= 5) and medium-paced bowling (*M*= 16.6, *SD*= 7.2), *t* (35) = -4.516, *p* < .001. The eta square statistic (0.40) indicates a large effect size (Cohen, 1988). There was not a significant difference in the percentage of time the batters tracked the ball pre-bounce when facing spin (*M*= 87.7, *SD*= 14.4) compared to medium-paced bowling (*M*= 82.8, *SD*= 15.9), *z*=-.713, *p* = .087. There was also no significant difference between the percentage of ball flight tracked post bounce between the two conditions of spin (*M*= 32.8, *SD*= 31.7), and medium-paced bowling (*M*= 39.1, *SD*= 26.6), *z*= -227, *p* = .820.

6.3.2.3 Ball flight analysis: elite vs. amateur when facing spin bowling.

Shapiro-Wilk Tests were administered to determine if the ball flight data for the elite and amateur batters when facing spin bowling were normally distributed. The results show that all of the data (percentage of total time tracked *p* < .001, percentage of pre-bounce ball flight tracked *p* < .001, percentage of post bounce ball flight *p* < .001, and the percentage of ball flight the participants attempted and failed to track *p* < .001) violated the assumption of normality. Therefore, Mann Whitney U Tests were administered. The results revealed that there was a significant difference in the percentage of the whole ball flight tracked between amateur batters (*M*= 78.8, *SD*= 7.5) and elite batters (*M*= 81.8, *SD*= 10.4), *U*= 432, *z*= -2.433, *p* = .015, with a large effect size (*r*=0.7). There was also a significant difference in the percentage of ball flight attempted and failed to track between amateur batters (*M*= 16.3, *SD*= 7.4) and elite batters (*M*= 10.5, *SD*= 5), *U*= 330.5, *z*= -3.576, *p* < .001, with a medium effect size (*r*= 0.4). There was no significant difference in the pre-bounce ball flight percentage tracked between amateur batters (*M*= 86.8, *SD*= 8.6) and elite batters (*M*= 88, *SD*= 13.6), *U*= 496.5, *z*= -1.706, *p* = .088. There was also no difference in the percentage of post-bounce ball flight tracked between amateur batters (*M*= 28.1, *SD*= 34.5) and elite batters (*M*= 29.2, *SD*= 31.6), *U*= 618.5, *z*= -0.357, *p* = .721.

6.3.2.4 Ball flight analysis: elite vs. amateur when facing medium-paced bowling.

Shapiro-Wilk Tests were administered to determine if the ball flight data for the elite and amateur batters when facing medium-paced bowling were normally distributed. The results show that all of the data percentage of total time tracked $p = .003$, Percentage of pre-bounce ball flight tracked $p < .001$, percentage of post bounce ball flight $p < .001$ and the percentage of ball flight the participants attempted and failed to track $p < .001$, violated the assumption of normality; therefore, Mann Whitney U Tests were administered. The results revealed that there was a significant difference in the percentage of post-bounce ball flight tracked between amateur batters (M= 26.4, SD= 29.1) and elite batters (M= 40.1, SD= 27.2), U= 457.5, z= -2.029, $p = .043$, with a small effect size (r= 0.2). There was also a significant difference in the percentage of ball flight attempted and failed to track between amateurs (M= 25.1, SD= 10.8) and elite batters (M= 16.6, SD= 7.2), U= 367.5, z= -3.159, $p = .002$, with a medium effect size (r= 0.37). There was not a significant difference in the percentage of the whole ball flight tracked between amateur batters (M= 66.4, SD= 12.5) and elite batters (M= 70.8, SD= 11.7), U= 521, z= -1.430, $p = .153$. There was also no significant difference in the percentage of pre-bounce ball flight tracked between amateur batters (M= 81.7, SD= 14.6) and elite batters (M= 83, SD=*15.7*), U= 582.5, z= -0.781, $p = .461$.

6.3.2.5 Ball flight individual analysis

Each participant's ball flight eye-tracking data (total percentage of ball flight tracked, percentage of pre-bounce ball flight tracked, percentage of post bounce ball flight and percentage of failed ball flight tracked) were analysed individually to determine whether individual participants used similar gaze behaviour during the ball flight when facing spin compared to medium-paced bowling. The results revealed that two of the six amateur players (participants 10 and 12) used different fixation locations pre-delivery when viewing spin bowling compared to medium-paced bowling. Also, two of the six elite batters (participants 3 and 5) changed their tracking strategy when facing spin compared to medium-paced.

Participant 3 (elite batter 3)

A Paired Samples T-Test revealed that participant 3 (elite batter 3) tracked the ball for a longer percentage of total ball flight when facing spin bowling (M= 85, SD= 4.2) compared to paced bowling (M= 80, SD= 4.7), t (5), = 2.710, $p = .042$. The eta squared statistic (0.59) suggests a large effect size (Cohen, 1988). Wilcoxon Signed Ranks Test also revealed that participant 3 tracked a large percentage of post bounce ball flight when facing medium-paced bowling (*M*= 48.2, *SD*= 19.7) compared to spin bowling (*M*= 27.6, *SD*= 25.8), *z*= -2.023, *p* = .034 with a large effect size (*r*= 0.83). There was no significant difference in the percentage of pre-bounce ball flight tracked or the amount of ball flight failed to track for participant 3.

Participant 5 (elite batter 5)

A Paired Samples T-Test revealed that participant 5 (elite batter 5) tracked the ball for a longer percentage of total ball flight when facing spin bowling (*M*= 81.5, *SD*= 8.8) compared to paced bowling (*M*= 69.5, *SD*= 6.4), *t* (5), = 3.103, *p* = .027. The eta squared statistic (0.66) suggests a large effect size (Cohen, 1988). There was no significant difference in the percentage of pre-bounce ball flight tracked, post bounce ball flight tracked, or the amount of ball flight failed to track for participant 5.

Participant 10 (amateur batter 4)

A Paired Samples T-Test revealed that participant 10 (amateur batter 4) tracked a significantly larger percentage of pre-bounce ball flight when facing spin bowling (*M*= 93.6, *SD*= 6.6) compared to medium-paced bowling (*M*= 81.9, *SD*= 9.5), *t* (5) = 2.635, *p* = .046. The eta squared statistic (0.58) suggests a large effect size (Cohen, 1988). There was no significant difference in the total percentage of bounce ball flight tracked, post bounce ball flight tracked, or the amount of ball flight failed to track for participant 10.

Participant 12 (amateur batter 6)

Paired Samples T-Tests revealed that participant 12 (amateur batter 6) tracked the ball for a longer percentage of total ball flight when facing spin bowling (*M*= 78.4, *SD*= 8.5) compared to paced bowling (*M*= 59.3, *SD*= 11.1), *t* (5), = 4.647, *p* = .006. The eta squared statistic (0.81) suggests a large effect size (Cohen, 1988). Participant 12 also failed to track the ball for a significantly longer period when facing paced bowling (*M*= 25.9, *SD*= 9.5) compared to spin bowling (*M*= 17.5, *SD*= 9.8), *t* (5) = -3.311, *p* = .021. The eta squared statistic (0.69) suggests a large effect size (Cohen, 1988). There was no significant differences in the percentage of pre-bounce or post-bounce ball flight tracked when facing spin compared to medium-paced for participant 12.

6.3.3 Correct vs. incorrect decision-making

The data was also analysed to determine if there was a difference in gaze behaviour when both the elite and amateur batters made a correct compared to incorrect decision when facing spin and medium-paced bowling. Table 6.6 shows the number of incorrect decisions made by the amateur and elite batters while facing spin and medium-paced bowling. Due to the small number of incorrect decisions made compared to correct decisions, there was not enough data to assess the impact of changes in gaze behaviour on decision making at an individual level. Therefore, data analysis was only conducted at a group level to assess the impact of gaze behaviour on decision making. The analysis was again split into two sections: pre-delivery and ball flight.

Table 6.6. Number of incorrect decisions made by both amateur and elite batters when facing spin and medium-paced bowling.

	Number of incorrect decisions made	
Amateurs batters	**Spin bowling**	**Medium-paced bowling**
1	2	2
2	2	2
3	3	3
4	3	1
5	1	3
6	1	2
Total	12/36	13/36
Elite Batters		
1	1	0
2	1	1
3	2	2
4	1	2
5	2	2
6	1	1
Total	8/36	8/36

6.3.3.1 Pre-delivery gaze behaviour: correct vs. incorrect decision-making for amateur batters.

Shapiro-Wilk Tests were administered to determine if the ball flight data was normally distributed. Results from the Shapiro-Wilk Test revealed that the percentage of time spent fixating on the upper body, ball, point of release and non-relevant locations for both correct and incorrect decisions when facing spin and paced bowling was normally distributed. The percentage of time spent fixating on the lower body for correct and incorrect decisions when facing spin and paced bowling violated assumptions of normality. To determine whether there was a difference in the percentage of time fixating on these locations when a correct vs. incorrect decision was made, Paired Sample T-Tests were administered for the normally distributed data and Wilcoxon Signed Rank Test were administered for the data which was not normally distributed. The results reveal that the gaze behaviour pre-delivery or during ball flight did not change when the amateur batters made an incorrect decision compared to a correct decision when facing spin or medium-paced bowling.

The results revealed that there was no difference in gaze behaviour pre-delivery when a correct decision was made compared to an incorrect decision for spin bowling. There was no significant difference between the percentage of time fixated on the ball for a correct (*M*= 63.8%, *SD*= 8.74%) compared to an incorrect decision (*M*= 54.3%, *SD*= 12%), t (5) = 1.622, p = .166. There was no difference in the percentage of time spent fixating on the non-relevant locations between correct (*M*= 13.7%, *SD*= 14.2%) and incorrect decisions (*M*= 15.5%, *SD*= 16.6%) t (5) = -0.532, p = .617. There was not a significant difference in the percentage of time spent fixating on the upper body for correct (*M*= 12.6%, *SD*= 9.2%) compared to incorrect decisions (*M*= 12.7%, *SD*= 17.2%) t (5) = 0.024, p = .982. There was no significant difference in the time spent fixating at the point of release for correct (*M*= 5%, *SD*= 1.9%) compared to incorrect decisions (*M*= 4.9%, *SD*= 4.8%) t (5) =-0.110, p = .916. There was no significant difference the time spent fixating on the lower body for correct (*M*= 6.1%, *SD*= 9.7%) compared to incorrect decisions (*M*= 7.5%, *SD*= 14%) z= --135, p = .893.

The results also revealed that there was no difference in gaze behaviour pre-delivery when a correct decision was made compared to an incorrect decision for medium-paced bowling. There was no significant difference between the percentage of time fixated on the ball for a correct (*M*= 66.8%, *SD*= 7.3%) compared to an incorrect decision (*M*= 57.7%, *SD*= 12.3%), t (5) = 1.860, p = .122. There was no significant difference in the percentage of time spent fixating on the non-relevant locations between correct (*M*= 13%, *SD*= 8.3%) vs. incorrect decisions (*M*= 15.6%, *SD*= 10.6%) *t* (5) = -0.942, *p* = .389. There was no significant difference in the percentage of time spent fixating on the upper body for correct (*M*= 9.5%, *SD*= 4.9%) compared to incorrect decisions (*M*= 12.9, *SD*= 3.2%) *t* (5) = 1.864, *p* = .121. There was no significant difference in the time spent fixating at the point of release for correct (*M*= 4.5%, *SD*= 2.9%) compared to incorrect decisions (*M*= 4.3%, *SD*= 2.7%) *t* (5) =-0.317, *p* = .764. There was also no significant difference in the time spent fixating on the lower body for correct (*M*= 2.6%, *SD*= 3%) compared to incorrect decisions (*M*= 1.4%, *SD*= 2.4%) *z*= -0.730, *p*= 0.465.

6.3.3.2 Pre-delivery gaze behaviour: correct vs. incorrect decision-making for elite batters.

Shapiro-Wilk Tests were administered to determine if the ball flight data were normally distributed. Results from the Shapiro-Wilk Test revealed that the percentage of time spent fixating on the upper body, ball, point of release for both correct and incorrect decisions when facing spin and paced bowling was normally distributed. The time spent fixating on the lower body for correct and incorrect decision-making when facing medium-paced bowling was also normally distributed. The time spent fixating on the lower body when facing spin bowling and time spent fixating on the non-relevant locations for correct and incorrect decisions when facing spin bowling violated assumptions of normality. To determine whether there was a difference in the amount of time fixating on these locations when a correct vs. incorrect decision was made, Paired Samples T-Tests were administered for the normally distributed data and Wilcoxon Signed Rank tests were administered for the data that was not normally distributed.

The results revealed that there was no significant difference in pre-delivery gaze behaviour when a correct decision was made compared to an incorrect decision for spin bowling. There was no significant difference between the percentage of time fixated on the ball for a correct (*M*= 61%, *SD*= 18.5%) compared to an incorrect decision (*M*= 60.9%, *SD*= 12.5%), *t* (5) = 0.017, *p* = .987. There was no significant difference in the percentage of time spent fixating on the upper body for correct (*M*= 26.1%, *SD*= 17.1%) compared to incorrect decisions (*M*= 22.2%, *SD*= 11%) *t* (5) = 1.094, *p* = .324. There was not a significant difference in the time spent fixating at the point of release for correct (*M*= 6.9%, *SD*= 2.8%) compared to incorrect decisions (*M*= 8%, *SD*= 2.6%) *t* (5) =-0.738, *p* = .494. There was no significant difference in the percentage of time spent fixating on the non-relevant locations between correct (*M*= 0%, *SD*= 0%) and incorrect decisions (*M*= 2.4%, *SD*= 5.9%), z = -1.000, p = .317. There was no significant difference between the time spent fixating on the lower body for correct (*M*= 1.1%, *SD*= 2.8%) compared to incorrect decisions (*M*= 0%, *SD* = 0%) z= -1.342, p = .180.

The results revealed that there was also no difference in pre-delivery gaze behaviour when a correct decision was made compared to an incorrect decision when the elite batters face medium-paced bowling. There was no significant difference between the percentage of time fixated on the ball for a correct (*M*= 60.9, *SD*= 5.2%) compared to an incorrect decision (*M*= 56.7%, *SD*= 7.8%), t (5) = 1.948, p = .123. There was no significant difference in the percentage of time spent fixating on the upper body for correct (*M*= 26.6%, *SD*= 8.9%) compared to incorrect decisions (*M*= 27.4%, *SD*= 12.9%), t (5) = -0.177, p = .868. There was no significant difference in the time spent fixating at the point of release for correct (*M*= 5.9%, *SD*= 0.6%) compared to incorrect decisions (*M*= 6.3%, *SD*= 1.1%) t (5) =-1.140, p = .318. There was no significant difference the time spent fixating on the lower body for correct (*M*= 2.1%, *SD*= 3%) compared to incorrect decisions (*M*= 1%, *SD*= 1.4%), t (5) = 1.560, p = .194. None of the elite batter fixated upon non-relevant locations when facing medium-paced bowling.

6.3.3.4 Ball flight: correct vs. incorrect decision-making for elite batters

Shapiro-Wilk Tests were administered to determine if the ball flight data were normally distributed. All of the data (total percentage of ball flight tracked, percentage of pre-bounce ball flight tracked, percentage of post bounce ball flight tracked, and percentage of ball flight failed to track) representing both correct and incorrect decisions when facing medium-paced bowling was above alpha level of 0.05 indicating normality. The data representing total percentage of ball flight tracked, percentage of post bounce ball flight tracked, and percentage of ball flight failed to track when facing spin was normally distributed. The data representing pre-bounce ball flight when facing spin violated assumption of normality.

Paired Sample T-Tests and Wilcoxon Signed Ranks Test revealed that there was no significant difference in the methods used to track the ball by elite batters when facing spin for correct vs. incorrect decisions. There was no significant difference in the total percentage of ball flight tracked for correct (*M*= 81.2, *SD*= 6.4) compared to incorrect decision-making (*M*= 87.4, *SD*= 7.2), t (5), -1.525, p = .188. There was no significant difference in the percentage of post bounce ball flight tracked for correct (*M*= 37.8, *SD*=

16.1) compared to incorrect decision-making (*M*= 11.2, *SD*= 15.4), *t* (5), 2.497, *p*= .055. There was no significant difference in the percentage of ball flight participants failed to track for correct (*M*= 9.7, *SD*= 1.1) compared to incorrect decision-making (*M*= 11.5, *SD*= 5.3), *t* (5), -0.923, *p* = .339. There was no significant difference in percentage of pre-bounce ball flight tracked correct (*M*= 87.2, *SD*= 8.6) compared to incorrect decision-making (*M*= 77.1, *SD*= 36.4), *z*= -0.943, *p* = .345.

Paired Samples T-Tests revealed that there were significant differences in the way elite batters tracked the ball when they made correct vs. incorrect decisions when facing medium-paced bowling. There was a significant difference between the total percentage of ball flight tracked for correct (*M*= 74.6, *SD*= 6.7) compared to incorrect decision-making (*M*= 63.7, *SD*= 10.2), *t* (5), 4.055, *p* = .012. The eta squared statistic suggests a large effect size (0.79). There was also a significant difference in the percentage of pre-bounce ball flight tracked for correct (*M*= 86.1, *SD*= 11.4) compared to incorrect decision-making (*M*= 77.9, *SD*= 13.5), *t* (5), 4.055, *p* = .015. The eta squared statistic suggests a large effect size (0.77). Finally, there was a significant difference in the percentage of ball flight participants failed to track for correct (*M*= 15.4, *SD*= 4.6) compared to incorrect decision-making (*M*= 21.8, *SD*= 4.9), *t* (5), -4.045, *p* = .016. The eta squared statistic suggests a large effect size (0.77). There was no significant difference in the percentage of post bounce ball flight tracked for correct (*M*= 44.2, *SD*= 21.8) compared to incorrect decision-making (*M*= 21.8, *SD*= 10.9), *t* (5), 2.702, *p* = .054.

6.4 Discussion

The aim of the study was to investigate and compare the and gaze behaviours of elite and amateur cricket batsmen, while facing human bowlers of varying velocities and bowling styles. A secondary aim was to investigate whether there was a change in gaze behaviour between correct and incorrect decision-making. The following section will offer a clear explanation and discussion relating to the pre-delivery gaze behaviours of amateur and elite batters, the methods they use to track the ball during its flight and the changes in visual strategies when they make a correct compared to incorrect decision.

6.4.1 Pre-delivery most attended to locations

Across both conditions of spin and medium-paced bowling, the ball was by far the most fixated upon location for both the elite and amateur batters. All of the batters in the study spent a longer percentage of pre-delivery fixating on the ball more than any other location. These findings are logical and intuitive; after all, cricket is a bat and ball sport, therefore, cricket batters need to attend to the ball. This finding corresponds with that reported from study one and study two and previous research within the field (e.g., McRobert et al., 2009). We also know, from previous spatial occlusion studies (e.g., Müller et al., 2006; Tayler & McRobert, 2004), that the presence of the ball and the bowling hand is crucial for batters to be able to predict the line and length (landing location) of the delivery. When the ball/bowling hand is occluded, batters are unable to predict the landing location of the delivery. Batting in cricket is at a fundamental level a one-on-one duel with the bowler. A bowler's aim is to restrict the batters' chance of scoring runs and/or get dismiss them (get them out). They use numerous strategies to achieve this, such as bowling slower or quicker balls, swinging the ball (moving the ball in the air), and bowling bouncers (short deliveries that pass that batter at head height). All of these types of deliveries are more effective if they are disguised (i.e. the batter does not know that they are about to be delivered). To achieve this, bowlers often disguise or try to hide (delays the onset of an informative cue) or otherwise try to deceive (presentation of false visual cues) the batter. One of the main ways that the bowler can achieve this is to cover or hide the ball during the run-up. The finding that batters fixated on the ball and bowling hand is therefore not surprising. The findings from this study, as well as those from study one and two of the research programme, are pretty conclusive; batters (both elite and amateur) gain valuable information pre-delivery by fixating upon the ball while in the bowler's hand during the run up.

Another location that both the elite and amateur batters spent a large percentage of time fixating upon was the head of the bowler. This was the second most fixated upon location of the elite batters and third most fixated upon for the amateur batters. Previous laboratory-based research has suggested that skilled batters will fixate more on the head/shoulders compared to less-skilled batters when viewing fast bowling (McRobert et al., 2009). The results from study one and two of this programme of research also suggest that amateur and semi-elite batters fixate upon the head for a substantial amount of the run up. The findings from the current study show that elite batters also find it necessary to view the bowler's head during pre-delivery. The reason the batters within this study fixated upon the head is not currently known, one possible explanation is that batters keep their vision on a central location (i.e., the head) and use their peripheral vision to attend to other nearby locations. It is possible to fixate vision at one location but attend and extract information from the periphery (Jonides 1981; Abernethy 1988b, Williams et al., 2000), in the literature, this has been described as either 'visual pivots' or 'gaze anchors'. In this instance, the batter might fixate upon the head of the bowler (anchor their vision here), but extract information from the shoulders, chest or arms of the bowler.

One of the key findings from study two was that the amateur batters fixate on a large number of non-relevant locations during the bowlers run up. Locations were deemed non-relevant if they occurred following the start of the bowlers run up but did not directly involve visual information needed to execute the skill of batting. Non-relevant fixations were defined as fixations made to locations away from the bowler (or their immediate vicinity), ball or the playing surface. The non-relevant locations were deemed by the researcher not to have any direct relationship to the delivery of the cricket ball. Typical non-relevant locations observed by the amateur batters during this experiments were fixations towards the stumps at the bowler's end, cars entering the ground, the clubhouse, items left of the floor outside of the net (e.g., kits bags, other people's kit, cricket balls), teammates training the other side of the cricket field and advertising hoardings around the ground. Similarly to study two, this current study also found that amateur batters spend a significant amount of the pre-delivery looking at non-relevant locations. Indeed, non-relevant locations were the second most fixated upon area for amateur batters after the ball. When compared to the elite batters you can clearly see that amateur batters spent significantly more time fixating upon non-relevant locations for both spin and medium-paced bowling. The amateur participants could not have gained any meaningful information which would have impacted or enhanced the execution of their batting performance from the non-relevant locations, however, five of the six amateur batters attended to non-relevant locations during the experiments.

By fixating on the non-relevant locations, the amateur batters removed the opportunity to acquire valuable information about the speed, direction and type of delivery the bowler is about to deliver. This is highly likely to reduce their ability to anticipate the delivery that is about to be bowled which in turn will lead to a reduction in successful decision-making and shot execution. This clearly highlights a defect in the gaze behaviour of the amateur batters within this experiment when compared to the elite batters. Reducing or removing the amount of non-relevant locations attended to therefore seems like a logical solution and good advice for batters, coaches and practitioners. Using eye-tracking technology in the applied world would give coaches and practitioners the tools to easily highlight whether their players attend to these non-relevant locations. If they do, then highlighting this problematic strategy might be the first step of a visual training intervention. Future research should highlight whether the findings that amateur batters fixate upon non-relevant locations are replicated in matches or just in training environments. If these fixations are replicated in matches this might highlight a significant flaw in the amateur batters' visual strategies, one that is highly likely to impact performance. If the batters only fixate on non-relevant information during training, then this highlights an error in their training approaches. This flawed training method might hinder the player's efforts to improve and evolve as cricketers as well as halt the development of their perception-action coupling and decision-making.

6.4.2 Pre-delivery spin vs. medium-paced bowling

When assessing the collated data of both the elite and amateur batters, results revealed that there were very few differences in the gaze behaviour before the ball was released. There was no difference in percentage of time spent fixating upon the ball, upper body, lower body, point of release or non-relevant location for either amateur or elite batters. On the whole, the data suggests that the batters within this study did not alter their fixation locations substantially as a result of the type of bowling they were facing. This supports the findings from the previous study (study two). However, this finding also contradicts previous laboratory-based research studies (McRobert et al., 2009) that suggest that batters altered their visual search strategy when observing fast compared to spin bowlers.

While there were only a few significant differences when assessing the collated data of the amateur and elite batters, when assessing the individual search strategies of each participant it became clear that the elite batters had more consistent search strategies compared to the amateur batters. Four of the six amateur batters' altered their gaze behaviour slightly when facing spin compared to medium-paced, whereas only two of the six elite batters changed their gaze behaviour. While the changes in gaze behaviour were minor, the elite batters employed more consistent gaze behaviour when facing spin and medium-paced bowling. This finding is consistent with eye-tracking research from other sports, which has demonstrated that experts have the ability to employ perceptual resources more efficiently and consistently than amateur players. Including: tennis (Williams, Singer, & Weigelt, 1998); basketball (Vickers, 1996); ice hockey (Vickers, Canic, Abbitt, & Liveingston, 1988); ball catching (Emes et al., 1994); table tennis (Ripoll 1989; Ripoll, Fleurance, & Cazeneuve 1987); pistol shooting (Ripoll et al., 1985); and rock climbing (Dupuy & Ripoll, 1989).

6.4.3 Elite vs. amateur pre-delivery gaze behaviour

As discussed above, when assessing the differences in gaze behaviour between elite and amateur batters, it became apparent that one of the main differences in visual behaviour was the percentage of time the amateur batters compared to elite batters fixated upon non-relevant locations. This substantial difference was found when participants faced both spin and medium-paced bowling and should be considered a key finding from this research. Another significant difference found in this study is that elite batters fixated upon the upper body for a longer duration compare to amateur batters when facing both spin and medium-paced bowling. Specifically, elite batters fixated upon the non-bowling arm significantly longer when compared to amateur batters for both spin and medium-paced bowling. This finding highlights a potentially crucial source of information that amateur batters seem unaware of and do not fixate upon. This information could provide them with vital cues regarding the landing location of the ball.

The non-bowling arm has been suggested to provide vital information about the speed of the ball that is about to be delivered. According to Bartlett, Stockill, Eliott and Burnett (1996), the front arm (the non-bowling arm) is the key to a smooth and effective bowling action and essential for the generation of bowling speed. It is understood that the extension and adduction of the non-bowling arm has a large impact on the bowling velocity by aiding lateral flexion and hyperextension in the coil (bowling) position (Burden, 1990; Davis & Blanksy, 1976). Indeed, the non-bowling arm is said to be so important in generating velocity that Salter, Sinclair and Portis (2007) suggested that the vertical velocity of the non-bowling arm along with the bowler's centre of mass velocity at back foot contact, maximum angular velocity of bowling humorous, and stride length, equate for 87.5% of the bowler's variation in release speed. Elite batters may therefore 'pick up on' more information about the speed of the up-coming delivery compared to the amateur batters by viewing the non-bowling arm. The batters might be able to use the information gathered from the non-bowling arm to predict not only when the ball will arrive, but also whether the bowler had planned to deceive the batter by bowling a slower ball or changing the bowling velocity.

Finally, when comparing elite vs. amateur pre-delivery gaze behaviour it became apparent that amateur batters spent a significantly longer percentage of pre-delivery fixating on the lower body, specifically the feet and hips, when facing spin bowling. Previous occlusion studies (Müller et al., 2006) suggest that batters do not gain vital information about the ball flight from lower body locations such as the feet or hips. For example, having occluded the lower body, Müller and colleagues reported that there was no significant reduction in the ability of a batter to predict the line and length of the ball that was about to be bowled. In fact, these researchers found that occluding the lower body resulted in an improvement in prediction performance. This outcome suggests that viewing the lower body may actually impede performance, most likely through distraction. The fact that amateur batters fixate upon these locations for a longer duration when compared to elite batters supports these findings. Highlighting this knowledge to amateur batters and explaining that very little information is gathered from the lower body might be an important step in a visual intervention.

6.4.4 Ball flight spin vs. medium-paced bowling

Similar to the findings from study two of this programme of research, there were differences in ball tracking when both elite and amateur batters faced spin compared to medium-paced bowling. The results highlighted a significant difference in the percentage of time both the elite and amateur participants tracked the ball when facing spin compared to medium-paced bowling. Both elite and amateur batters tracked the ball for a significantly longer percentage of ball flight duration when facing spin bowling compared to medium-paced bowling. The elite and amateur batters also failed to track a significantly higher percentage of the ball flight when facing medium-paced bowling compared to spin bowling. While these findings are in agreement with the previous studies (study one and study two), they do contradict previous research such as Croft et al. (2010) who suggested that changing the bowling velocity does not have an impact on how batsmen track the ball. The findings from the first three studies in this programme of research suggest otherwise and highlight that both amateur and elite batters track significantly more of the ball flight when facing spin bowling compared to medium-paced bowling. Croft and colleagues' findings might be explained due to the small variation of ball velocities used in their experiments and the fact that they used bowling machines to deliver the ball. The use of a bowling machine within their research design meant that the batter would gain no pre-delivery information to help anticipate the speed, line or length of the delivery. The batters would not receive any advanced cues from the body or run up of the bowler and therefore, might need to employ the same tracking strategy for all types of bowling. As this research has highlighted, when these advance cues are available from the bowler's run up, batters alter the visual strategies and track the ball for longer when facing slower bowling compared to higher velocity deliveries

6.4.5 Elite vs. amateur ball flight analysis

The results revealed that there was a significant difference in the percentage of the whole ball flight tracked between amateur batters and elite batters when facing spin bowling, with elite batter tracking more of the ball flight. There was also a significant difference in the percentage of ball flight attempted and failed to track between amateur batters and elite batters when facing spin bowling, with amateur batters failing to track more of the ball flight. This finding was replicated when facing medium-paced bowling with amateur batters failing to track the ball for a significantly high percentage of time compared to elite batters There was also a significant difference in the percentage of post-bounce ball flight tracked when facing medium-paced bowling between amateur batters and elite batters, again elite batters tracking more post bounce. These results combined highlight how elite batters track a higher percentage of the ball flight when facing spin and medium-paced bowling compared to their amateur counterparts.

Land and McLeod (2000) reported that cricket batters facing what they described as 'medium-paced' deliveries (25 m/s, similar to the velocities used in the current study to represent the spin bowler) typically pursuit tracked the ball for between 50% and 80% of ball flight, before producing a predictive saccade to the expected bounce point. Croft et al. (2010) reported similar results when facing speeds of between 61.2–90km/h or 17–25 m/s (again, similar speeds to spin bowling in the current experiment), with typical durations of pursuit tracking prior to a saccade between 63% and 71%. The percentage of ball flight pursuit tracked in the current study (elite M= 81.8, amateur M= 78.8) is slightly higher than previous research, suggesting that when batters are presented with advance cues (something they were denied in both Croft and Land and McLeod's research), they are able to track the ball for a longer duration. These findings also highlight that when the bowling velocities increase from spin bowling to medium-paced bowling the percentage of ball flight that is pursuit tracked significantly reduces. Both elite batters and amateur batters track the ball for a longer duration when facing spin compared to medium-paced. The results also highlight that elite batters are able to track the ball for a greater percentage when compared to amateur batters. Conclusions can therefore be made to suggest that the longer you 'watch the ball' i.e. the longer you are able to track the ball during its flight, the higher chance you will have to successfully predict the landing location and intercept the ball. While it doesn't seem possible to track the whole of the ball flight as traditional coaches' advice might suggest, tracking a higher percentage of the ball flight is a trait that elite batters have when compared to amateurs.

6.4.6 Correct vs. incorrect decision-making

Decision-making plays a vital role in successful sporting performance and can be the difference between success and failure. Within cricket, batters are required to process information and make decisions about how to respond in time periods that push the limits of human performance (Cotterill & Discombe, 2016). Therefore, successful batting performance can be attributed to the effectiveness of a batter's decision-making. The eye-mind hypothesis (Just & Carpenter, 1984) states that there is a strong relationship between where an individual is looking and what that person is thinking about. Indeed, it is believed that fixations allow attention to be directed to specific details from the visual scene in order to process information and guide decision-making (Panchuk et al., 2015). Due to the important role that eye-movements play in the decision-making process, it was hypothesised at the start of this programme of research that both the elite and amateur batters would display different eye movement when they make a correct decision compared to an incorrect one. In the previous study (study two), this hypothesis was rejected as the results showed that there was no difference in the batters gaze behaviour pre-delivery or the method that amateur batters used to track the delivery during the ball flight when they made correct vs. incorrect decisions.

Many of the key findings from study two were replicated in this study. Amateur and elite batters did not change their gaze behaviour pre-delivery when they made a correct decision compared to an incorrect decision. This outcome was found when facing both spin and medium-paced bowling. When facing spin bowling there was no significant difference in the method that amateur or elite batters used to track the delivery when they made a correct compared to incorrect decision. However, when facing medium-paced bowling significant differences were found in the methods used to track the ball during the ball flight for both the elite and amateur batters. Amateur and elite batters failed to track a significantly higher percentage of the ball flight when they made incorrect decision compared to correct decision-making. For the elite batters, there was also a significant reduction in the percentage of pre-bounce ball flight tracked for correct compared to incorrect decision-making. This again adds support to the claims that the longer you can track the ball during the ball flight, the more chance you have to successfully intercept the ball and execute the shot. These findings also highlight that the eye-movements and the visual behaviour of the elite athletes when facing medium-paced bowling has an impact on their decision-making ability. If batters change their method of tracking the ball, and if batters 'take their eyes' off the ball for longer periods, they are less likely to make a correct decision.

6.5 Conclusion

The key results from this study highlight that amateur batters fixate upon non-relevant locations (locations that would not provide any meaningful information about the delivery that is about to be delivered) for a significantly longer period of time compared to amateur batters. This finding is something that coaches, practitioners and amateur batters themselves should be aware of. These batters might be unaware that they spend such a high proportion of the pre-delivery time looking at areas of their visual field that will not provide them with any meaningful information. Changing this behaviour would lead to a more performance specific visual strategy and potentially significant improvements in batting performances. Another key finding is that elite batters fixate upon the upper body, specifically the non-bowling arm for significantly longer when facing both spin and medium-paced bowling compared to amateurs. It is estimated that this location provides the batters with vital information about the velocity of the delivery (Bartlett et al., 1996; Burden, 1990; Davis & Blanksy, 1976). By not attending to this area, amateur batters might be missing out on this important advance information specifically about the speed of the delivery.

When assessing the ball flight information, the results in this study highlight that elite batters track a higher percentage of the ball flight when facing spin and medium-paced bowling compared to their amateur counterparts. When facing medium-paced bowling, significant differences were found in the methods used to track the ball during the ball flight for both the elite and amateur batters when they made a correct compared to incorrect decision. Traditional coaches' advice to "watch the ball" therefore might be the best advice to give, even if it might not be possible to do this for 100% of the ball flight. Tracking the ball flight for longer seems intuitively logical and this study highlights that elite batters do this for a higher percentage of time compared to amateur batters.

This study provides a clear understanding of how amateur and elite batters' visual systems allow them to perform the skill of batting. It also highlights some significant differences between the two populations, which might go a long way in differentiating between the skill levels. By comparing the differences between the elite and amateur batter, it is possible to begin to plan and develop strategies and advice for coaches to help amateur and developing batters develop more efficient visual performance. Indeed, once research links visual ability with sporting performance, the next logical step is training vision to provide batters with an advantage. Clear advice and identifying visual deficiencies (i.e. fixating on non-relevant locations), might be the first steps in helping batters improve their vision and ability to anticipate and watch the ball for longer periods of the ball flight.

Chapter 7.0

General Discussion

The following chapter provides the reader with the main findings that emanated from chapters three, four and five, as well as the cross-study findings and implications of these findings. The chapter will also present a discussion relating to eye-tracking methodological design, specifically in relation to naturalistic vs. laboratory research. The chapter will conclude with some recommendations for future research with regards to sport specific eye-tracking calibration, future research and limitations of the current research programme.

7.1 Summary of findings: study one

Study one provided a crucial insight into the fixation location and gaze behaviour used by semi-elite cricketers when facing different types of bowling (spin bowling, medium-paced bowling and fast bowling). It was hypothesised that batters would fixate on different aspects and segments of the bowlers' body when facing spin compared to facing medium pace or fast bowlers as suggested by the previous research of McRobert et al. (2009). Contrary to the hypothesis, when comparing the differences in pre-delivery gaze behaviour across the three conditions, the results revealed no statistically significant differences in the amount of time the participants spent fixating upon the ball/bowling hand, the point of release, the upper body, or the lower body of the bowler. These findings suggest that the participants in this study fixated upon very similar locations when viewing the footage of the three different bowling types (spin, medium-paced and fast bowling). In accordance with previous research e.g. McRobert et al. (2009) and Müller et al. (2006) it was hypothesised that the batters would fixate upon numerous bodily location pre-delivery. These locations included the wrist/hand and the head of the bowler as well as the ball and the point of release. Study one highlighted that across the three bowling conditions the most fixated upon location was the ball/bowling hand. The second most fixated upon to location was the head of the bowler, with the third most fixated upon location being the point of release. The participants consistently moved their vision to the point where the ball would be released before the bowler released the ball. The finding that participants viewed the ball, head and point of release were consistent across all of the bowling types.

Following the release of the ball it was hypothesised that the batters in study one would utilise smooth pursuit for all, or the majority of, the ball flight when facing spin bowling, as the ball velocity was slower enough to track throughout its flight. It was also hypothesised that the batters would not pursuit track the ball through the entire flight when facing medium paced or fast bowlers, instead they would make a predictive saccade as suggested in the previous research (Croft et al., 2011; Land & McLeod, 2010; Mann et al., 2013). The results of this study highlighted that there was a significant difference in the percentage of ball flight that batters tracked before making a predictive saccade across the three conditions of spin, medium-paced and fast paced bowling. While the batters did not utilise smooth pursuits for the entire ball flight while facing spin bowling as hypothesised, the data shows that the participants either pursuit tracked the ball for a significantly longer percentage of ball flight or kept their vision fixated on the point of release for a longer percentage of ball flight when viewing medium-paced and spin bowling compared to fast pace bowling. In contrast, the data suggests that there was no difference in the percentage of ball flight tracked before the predictive saccade when batters viewed the spin bowling compared to medium bowling. When viewing fast pace bowling, the batters in this experiment pursuit tracked the ball for less of its flight (45.3%) compared to spin (62.8%) and medium-paced bowling (59.2%).

The ball flight results from study one show that all seven participants made a predictive saccade to move their central vision to the estimated point where the ball would bounce. These results are supportive of previous eye-tracking focused studies in the sport of cricket (Croft et al., 2010: Land & McLeod; Mann et al., 2013). It is estimated that this predictive saccade allowed the batters to 'get ahead' of the ball and wait for it to come into their visual field. Without this strategy, the player could risk their gaze lagging behind the ball, thus not being able to 'see' the ball at bounce. Studies have also shown that this strategy is utilised by skilled baseball, tennis, and table tennis players (Glencross & Cibich, 1977; Howarth et al., 1984; Sheppard & Li, 2007). While this finding was somewhat expected, it was interesting to see that this strategy is still employed when viewing a video of cricket bowling.

While all the participants in study one produced a predictive saccade to position their gaze at the location of ball bounce, one interesting finding was that two of the participants did not try to track the initial phase of ball flight. Instead, these participants kept their gaze fixated upon the point of release before making the predictive saccade towards the bounce location. Therefore, the cricketers in this study utilised two distinct strategies for tracking the ball during the ball flight. Two batters kept their gaze stationary following ball release (i.e., kept fixating on the point of release and did not pursuit track the initial ball flight) before making a predictive saccade to the bounce location. This strategy was consistent across the different bowling conditions of spin, medium and fast pace bowling. The other five batters' pursuit tracked the initial stages of ball flight for varying durations, before making the predictive saccade.

One explanation for the lack of pursuit tracking from participants three and seven could be that the artificial design of the task meant batters could not move their head while viewing the video footage. Mann et al. (2013) highlighted that for successful cricket batting, it is important to couple the head movements with the ball. Removing this ability to move the head (due to the inclusion of the eye tracker) might have adversely impacted upon the normal tracking behaviour of the batters. Another possible explanation for this outcome is that the cricketers used their peripheral vision to 'pick up' and process enough information from their initial location of ball release. The batters might have fixated their gaze centrally (at the point of release) and used their peripheral vision to gain information regarding the ball's speed and position (Haywood, 1984; Williams et al., 2004).

7.2 Summary of findings: study two

Study two took place in a more ecologically valid cricket practice (net) environment with participants wearing mobile eye-tracking equipment when facing spin and medium-paced bowling. Unlike study one, study two allowed for the interception of a cricket ball to occur, meaning the dorsal visual pathway would be activated. Study two represents the first naturalistic eye-tracking in cricket study and the data provides crucial insight as to how amateur batters track the ball during flight and what visual cues they utilise before the ball is released.

It is hypothesised that the batters would fixate on varying aspects of the bowler's body (mainly upper body) and according to study one would spend more time fixating on the bowlers' hand/the ball, the head of the bowler and the point of release. It was also hypothesised that there would be no significant differences in the gaze behaviour of batters when facing different types of bowling. As hypothesised and in accordance with study one, the ball/bowling hand was by far the most fixated upon location with participants spending a longer percentage of the pre-delivery fixating here than any other area across both conditions of spin and medium-paced bowling. The head was also the second most fixated upon location, suggesting that, when facing a human bowler in a real training environment, the head is considered an important pre-delivery location for the batters. In accordance with study one, and previous eye-tracking research (Shank &

Haywood, 1987; Singer et al., 1998; McRobert et al., 2009), all batters positioned their gaze towards the point of release ahead of the ball, i.e., batters moved their gaze to a location above the bowler's right shoulder (the point of release) in anticipation of the ball release, before the ball reached this point. Every participant made this fixation towards the point of release for both the condition of spin and medium-paced bowling. There were no significant differences in the amount of time the participants kept their gaze at this location across the conditions, suggesting that this strategy and the timing of this strategy is similar for all types of bowling. This 'real world' finding provides more support for the idea that cricket batters use this strategy to enable them to get their vision 'ahead' of the ball, allowing the ball to come into their vision.

One of the most surprising findings from study two was the amount of time participants spent fixating on non-relevant information. This outcome was not found in the first laboratory-based study, with semi-elite batters. Locations in this study were deemed non-relevant if they did not directly involve the visual information needed to execute the skill of batting. Typical non-relevant locations included: the stumps at the bowler's end; cars entering the ground; the clubhouse; and items left on the floor (e.g., kitbags, balls, bats etc.). The participants could not have gained any meaningful information that could positively impact upon the execution of their batting performance from these locations, however, all seven participants fixated upon non-relevant locations during the experiments.

When comparing the pre-delivery data of participants facing spin compared to medium-paced bowling, the results revealed that as hypothesised, the batters fixated upon similar locations. In accordance with study one, there were no statistically significant difference in the percentage of pre-delivery the participants spent fixating upon the ball, upper body or lower body across the two condition of spin vs. medium-pace. Non-relevant fixations were also assessed and again no differences were found between the conditions. There was however, a significant difference in the percentage of time batters spend fixating upon the point of release, with the batters spending a longer percentage of pre-delivery fixating here when facing spin bowling compared to medium-paced bowling.

In accordance with study one, it was hypothesized that the batters would produce predictive saccades when facing both spin and medium-paced bowling. It was also hypothesised that the batters would pursuit track the ball for a longer period (before making a predictive saccade) when facing spin compared to medium-paced bowling. The data suggests that all participants made a predictive saccade to move their central vision to the estimated point where the ball would bounce. Again, in accordance with study one, significant differences were seen in the percentage of ball flight tracked between the slower and faster bowling velocities. There was a significant difference with participants tracking the ball for a significantly longer duration when facing spin bowling compared to medium-paced bowling. Participants tracked the ball for a significantly longer period of the pre-bounce ball flight when facing spin compared to medium-paced bowling. Participants also attempted to track the ball but failed for a higher percentage of ball flight when facing medium-paced bowling compared to spin bowling.

An additional purpose of the methodological design of study two was to assess whether any changes in vision impacted the decision-making of the batter. Due to the extreme time constraints in sport such as cricket, batters are required to process information and make decisions about how to respond in time periods which push the limits of human performance (Cotterill & Discombe, 2016). Therefore, successful performance can be attributed to the effectiveness of an athlete's decision-making. The eye-mind hypothesis (Just & Carpenter, 1984) states that there is a strong correlation between where an individual is looking and what that person is thinking about. Indeed, it is believed that fixations allow attention to be directed to specific details from the scene, in order to guide decision-making or motor control skills (Panchuk et al., 2015) and that eye-tracking data can serve as an assessment of decision-making (Vachon & Tremblay, 2014). Due to the important role that eye-movements play in the decision-making process, it was hypothesised that participants would produce significant differences in the method of tracking the ball and different pre-delivery gaze behaviours when they made a correct decision compared to an incorrect decision. However, contrary to the hypothesis, the results reveal that the gaze behaviour, both pre-delivery and during ball flight, did not change when the batter made an incorrect decision compared to a correct decision when facing spin or medium-paced bowling.

7.3 Summary of findings: study three

Study two was the first study to track the vision and gaze behaviour of crickets in the 'real-world' (i.e., facing real bowlers, viewing the pre-delivery and ball flight and having the chance to intercept the ball). Study two gave us a clearer understanding of what pre-delivery locations amateur batters find important to view and how they track the ball during its flight. While this information is extremely valuable, study three compared elite and amateur batters' gaze behaviour allowing us to gain a better understanding of the visual processes involved in batting at the elite level and how this might differ from amateur players. This knowledge can subsequently be used and applied by coaches and skill acquisition experts to help them develop and deliver practice scenarios, conditions and training programmes (Eklund & Tenebaum, 2014), something which is discussed further in chapter seven of this thesis.

It was hypothesised that the batters within study three would fixate upon the bowlers' hand/ball and the head of the bowler, as well as the point of release. As expected, and as reported in studies one and two, the ball/bowling hand was by far the most fixated upon location for both the elite and amateur batters across both conditions of spin and medium-paced bowling. All of the participants spent longer fixating here than any other location. Another location that both the elite and amateur batters spent a large amount of time fixating upon was the head of the bowler. This was the second most fixated upon location of the elite batters and third most fixated upon for the amateur batters. One of the key findings from study two was that the amateur batters fixate on a large number of non-relevant locations during the bowlers run up. As with study two, results from study three also highlight that amateur batters spend a significant amount of the pre-delivery looking at non-relevant locations. Indeed, non-relevant locations were the second most fixated upon area for amateur batters after the ball.

It was hypothesised that there would be significant differences in the eye-movements of elite compared to amateur batters. In accordance with the hypothesis, a number of significant differences were apparent. One of the most interesting differences was that the amateur batters spent a significantly longer amount of pre-delivery time fixating upon non-relevant locations for both spin and medium-paced bowling when compared to professional batters. The amateur participants could not have gained any meaningful information which would have impacted or enhanced the execution of their batting performance from the non-relevant locations. However, five of the six amateur batters attended to non-relevant locations during the experiment. This finding highlights a potentially crucial area that could be addressed when working with amateur batters. Another significant difference reported in study three was that elite batters fixated upon the upper body for a longer percentage of pre-delivery compared to amateur batters when facing both spin and medium-paced bowling. Specifically, elite batters fixated upon the non-bowling arm significantly longer when compared to amateur batters. This finding highlights a potentially crucial source of information that amateur batters seem unaware of and do not fixate upon. This information could provide them with vital cues regarding the landing location of the ball.

It also became apparent that the amateur batters spent a significantly longer percentage of the pre-delivery fixating upon the lower body of the bowler compared to their elite counterparts while facing spin. When facing both spin and medium-paced bowling the amateur batters spent significantly longer fixating on the feet of the bowler as well as the hips. Previous occlusion studies (e.g. Müller et al., 2006) suggest that batters do not gain vital information about the ball flight from lower body locations such as the feet or hips. For example, having occluded the lower body, Müller and colleagues reported that there was no significant reduction in the ability of a batter to predict the line and length of the ball that was about to be bowled. In fact, these researchers found that occluding the lower body resulted in an improvement in prediction performance. This outcome suggests that viewing the lower body may actually reduce batting performance, most likely through distraction. The fact that amateur batters fixate upon these locations for a longer duration when compared to elite batters supports these findings. Highlighting this knowledge to amateur batters and explaining that very little information is gathered from the lower body might be the first step in a visual intervention. Finally, there was a significant difference in the percentage of pre-delivery that elite batters compared to amateur batters fixated upon the point of release when facing medium-paced bowling, with elite batters fixating here for a longer percentage of pre-delivery.

In relation to the ball flight findings, it was hypothesised that batters would pursuit track the ball for a longer duration of the ball flight when facing spin bowling compared to medium-paced bowling. It was also hypothesised that the elite batters would pursuit track a significantly high percentage of ball flight compared to amateur batters. When assessing the ball flight data from study three, the results demonstrated that there were differences in ball tracking when both elite and amateur batters faced spin compared to medium-paced bowling. In accordance with the results presented in study one and two, there was a significant difference in the percentage of time both the elite and amateurs tracked the ball when facing spin compared to medium-paced bowling. Both elite and amateur batters tracked the ball for a significantly longer percentage of ball flight when facing spin bowling compared to medium-paced bowling. The elite and amateur batters also failed to track a significantly higher percentage of the ball flight when facing medium-paced bowling compared to spin bowling. The ball flight data from study three also revealed that there was a significant difference in the percentage of the whole ball flight tracked between amateur batters and professional batters when facing spin bowling, with elite batters tracking more of the ball flight. Amateur batters also failed to track a significantly higher percentage of ball flight when facing spin bowling flight compared to the elite counterparts. This finding was replicated when facing medium-paced bowling. The final significant difference showed that the professional batters tracked a higher percentage of post-bounce ball flight when compared to the amateur batters. The difference between elite and amateur ball tracking highlights that elite batters track a significantly higher percentage of the ball flight when facing spin and medium-paced bowling compared to their amateur counterparts.

In study two, the results suggested that there were no differences in the batters' pre-delivery eye movements or the method that amateur batters used to track the delivery during the ball flight when they made correct compared to incorrect decision. It was therefore hypothesised that these findings would be replicated within study three. Most of the findings from study two were replicated in the third study; amateur and elite batters did not change their gaze behaviour pre-delivery when they made a correct decision compared to an incorrect decision. This outcome was present when facing both spin and medium-paced bowling. When facing spin bowling, there was no significant difference in the method that amateur or elite batters used to track the delivery when they made a correct compared to incorrect decision. However, when facing medium-paced bowling, significant differences were found in the methods used to track the ball during the ball flight for both the elite and amateur batters. Amateur and elite batters failed to track a significantly higher percentage of the ball flight when they made incorrect decisions compared to correct decision-making. For the professional batters, there was also a significant difference in the total percentage of ball flight tracked for correct compared to incorrect decision-making and a significant difference in the percentage of pre-bounce ball flight tracked for correct compared to incorrect decision-making. This suggests that the longer you can track the ball during the ball flight, the more chance you have to make a successful decision, successfully intercept the ball and execute the shot. These findings also highlight that the eye-movements and the visual behaviour of the elite athletes when facing medium-paced bowling can have an impact on their decision-making ability. If batters change their method of tracking the ball, and if batters 'take their eyes' off the ball for longer periods, they are less likely to make a correct decision.

7.4 Cross-study finding and implications

7.4.1 Most fixated upon locations across all studies

Across the three studies presented in this programme of research, batters, whether elite or amateur, in the lab or batting in a net, fixated upon a number of consistent locations. The ball/hand of the bowler was by far the most fixated upon location, followed by the head and the point of release. Non-relevant locations were also fixated upon in study two and three by amateur batters.

7.4.2 Ball/bowling hand

The finding that batters fixate upon the ball/bowling hand is both logical and intuitive; after all, cricket is a bat and ball sport, therefore, logic dictates that cricket batters need to attend to the ball. Simon Hughes, a world-renowned cricket analyst, interviewed a number of international cricketers for his book Who Wants to be Batsmen? During these interviews, one of the discussion points was what the batters looked at during the bowler's run up. Ricky Ponting (former Australian cricketer who captained what is widely regarded as one of the best cricket sides of all time) stated that he focused on the ball three times as the bowler was running in: once at the top of his mark, once halfway through and once just before delivery. Kevin Pietersen (former England cricket captain who scored over thirteen thousand international runs) highlighted that he stared intently at the ball throughout the whole of the bowler's approach. He was particularly interested in identifying the seam position as well as which side the shiny side of the ball was facing and which way the rough side was facing. This helped Kevin to identify which way the ball would swing during the delivery. Desmond Haynes (who scored over sixteen thousand international runs for the West Indies) also zoomed in on the seam and the bowler's hand during the run up. He stated that he tried to read the manufacturer's small print on the ball during the bowler's run up. This led to his saying "made in England, sent to Barbados" after hitting the ball out of the ground for six (Hughes, 2015). Indeed, watching the ball is highlighted frequently when you listen to some of the greats of the game talk about batting. Another example of this is Graham Gooch (one of the most successful cricket batters in English history and a former England batting coach). Gooch advocates watching the ball closely on a bowler's approach to the crease: "concentrate on looking at the bowler as he runs in, look at the arm, then look at the ball" (12, p.15). Top cricketers often cite watching the ball during the bowler's run up as vitally important for batting. It might seem obvious, but the results from study one, two and three of this programme of research, show that vital cues are gathered from the ball and bowling hand during the run up and batters spend more time fixating on the ball/bowling hand compared to any other area of the visual scene.

The finding that the ball is the most fixated upon location provides additional support for the findings of McRobert et al. (2009), who also reported that batters spent more time fixating on the ball-hand compared to any other locations. Previous occlusions studies (Müller et al., 2006; Tayler & McRobert, 2004) have also highlighted that the presence of the ball and bowling hand is crucial for batters to be able to predict the line and length (landing location) of the delivery. When the ball/bowling hand is occluded, batters are unable to predict the landing location of the delivery. It therefore seems crucial to 'pay close attention' to the bowling hand/ball in order to predict the characteristics (e.g., line and length) of the delivery. Deception (i.e. the purposeful presentation of false visual cues) and disguise (i.e. delaying the onset of an informative cue) are important techniques used by skilled bowlers to minimise batters ability to anticipate the delivery and increase the chances of inducing a mistake from batters (Brault et al., 2010; Jackson et al., 2006). In cricket, bowlers often achieve this outcome by hiding the ball, or disguising the type of delivery (in or away swing, slower ball, etc.) that they are preparing to bowl. Therefore, in order to anticipate the type of ball delivered by the bowler, cricket batters need to extract information from the bowling hand/ball. The ball/hand is considered a vital visual cue for batters as it provides information about the type of deliver the bowler will bowl. How the bowler grips the ball, as well as the position of the seam, dictates the amount and type of movement that is produced and the type of ball that will be bowled (McRobert et al., 2009). The findings from this programme of research are pretty conclusive; batters (both elite and amateur) gain valuable information pre-delivery by fixating upon the ball while in the bowler's hand during the run up.

7.4.3 Head

The second most fixated upon location across the three studies of this programme of research was the head of the bowler running in to bowl. Previous laboratory-based research has suggested that skilled batters will fixate more on the head/shoulders compared to less-skilled batters when viewing fast bowling (McRobert et al., 2009). The results from this programme of research suggest that amateur batters as well as elite batters fixate upon the head for a substantial proportion of the run up. The reason the batters fixate upon the head is not currently known. Indeed, it seems to be much less of an obvious location to view compared to the ball/bowling hand. What valuable information about the upcoming delivery could batters possibly get from viewing the head of the batters? This poses a question for future research studies. Spatial occlusions studies could explore whether the presence of the bowler's head is necessary to predict the line and length of the ball being bowled. Eye-tracking methodologies could be created, and batters could be asked if they know why they fixated upon different locations.

While it is not known why batters fixate upon the head of the bowler during the run up, one possible explanation is that batters employ the strategy to keep their vision on a central location for a large percentage of the pre-delivery and use their peripheral vision to attend to other nearby locations. The visual system allows individuals to reposition attention within their visual field without moving their central vision (Jonides, 1981; Abernethy, 1988b, Williams et al., 2000). In other words, it is possible to look at one location but attend and extract information from the periphery. In the literature, two terms have been created (and used almost interchangeably) to define this strategy 'visual pivots' or 'gaze anchors'. In this instance, the batter might fixate upon the head of the bowler, but extract information from the shoulders, chest or arms of the bowler. Gaze anchors have been found in other sports such as karate, where performers fixate on a central point such as their opponent's head or chest but use information from the movements of the limbs in anticipating the direction of their opponent's attack (e.g. Williams & Elliott, 1997). Similarly, it has been argued that in time-constrained situations (e.g. 3 vs. 3 situations in an football scenario) skilled football players fixate on the ball with their foveal vision, while using peripheral vision to monitor the environment, the positions of team-mates and opponents in the periphery (Williams & Davids, 1997). While the batters in this current study clearly move their foveal vision to fixate upon key parts of the bowler during the run up (e.g. ball/bowling hand, head, non-bowling arm etc.), all batters fixated upon the head. Batters might employ this gaze anchors to keep their foveal vision in a central location and use their peripheral vision to pick up information from the bowlers.

7.4.4 Point of release

All of the batters (both elite and amateur) positioned their gaze at the point of release ahead of the ball; batters moved their gaze to a location above the bowler's right shoulder in anticipation of the ball release, before the ball reached this point when facing spin, medium-paced and fast bowling. This outcome was not only found in the naturalistic studies, but also in the laboratory when viewing video footage. This finding supports research from other sports such as tennis where players have been shown to make a predictive saccade and fixate on the anticipated contact point of a tennis serve (Singer, 1998). In baseball, Shank and Harwood (1987) suggested that batters position their gaze at the anticipated release zone of the baseball pitcher. McRobert et al. (2009) also reported that skilled cricket batters spent more time fixating on the predicted ball release area when compared to the less skilled batters.

One possible explanation for the visual strategy of the batters positioning their gaze at the point of release is that it enables batters to get their vision 'ahead' of the ball. This approach allows the ball to come into the location of their gaze. This strategy also allows the batters to make sure their vision is stationary at the point where the ball will arrive when the ball is released. Humans cannot process information while moving their vision i.e. during a saccadic eye-movement, a term known as saccadic suppression (Ditchburn 1973; Festinger 1971; Massaro 1975). Therefore, in order to process information during the vital ball release phase, a saccade cannot be taking place. It is hypothesised that the early saccade to the point of release allows the batters to make sure their vision is stationary, and that saccadic suppression does not occur at the vital point when the ball is released. It seems crucial that batters have their eye fixated upon the point of release before the ball arrives.

7.4.5 Non-relevant locations

One surprising discovery from this programme of research, specifically findings from study two and three, is the large period of time amateur batters fixate upon non-relevant cues and locations. Non-relevant fixations were defined as fixations made to locations away from the bowler (or their immediate vicinity), ball or the playing surface. Typical non-relevant locations observed during experiments' two and three included fixations towards the stumps at the bowler's end, cars and other vehicles entering the ground, the clubhouse, items left of the floor outside of the net (e.g., kits bags, other people's kit, cricket balls), teammates training the other side of the cricket field, fire exits, and advertising hoardings around the ground and the indoor training facility. Amateur batters could not have gained any meaningful information from these locations and as such these findings are somewhat surprising. Logic would suggest that fixating on areas that are not directly related to the task in hand would likely have a negative impact on performance. When compared to the elite batters in study three and the semi-elite batters in study one, it became apparent that this was only behaviour exhibited by the amateur batters. The elite batters in study three spent very little time, if any, fixating on these non-relevant locations, while in the laboratory-based study semi-elite batters did not fixate upon non-relevant locations.

How elite and amateur batters control their eye movements seems to be one of the differencing factors between the two populations. The findings from this programme of research suggest that elite batters may have more control of their attention, or employ mainly top-down, endogenous attentional control. Top-down attention is controlled by our memories, experiences and knowledge of certain situations rather than sensory information in the environment (Corbetta & Shulman, 2002). Top-down processing originates from the higher cortical areas and is linked to awareness, insight, and understanding. On the other hand, you could argue that amateur batters' visual attention is to some extent controlled via bottom-up or exogenous attention. Attention can be drawn exogenously, by a salient external stimulus, which automatically grabs the attention of the athletes and re-directs it to a new location. Exogenous attention is rapid, and often only maintains attention for a brief time (Posner et al., 1980). The elite and semi-elite players within this programme of research may have learnt to ignore the bottom-up stimuli and maintain top-down focus, however the amateur batters may not have mastered this skill.

To further understand why this might occur, it is worth considering theories of attention. In sport, Norman's (1968, 1969) pertinence model is probably the most popular fixed-capacity theory of attention. The model implies that a performer builds up a vast store of experience through learning, which is used to interpret events encountered in the environment similar to those previously experienced (Williams & Davids, 1998). The representations that are deemed the most pertinent inputs are then selected for further analysis and specific attention (Williams et al., 2000). Norman argues that experience is, therefore, crucially important if an individual wants to contextualise their environment. In sports such as cricket, by gathering extensive task-specific knowledge and experience, the elite players are able to identify the important information within their visual display. The elite players would have the ability to focus attention on the relevant and pertinent cues and ignore the irrelevant sources of information. This would explain why amateur batters fixated upon non-relevant locations, whereas the elite batters were able to focus on more relevant locations which would provide key information about the task at hand.

Flexible capacity theorists of attention argue that the fixed capacity models, such as Norman's pertinence model, are too rigid and inflexible to successfully describe how we control our attentional resources. Instead, these critics propose that rather than having a ridged fixed attentional capacity, this capacity can change according to the nature of the task (Kahneman, 1973). One example of a flexible capacity model is Kahneman's (1973) flexible model of attention. Kahneman believes that one of the first components to impact upon the allocation of attention is arousal. In this way, Kahneman's model is an extension of the simplified cue utilisation theory (Easterbrook, 1959). Easterbrook suggests that arousal is the only thing that moderates focus and attention. Under low arousal, an athlete's attention is too broad thus focusing on both relevant and irrelevant cues. As arousal levels increase, attention narrows and the irrelevant cues are blocked out. If this theory is to be believed then the root cause for the differences in gaze behaviour and attentional focus of the batters within this programme of research would be their arousal levels. For this viewpoint, it could be argued that the arousal levels of the amateur participants were not as high as that of the elite level batters hence their attention was broader thus allowing them to attend to the non-relevant locations. This theory might also suggest that the elite batters train with more intensity and purpose, inducing higher levels of arousal compared to amateur batters. To determine whether arousal levels are the reason for the broader attention of the amateur batter, future research could highlight whether the finding that amateur batters fixate upon non-relevant locations are replicated in real match situations or just in practice environments. If these outcomes are replicated in matches, then this highlights a significant flaw in the amateur batters' visual strategies, one that is likely to impact performance. If the amateur batters only fixate on non-relevant information during training, then this suggests there is an error in their training approaches - potentially that the environment is not realistic enough or that the participants levels of arousal are significantly different than a match day.

In Kahneman's (1973) model, the allocation of attention is also determined by two other factors; momentary intention and enduring dispositions. Enduring dispositions are the allocation of our attention to novel signals, or to objects that might move or suddenly present themselves (e.g., a call from a teammate, movement behind or next to the bowler or a photographer's flash). It might be that the elite batters within the experiments were less likely to be distracted by these enduring dispositions when compared to the novices because their arousal levels were higher, or that they have developed strategies to reduce the impact of these suddenly occurring events. While this might be the case, the vast majority of non-relevant locations within the studies in this programme of research were stationary and ever present. The researcher went to great lengths to reduce the amount of potential distractions within the field of view of the batters. Momentary intentions, on the other hand, are instructions given to the athlete such as ‘watch the ball’. These instructions have previously been referred to as developing a performer’s mindset (Williams et al., 2000) and it is believed that through experience and coaching, players can develop mindsets to be alert and attend to certain important cues in the environment. Clearly, this is very similar to what Norman (1968, 1969) termed pertinence factors. That is, athletes are able to allocate visual attention to the important cues and ignore the irrelevant locations through experience and training.

The above theories offer a number of plausible explanations for why amateur batters fixate on non-relevant locations whereas elite batters do not. However, whatever the reason, by fixating on the non-relevant locations, the amateur batters removed the opportunity to acquire valuable information about the speed, direction and type of delivery the bowler is about to deliver. This is highly likely to reduce their ability to anticipate the delivery that is about to be bowled, which in turn will lead to a reduction in successful decision-making and shot execution. This clearly highlights a defect in the gaze behaviour of the amateur batters within this experiment when compared to the elite batters. Reducing or removing the amount of non-relevant locations attended to therefore seems like a logical solution and good advice for batters, coaches and practitioners. Using eye-tracking technology in the applied world would give coaches and practitioners the tools to easily highlight whether their players attend to these non-relevant locations. If they do, then highlighting this problematic strategy might be the first step of a visual training intervention.

7.5 Key findings relating to the differences in pre-delivery gaze behaviour when facing spin, medium-paced and fast bowling.

When assessing the pre-delivery results from the three studies, it becomes clear that there was very little difference between the elite batters’ gaze behaviour when viewing spin, medium-paced or fast bowling. Indeed, in the laboratory-based study, the eye movements for spin compared to fast pace bowling were remarkably similar, with only minor variations noted in gaze behaviour when viewing the medium-paced bowler. In studies two and three, no statistically significant differences were found in the amount of time the batters spent fixating on the ball, upper body, lower body, the point of release or non-relevant locations across the two condition of spin and medium-pace. On the whole, however, the data from each of the studies suggests that the participants across the three studies did not fixate upon different location prior to the release of the ball as a result of the type of bowling they were facing.

The finding that there were no statistically significant differences in gaze behaviour when viewing spin compared to medium-paced bowling contradicts previous research within the field (McRobert et al., 2009). McRobert and colleagues reported that batters altered their visual search strategies as a function of observing fast and spin bowlers. McRobert and colleagues argued that when viewing spin bowling, batters would use longer fixations and spend more time extracting information from the ball-hand location compared to fast bowlers. In comparison, when viewing fast bowling McRobert and colleagues suggest that batters would spend more time fixating on the on the ball-hand and central body locations. The findings from the current programme of research contradict this and suggest that participants tended to fixate upon very similar locations in order to gather the important pre-delivery information when facing spin and medium-paced bowlers. This suggests that the same body locations were considered important and demanded the attention of the participant regardless of the bowling style.

When examining the individual participants' gaze behaviour when facing spin compared to medium-paced bowling very few differences were noted. However, in study three it became clear that the elite batters had more consistent gaze behaviour compared to the amateur batters. While the changes in fixation locations for the amateur batters was minor, the elite batters employed more consistent gaze behaviour when facing spin and medium-paced bowling. This finding is consistent with eye-tracking research from other sports, which has demonstrated that experts have the ability to employ perceptual resources more efficiently and consistently than amateur players, including: ball catching (Emes et al., 1994); basketball (Vickers, 1996); ice hockey (Vickers et al., 1988); pistol shooting (Ripoll et al.,1985); rock climbing (Dupuy & Ripoll, 1989); table tennis (Ripoll, 1989; Ripoll, Fleurance & Cazeneuve, 1987) and tennis (Williams et al., 1998);

7.6 Key findings relating to the differences in ball flight gaze behaviour when facing spin vs. medium and fast pace bowling.

When assessing the ball flight data, it became apparent that consistently across the three studies batters tracked the ball for a longer percentage of the ball flight when facing spin compared to medium-paced or fast bowling. They also tracked a significantly higher percentage of ball flight prior to making a predictive saccade to the bounce location. Previous eye-tracking cricket research, for example Land and McLeod (2000), reported that cricket batters facing what they described as medium-paced deliveries (90km/h or 25 m/s, similar to the velocities used in the current study to represent the spin bowler) typically pursuit tracked the ball for between 50% and 80% of ball flight before making a predictive saccade to the bounce location. Croft et al. (2010) reported similar results when facing speeds of between 61.2–90km/h or 17–25 m/s (again, similar speeds to spin bowling in the current experiment), with typical durations of pursuit tracking prior to a saccade between 63% and 71%. The findings in this from study one are in line with the previous research of Land and McLeod and Croft et al. (2000) as participants' tracked the ball on average for 62.8% of the ball flight before making a predictive saccade. However, when you assess the results from the real-world studies (study two and three) the percentages of ball flight tracked prior to a predictive saccade being made increases (see table 7.1). The work by Croft and colleagues (2010) also suggests that a change in ball velocity does not directly alter the gaze behaviour of the batters during ball flight. The results from the three studies within this this programme of research suggest otherwise. The results highlight that when the bowling speed is slower, batters both elite and amateur, track the ball for a longer period.

Table 7.1. Percentages of pre-bounce ball flight tracked for each of the three studies.

Thesis Study	Percentage of pre-bounce ball flight tracked before a predictive saccade was made.
Study One	Spin: *M*= 62.8, *SD*= 14.2, Medium-paced: *M*= 59.2, *SD*= 8.8, Fast: *M*= 45.3, *SD*= 8.2.
Study Two	Spin: *M*= 86, *SD*= 7.7, Medium-paced: *M*= 71.9, *SD*= 15.9.
Study Three	Amateur- Spin: *M*= 86.8, *SD*= 4.0, Medium-paced: *M*= 81.8, *SD*= 9.3. Elite- Spin: *M*= 88, *SD*= 7.3, Medium-paced: *M*= 83, *SD*= 10.6

One possible explanation for why Croft et al. (2010) reported no differences in methods to track the ball flight between as the bowling velocities changed might be the small variance of ball speed used within their study (61.2–90km/h or 17–25 m/s). Another possible explanation might be that Croft et al. (2010) randomised the ball speed between trials. This left the batters with little knowledge about what the speed would be for the next delivery. The use of bowling machines in Croft et al. (2010) study meant that the batter would gain no pre-delivery information prior to the release of the ball to help predict the type, speed direction of the ball that was about to be delivered. Yet, in a real-world setting, it is extremely likely that the batter would gain some crucial information about the type of ball and speed of delivery. Even the length of bowler run up would provide some basic information about the predicted speed and type of bowl they will face. The use of a bowling machine meant that the participants would not receive any advanced cues from the body or run up of the bowler. Trying to predict the ball speed of a random ball which is fired out of a bowling machine is an impossible task, therefore batters may have needed to employ the same tracking strategy for all of the deliveries that faced. As this research has highlighted, when these advance cues are available from the bowler's run up, batters alter the visual strategies and track the ball for longer when facing slower bowling compared to higher velocity deliveries.

Pinder et al. (2009) suggest that batting against a bowling machine is not the best practice method, as bowling machines are not representative of the tasks batters encounter in real competition. Batting against a bowling machine is vastly different to batting against a human bowler (Bartlett, 2003), as using bowling machines completely disregards the pre-delivery information that is available to the batters in a naturalistic environment. Indeed, Pinder et al. (2009) found that batting against a bowling machine is extremely different to batting against a human bowler. While batting against a medium–fast bowling machine compared to a bowler of the same speed, batters produced significant adaptations to their movement, timing and coordination (Pinder et al., 2009). The previous research highlights that the use of bowling machines can alter the movement patterns of a batter. The results from this programme of research suggest that the use of bowling machine can also alter the visual strategies employed by batters. A bowling machine points at a certain location and allows for accurate, predictable and stable projection of balls (Renshaw et al., 2007). When batters face a bowling machine, it is therefore extremely obvious where the ball is likely to bounce. Due to the predictability of the bowling machines used in the studies by previous eye-tracking researchers, it is questionable as to whether the ball tracking employed by the participants is representative of real-world tasks. The question of whether these batters would produce the same gaze behaviour when facing human bowlers is very valid. If the batters know where the ball will bounce (as they do when facing a bowling machine), but they are not sure what speed the ball will be travelling, surely, they will move their vision to the predicted bounce location early? The data presented in this programme of research highlights that batters still make a predictive saccade to the location of the ball bounce, however when facing a human bowler, this saccade is made after pursuit tracking a larger percentage of the pre-bounce ball flight. When presented with advance information, it seems batters changed their strategies and method for tracking the ball. In real world situations, batters typically pursuit track the ball for longer periods of ball flight when the ball velocity is slower and for a shorter percentage of ball flight when facing a fast bowler.

7.7. Differences in gaze behaviour between elite and amateur batters

The pre-delivery results highlighted that there were a number of key differences in the gaze behaviour prior to the release of the ball between elite and amateur batters. As discussed above, one of the main differences between the demographics was the amount of time that amateur batters compared to elite batters fixated upon non-relevant locations. This substantial difference was found when facing both spin and medium-paced bowling and should be considered a key finding from this research. Another significant difference highlights that elite batters fixated upon the upper body for a longer duration compare to amateur batters when facing both spin and medium-paced bowling. Specifically, elite batters fixated upon the non-bowling arm significantly longer compared to amateur batters. This finding highlights a potentially crucial source of information that amateur batters seem unaware of and as a result, do not fixate upon. This information could provide these batters with vital cues regarding the landing location of the ball. The non-bowling arm may provide vital information about the velocity of the next delivery. Anecdotally, coaches and bowlers will tell you how important the front arm is for generating pace. For example, Brett Lee, one of the fastest Australian bowlers of all-time, states "I'm a lot more explosive at the point of delivery and get a lot more pace by pulling down with my front (non-bowling) arm" (Mitchell, 2002). When current England international fast bowler Chris Woakes discussed his bowling action, he stressed the importance of using the front arm (non-bowling arm) and explains how this helps him generate pace:

> I learned that if I used my front arm more it would increase my pace. People say you need to get your front arm high, but it's more important what you do with that front arm. What I worked on was to get my elbow up as high as I could, and once it got to that point, letting the elbow pull down the left side of my body as sharply as possible, acting like a lever to pull the body through the action. It works almost like a delayed reaction – you want the elbow to come down before the bowling arm comes over, working like a slingshot. Only then do you get that snap (Wisden, 2015).

Biomechanical research has also highlighted the importance of the non-bowling arm. According to Bartlett et al. (1996), the front arm (non-bowling arm), is essential to a smooth and effective bowling action and crucial for the generation of bowling speed. It is understood that the extension and adduction of the non-bowling arm has a large impact on the bowling velocity by aiding lateral flexion and hyperextension in the coil (bowling) position (Burden, 1990; Davis & Blanksy, 1976). Indeed, the non-bowling arm is said to be so important in generating velocity that Salter et al. (2007) suggest that the vertical velocity of the non-bowling arm along with the bowler's centre of mass velocity at back foot contact, maximum angular velocity of bowling humorous, and stride length equates for 87.5% of the bowler's variation in release speed. Professional batters may therefore 'pick up on' more information about the speed of the upcoming delivery compared to the amateur batters by viewing the non-bowling arm. They might be able to use the information gathered from the non-bowling arm to predict not only when the ball will arrive, but also whether the bowler had planned to deceive the batter by bowling a slower ball or changing the bowling velocity.

The results from the final study within this programme of research suggest that the elite batters in the study track the ball for a greater percentage of the ball flight when compared to amateur batters. This finding is in agreement with previous research by Land and McLeod (2000), who reported that the best (professional) batter in their study showed more pursuit tracking than both of the amateur batters (a talented amateur and novice amateur). Conclusions can therefore be drawn suggesting that the longer you 'watch the ball', (i.e., the longer you are able to track the ball during its flight), the higher chance you will have to successfully predict the landing location and intercept the ball. While it doesn't seem possible to track the whole of the ball flight as traditional coaching advice might suggest, tracking a higher percentage of the ball flight is a trait that elite batters have when compared to amateurs.

7.8 Decision-making and gaze behaviour

Decision-making plays a vital role in successful sporting performance and can be the difference between success and failure. Within cricket, batters are required to process information and make decisions about how to respond in periods of time that push the limits of human performance (Cotterill & Discombe, 2016). Therefore, successful batting performance can be attributed to the effectiveness of a batter's decision-making. It has been suggested that skilled athletes' superior anticipation and decision-making performance is underpinned by visual behaviours (Campbell & Moran, 2014, Williams et al., 1994; Roca et al., 2018). These visual behaviours involve more efficient search strategy which enables more time to be spent analysing the task relevant stimuli and gaining crucial information rather than producing saccadic eye-movements to search the visual scene (Williams et al., 2000). It is also assumed that successful decision-makers used more goal-oriented or goal-directed visual search strategies and fixate their gaze on key elements for longer, which results in superior decision making performance, faster decision response times and superior response accuracy (Vaeyens et al., 2007; Moreno et al., 2002, Piras, 2009, 2010; Lee, 2010, Hancock & Ste-Marie, 2013). While batting in cricket, decision making is of the upmost importance (Cotterill, 2014). For every delivery, the batter needs to make an effective decision regarding the velocity and location of the ball and the appropriate response. Due to the nature of cricket batting, where one mistake or poor decision can cost the batter their wicket and have a significant impact on the game, poor decisions from batters are uncommon. This is especially true for talented batters. According to Vickers (2007), vision-in-action studies should continue until the participant performs an equal numbers of success vs. unsuccessful trials. However, due to the nature of the game, this even split between correct and incorrect decision making is extremely unlikely when collecting data with cricket batters. The lack of incorrect decisions compared to correct decisions meant that the data could only be assessed at a group level. Batters did not produce enough incorrect decisions to analyse the data at an individual level (see tables, 5.6 and 6.6).

Due to the important role that eye-movements play in the decision-making process, it was hypothesised at the start of this programme of research that both the elite and amateur batters would display different eye-movements when they make a correct decision compared to an incorrect decision. In study two, this hypothesis was rejected as the results showed that there was no difference in the amateur batters' gaze behaviour pre-delivery or the method used to track the delivery during the ball flight when they made correct compared to incorrect decisions. Most of the findings from study two were replicated in the final study of the thesis. Amateur and elite batters did not change their pre-delivery gaze behaviour when they made a correct decision compared to an incorrect decision. This outcome was found when facing both spin and medium-paced bowling. When facing spin bowling there was no significant difference in the method that amateur or elite batters used to track the delivery when they made a correct compared to incorrect decision. However, when facing medium-paced bowling significant differences were found in the methods used to track the ball during the ball flight for both the elite and amateur batters. Amateur and elite batters failed to track a significantly higher percentage of the ball flight when they made incorrect decisions compared to correct decision-making. For the professional batters, there was a significant difference in the total percentage of ball flight tracked for correct (*M*= 74.6) compared to incorrect decision-making (*M*= 63.7) and a significant difference in the percentage of pre-bounce ball flight tracked for correct (*M*= 86.1) compared to incorrect decision-making (*M*= 77.9). This again adds support to the claims that the longer you can track the ball during the ball flight, the more chance you have to successfully intercept the ball and execute the shot. These findings also highlight that the eye-movements and the visual behaviour of the elite athletes when facing medium-paced bowling has an impact on their decision-making ability. If batters change their method of tracking the ball, and if batters 'take their eyes' off the ball for longer periods, they increase the chances of making an incorrect decision with regards to shot selection.

7.9 Methodological and eye-tracking implications: laboratory vs. naturalistic studies

While numerous studies have investigated the vision of sportsmen, few have conducted the research in 'real-world' environments. Instead, the majority of these studies have used video footage on a computer screen or projected the footage onto a laboratory wall (e.g., McRobert et al., 2009). While these studies have increased and advanced our knowledge within the fields of anticipation, decision-making and visual-search, viewing of pictures or video footage presented on a display still represents a somewhat artificial task (Duchowski, 2002). As such, there are still questions relating to the reliability of these findings. There are obvious benefits to the use of video-based methodologies. Video displays offer the researcher complete control over a broad range of variables and trials to be completed within the experiment. It also presents a more eye-tracking-friendly environment, as the researcher can carefully restrict or monitor the movements of the participants. However, while increasing control and providing methodological convenience, video displays are limited when one is seeking to accurately simulate and represent ballistic movement in the natural environment. The two-dimensional nature of the stimulus presented may not adequately represent the dynamic nature of sport (Abernethy, Burgess-Limerick, & Parks, 1994). When presenting video footage, some information is inevitably diminished or lost through the recordings (even with modern high definition footage) and the 2D format inhibits the ability for participants to utilise three-dimensional information which can be crucial in aiding depth perception (Mann, Abernethy, & Farrow, 2010).

Another valid criticism of the use of video-based methodologies is that these studies dissociated perception and action, numerous methodological designs have utilised simple verbal or written responses. A number of studies have attempted to overcome this issue by incorporating simplified movements in their testing paradigms (e.g., Savelsbergh et al., 2002; Williams et al., 1995; McRobert et al., 2009). However, these simplified movements typically fail to afford the participant the opportunity to actually intercept the moving object (Mann et al., 2010). The majority of these simplified movement tasks require the participant to make a shadow or fake response to simulate intercepting a moving object. However, as Króliczak et al. (2006) suggest, this shadow or fake movement may not be sufficient to activate the 'vision-for-action' pathway. Further fMRI evidence from Króliczak et al. (2007) demonstrated that a real interceptive actions are mediated by different neural processes when compared to shadowed or fake movement responses. This finding shows that a shadowed interceptive action will not necessarily activate the same areas of the brain which is typically activated by a real interceptive action (Mann et al., 2010). The results from the above research suggest that simplified responses that are do not allow participant to actually intercept the traveling object, actual fall short of testing the dorsal (vision-for-action) visual pathway. As such, a vast amount of the research in the field is likely to misrepresent the true ability of skilled performers (Mann et al., 2010).

While there are some theoretical issues with presenting video footage for eye-tracking research, there is a distinct lack of research exploring the differences in eye-movements when participants perform in the real world compared to when they view video footage. When examining the results from the three studies within this programme of research, some clear differences emerge between the laboratory-based study and the two real-world studies. The majority of these differences can be found in the method used to track the ball during the flight. In study one, when watching video footage of bowlers, batters tracked a shorter percentage of ball flight than the participants within study two and three. The differences in ball flight information between study one, two and three might be due to the 2D format of the video which, as suggested by previous authors, could have inhibited the participants' ability to utilise three-dimensional information and perceive the depth of the ball travelling towards them (Mann et al., 2010). These findings suggest that the use of a video-based methodological design might not be the most appropriate for eye-tracking studies when looking to explore how participants view travelling objects, especially if that object is moving towards or away from the participant. When, however, you compare the pre-delivery search strategies of the participants from study one, two, and three, the findings are remarkably similar. These findings suggest that there may not be a big difference in gaze behaviour of batters when viewing video footage compared to facing a real bowler. This provides some support for the use of video-based experiments when the goal is to understand the gaze behaviour of athletes.

There are obvious pros and cons for both mobile and desk-mounted eye-tracking. When using the desk-mounted eye-trackers, you can be confident that the environment is conducive to eye-tracking, the participant is seated and comfortable and will not move throughout the experiment, therefore no disruptions in calibration will occur. The desk mounted calibration process is very accurate (usually offering a 9-point calibration) and the data collected is extremely detailed. Conversely, the mobile eye-trackers are often more difficult to set up, the participants are constantly moving which risks calibration slips, and numerous external factors (sunlight, calibration slips, sweat, eye-lashes, glasses, equipment) can interfere with the quality of the data collected. The mobile eye-trackers, however, have the distinct advantage of providing greater ecological validity through context specific field-based research (Discombe & Cotterill, 2015). There are obviously situations when it is not possible to use one of these systems. There are certain sports which lend themselves to real world eye-tracking and other sports that do not. For example, you could not put a mobile eye-tracker on a rugby player and ask them to tackle an opponent. The controlled nature of the laboratory may be the only option for certain research questions. If the research question is exploring gaze behaviour of an athlete and does not involve tracking an object where depth perception might be crucial, desk mounted laboratory methodologies might be appropriate. Having said that, eye-tracking technology has advanced greatly over the past 20 years with cheaper, faster, more accurate systems now readily available. Therefore, if possible, the best, most ecologically valid, method would be to use head mounted systems and track the vision of athletes in the real world. Future research should consider comparing visual characteristics of athletes across numerous tasks, including those in the laboratory compared to those in the actual sport setting (Mann et al., 2007). The following section highlights the steps put in place during this programme of research to increase the ecological validity and task representative design.

7.10 Ecological validity and representative design

In a perfect world, this research would have progressed from the laboratory setting to real world cricket matches. Ideally, the participants within studies two and three would have worn eye tracking glasses in a real competitive cricket match, in a real cricket stadium, in front of fans, with the potential for all the associated psychological challenges that go hand-in-hand with competitive sport. However, for numerous logistical and technological reasons, this level of ecological validity and representative design was not possible. The main reason why it was not possible to collect real match eye tracking data is the limited technology. Mobile eye trackers require regular calibration checks with recalibration required after large body movements. The eye trackers also have a limited wireless internet range (needed to live monitor calibration), meaning that the researcher would need to be relatively close to the glasses in order to monitor calibration. This would not be possible in a real match scenario. Another reason why collecting data during a real match is almost impossible is that participants, particularly professional players, are extremely unlikely to agree to wearing any addition unfamiliar equipment that could interfere with their performance during a competitive match. Due to the technical and logistical issues associated with eye tracking, the most appropriate way to collect data within studies two and three were therefore within a practice (net) scenario. With all research there will be a trade-off between ecological validity, representative task design and what is possible due to the constraints of the experiment. Ecological validity should be considered for each experimental design as either low or high and not either present or absent (Araujo et al., 2007). While it was not possible to collect data in a real match scenario, numerous constraints were put in place throughout the entire programme of research in order to try and increase the ecological validity of the studies.

While study one was a laboratory-based eye tracking experimental design and therefore the ecological validity of the study can be considered low, a number of steps were put in place. The first and most obvious of these was the brief read to the participant before they took part in the data collection (see section 4.2.4). The participants were also asked to respond (via a tap of the hand) with a decision regarding whether they would have attacked the ball or defended the ball following each delivery. The decision-making aspect of the task was included so the batters would view the video footage as if it was a real game scenario rather than just watching video clips of a bowler. This programme of research could have continued to collect data within a laboratory setting using mobile eye trackers and video footage of bowlers (e.g. McRobert, 2009) or could have used a bowling machine in a practice environment for increased experimental control (e.g. Croft et al., 2010; Land & McLeod, 2000; Mann et al., 2013). However, in order to reach the highest possible level of ecological validity, studies two and three took place during a real cricket net (practice) environment, while the participants faced real bowlers of a similar standard to themselves. The participants performed in their regular training environment, wore their own cricket equipment, batted (performed) in accordance to their own style and tactics, and were read a brief before data collection occurred. Critically, to increase the representative task design within studies two and three, the experimental design allowed for the actual movements of the batsmen to occur, i.e. for the batsmen to intercept the ball and make bat-to-ball contact. The ecological validity and task representation within eye tracking studies is always a challenge, specifically with the current technology. Should mobile eye tracking technology advance in future, then collecting in a real match scenario would be the perfect scenario and the most ecologically valid experimental design. Having said that, through careful experimental design and numerous pilot studies, the researcher believes that studies two and three should be considered to have a high level of ecological validity, particularly in comparison to previous eye-tracking studies.

7.11 Methodological and eye-tracking implications: sport specific eye-tracking calibration

There are numerous factors that can influence the data collection and data quality when using eye-tracking equipment. The first and most obvious of these is camera set up. The hardware setup significantly influences data quality and the rate of data loss; it is vitally important for eye-tracking research that the time is taken to make sure that the eye tracker is correctly fitted to the participant. The second factor which dictated data quality is calibration. It is important that each participant goes through calibration and validation for numerous reasons (e.g., differences in eye size, eye position, seating position, variation between glasses etc.), all of which will have an effect on the quality of data recorded (Holmqvist et al., 2011). To obtain the gaze direction in space, all available eye-trackers currently need to be calibrated (Kredel, Veter, Klosterman & Hossner, 2017). If this is not done accurately then the likelihood of collecting any usable data is extremely low.

A lesson learnt the hard way through this programme of research was the challenge of calibrating an eye-tracker for use within a real cricket environment. Numerous pilot tests were administered before a calibration process was established which, provided high quality eye-tracking data. The researcher started these pilots test by following the manufacturer's guidelines for calibration, which consisted of the following: *Select one or three point. Select a target point in the field of view and ask the participant to focus on this point. This point should, ideally, be at a distance of about 1.5m between the participant and the calibration object. Your participant should sit or stand comfortably while looking straight ahead without moving the head. The object should be at the middle of the scene camera image for optimal accuracy. Tap on the screen to pause at the last estimated gaze* *point. Then a position marker can be dragged over the screen to the desired position. Releasing the finger accepts the point. A check mark on the corresponding Calibration button indicates whether a calibration has been performed. Click Accept to continue or Cancel to perform the calibration again. The gaze calibration can now be validated by looking at the live preview.* While this calibration works well for general day-to-day tasks and seemed to be tracking the participants' gaze accurately, when the batter moved to a distance of 22 yards away (the length of a cricket wicket) the calibration was not accurate enough to pinpoint exactly where the participant was looking. Through trial and error and numerous conversations with the manufacturer (SMI), a calibration design was created. This consisted of the following steps.

1. While already in the net (where they would bat), the eye-tracker was attached to the participant so they felt comfortable wearing the system. The quality of the tracking was checked and the researcher made sure that glasses were tracking the pupil accurately. If needed at this stage, different nosepieces were changed and the positioning of the glasses was altered so that the glasses sat correctly on the batter's face.
2. The participant then put on the rest of their equipment, including batting gloves and cricket helmet. Through two pilot studies, it became apparent that there was one brand of helmet, Masuri helmets, which were much easier to fit over the glasses. Therefore, the researcher took three sizes of Masuri helmets (small, medium and large) when collecting data. The large majority of the participants had, and therefore used, their own Masuri helmet.
3. After the participant had their helmet on, the setup of the eye tracker was then re-checked to make sure the camera was still accurately tracking the pupil. The eye-tracker was secured as tightly as possible and the researcher made sure that the helmet and the helmet straps were not in contact with the eye-tracker.
4. The three-stage calibration process was then administered to the participants, while they were wearing all their equipment, holding their bat, and standing side on in their regular batting stance.
5. The calibration took place at 22 yards where the bowler would subsequently release the ball. Three bright yellow tennis balls were placed at three different heights on top of camera light stands and used as the target points for the calibration.

6. When calibration was complete, it was checked in the live view preview by asking the batter to look at different parts of their visual scene.
7. The recording device was then carefully placed in the waist belt by the researcher, where it was stored throughout the experiment collecting the data.
8. Calibration was monitored throughout the experiment via a remote wireless connection to an Acer laptop. If at any point the calibration slipped, the calibration process was restarted. Calibration was checked every two balls by asking the batter to look at different points of their visual scenes.

One of the key lessons learned regarding the calibration of the SMI mobile eye-trackers is that sport specific calibration should be regarded as best practice. This is something that is not in the instruction manual and something that is rarely mentioned by many researchers or academics. Indeed, one of the selling points or advertised benefits of these newer mobile eye-trackers is how easy they are to calibrate, with some manufacturers advertising that their systems are extremely accurate and do not require calibration. However, when the researcher employed a sport specific calibration, the quality and accuracy of the data dramatically improved. Subsequently, the researcher has found that sport specific calibration is also important in other sports including golf, darts and tennis. Key recommendations from this programme of research is that researchers should always calibrate at the targeted recording distance (e.g., 22 yards for cricket or 7 feet 9.25 inches for darts etc.). Calibration should also take place with the participant standing or sitting in their regular stance. For this programme of research, batters typically stood side on to the bowler with their head looking over their left shoulder (for right handed batters). Following these guidelines can significantly improve accuracy of eye-trackers.

7.12 Future research

More research is needed to explore the validity and reliability of using video-based eye-tracking methodologies within cricket. The results from this programme of research suggest that batters do not track a ball travelling towards them in the same way when viewing a video compared to in the real world. However, the results also suggest that the fixation locations attended to before the ball was released were very similar when viewing the video compared to the real world. More research is needed to determine whether presenting video footage for eye-tracking studies is a valid methodology. This research should use a repeated measure design with the same participants facing video footage of a bowler and having their vision tracked via a desk or remote eye tracker, and then facing that same bowler in a real net situation while wearing a mobile eye tracker.

Future research studies also need to determine whether batters facing modern bowling machines, which project and incorporate video displays of bowlers as the approach the crease, produce the same eye-movements as when facing bowlers in the real world. These new bowling machine systems claim to increase the ecological validity of the training method by recreating a naturalistic environment. It is believed that this will improve timing and movement and help batters develop decision-making abilities. The most established of these systems is ProBatter. ProBatter is a state-of-the-art-bowling machine which projects life size video footage of a bowler as they run into bowl. The ball then subsequently appears and is delivered from a hole in the screen to coincide with the bowler's ball release. The designers of ProBatter argue "the life-like simulator allows batters to experience game-like conditions resulting in improved timing, rhythm and realistic match performances" (ProBatter Sports, 2011, "Cricket", para. 1.). Indeed, the manufacturers and users (e.g., international cricket teams) have amassed a wide range of video footage of different bowlers around the world and international batters now have the ability to view almost any international bowler. However, while this seems like an improvement over generic bowling machines, ProBatter, has yet to be scientifically tested and explored. There are still a large number of questions about the benefit that ProBatter offers over conventional bowling machines. For example, just like traditional bowling machines, ProBatter has a fixed release point. When facing ProBatter, the batters know that the ball will be fired out of the hole behind the screen where the bowling machine is positioned. When facing a traditional bowling machine, logically batters fixate their gaze upon this hole where the ball will be delivered from (Croft et al., 2010; Land & McLeod, 2000). It is unknown whether, when facing ProBatter, batters will position gaze the hole of the bowling machine or attend to the pre-delivery information presented in the video. If batters do attend to the video presentation of the bowler running in, is this gaze behaviour the same as when they face the bowler in a naturalistic environment? Future research should track the vision of batters when they face a video of a bowler presented via ProBatter and then face the same bowler in a real-world situation. If these gaze behaviours of the batters change between condition, then this challenges the validity of the ProBatter system. If the gaze behaviour of the batters is different, then this might inhibit the perception-action coupling and the ability of the batter to develop anticipation and decision-making abilities. Indeed, if the gaze behaviour does change then you could argue that this machine is harmful for batting performance. Portus and Farrow argued back in 2011 that a systematic series of research investigating the decision-making of batters, shot execution (kinematics and kinetics), and gaze tracking are required to detail ProBatter's viability as a significant improvement to more traditional ball machines. These questions remained unanswered.

Another important aspect that has often been overlooked in both eye-tracking and decision-making research in sport is that athletes routinely compete and make decisions while performing under various mental and physical stressors (Helper, 2015). Previous research has been inconclusive as to whether these stressors improve decision-making (e.g., Royal et al., 2006) or inhibit decision-making (e.g., Bar-Eli & Tractinsky, 2000; Kinrade, Jackson & Ashford, 2015). However, what has been demonstrated is that factors such as stress, arousal, anxiety and pressure have the potential to impact decision-making and the attentional control of athletes. A few common explanations for the disruption in performance and decision-making when athlete experience stress have routinely been suggested. Of these, perhaps the most popular and well-documented include: attentional narrowing, distraction (or hypervigilance) by irrelevant or threatening cues, reinvestment of cognitions to automatic skill, and inefficient attentional allocation (Janelle, 2002). All of these theoretical explanations suggest that when psychological or physical activation occurs, decision-making and visual attention may be disrupted. Since sport is typically performed under strict temporal constraints and athletes face a wide range of potential physiological stressors, researchers should attempt examine vision and employ eye tracking research under more realistic conditions (i.e. match situations) (Williams et al., 2000). It might be that expert novice-visual differences may become more apparent when athletes are tested under high levels of psychological and physiological stress and fatigue (Williams and Horn, 1995).

With stress, anxiety and arousal potentially impacting upon visual attention, eye-movements and decision-making, it seems important for future research to conduct decision-making and eye-tracking experiments in environments that attempt to recreate these conditions. If possible, and if advancements in eye-tracking technology allow (i.e., researchers do not need to constantly re-calibrated during data collection), the ideal environment for this is an actual match situation. This suggestion, however, seems unlikely and as such researchers should try to create testing environments that recreate a stressful situation as realistically as possible.

Occlusion studies have highlighted which areas of the body batters need to anticipate the landing location of the ball (Müller et al., 2006). Eye-tracking studies such as the three in the presented programme of research and previous research (McRobert et al., 2009) have highlighted what batters fixate on when the bowler is approaching the crease. While this information is extremely informative, these studies cannot highlight why these areas are deemed so important. Theoretical explanations have been suggested however future research should investigate via interviews if batters are consciously aware of where they look and if they know why they look in these locations. These findings can have important implications for development of visual training programmes and the advancement of decision-making training programmes.

7.13 Limitations

One of the main limitations of the studies within this programme of research is the small sample sizes and as such the results should be interpreted with caution. Given the exploratory nature of the research and the fact that it was the first of its kind in a contemporary area of research, further studies should look to incorporate a larger sample size in order to determine whether these findings can be generalised to the wider population. However, in doing so, researchers need to consider the amount of time required for frame-by-frame data analysis. For instance, participants in study one were presented with 6 video clips of each bowling condition (medium-paced, fast pace, spin bowling), with both pre-delivery and ball flight data analysed. The eye tracker recorded at 1000 frames per second, which resulted in a substantial amount of data analysis per participant. Thus, the painstaking nature of 'real world' frame-by-frame eye-tracking research (Lappi, 2015) continues to be one of the main drawbacks of the field.

Another limitation of study two and three within this programme of research is the lack of fast bowling measured. In study one, the research presented video footage of spin bowling, medium-paced bowling and fast bowling. However, this was not possible to replicate in study two or three. One obstacle to this in study two was the lack of genuinely quick bowlers available at amateur level. Genuine quick bowlers are hard to find, especially at club level and as such recruiting a bowler who was significantly faster than the medium-paced bowler proved to be a challenging task. However, perhaps the biggest drawback, specifically for study three when working with elite athletes, was the restrictions coaches place on fast bowlers. Fast bowlers have the highest injury prevalence in professional cricket (Newman, 2003; Orchard, James, & Portus, 2006), with high risk injuries being lumbar stress fractures or other lumbar injury (Newman, 2003). Research suggests (Dennis, Farhart, Goumas & Orchard, 2003) that fast bowlers who averaged more than 188 deliveries a week (31.5 overs) of have less than two days rest between bowling sessions, were significantly more likely to develop injuries, specifically lower back injuries, compared to bowlers who had more rest of bowled less frequently. As such, and due to the extremely high injury rates of fast bowlers, coaches are rightly protective of their athletes. Coaches typically monitor the workload of their bowlers closely and when approaching the elite coaches to recruit participants for study three, all ruled out allowing a fast bowler to participate. If the vision of batters is to be assessed while facing genuinely fast elite level bowlers then this research may need to be funded or conducted by an elite club or elite performance pathway.

A final limitation for the programme of research relates to the data collected for correct vs. incorrect decision making. As highlighted previously, due to the nature of the sport, the participants used within this study (i.e. experienced amateurs and elite level batters) are unlikely to make poor decisions consistently. The eye-tracking data collected is therefore heavily weighted toward successful decisions. While enough data was collected for incorrect decisions made to assess the data at group level for both the amateur and elite batters, the participants did not make enough incorrect decisions to assess the data at individual level for statistical testing. The decision-making data within this programme of research therefore needs to be interpreted cautiously and further research is needed to explore whether gaze behaviour impacts cricket batters' decision making.

7.14 Conclusion

This programme of research provides the first comprehensive eye-tracking cricket research where batters' vision is tracked during pre-release and all the way through the ball flight. The research has moved from laboratory-based setting using desk-mounted eye-trackers, with a strict control of all the variables through to a real-world batting scenario where batters wore mobile eye-trackers and faced real bowlers. The research has highlighted the key locations that batters fixate upon pre-delivery in order to predict the landing location of the ball. It also highlights how batters track the ball through the flight and it has been demonstrated that batter do not keep their 'eyes on the ball' the entire ball flight. Instead, as expected, they make a predictive saccade to get their vision ahead of the ball. Finally, the thesis has highlighted some clear differences between elite and amateur batters gaze behaviour and ball tracking.

This research has provided us with a clear understanding of how amateur and elite batters' visual systems allow them to perform the skill of batting. It also highlights some significant differences between the two populations, which might go a long way in differentiating between the skill levels. By comparing the differences between the elite and amateur batter, it is possible to begin to plan and develop strategies and advice for coaches to help amateur batters develop more efficient visual performance. Indeed, once research links visual ability with sporting performance, the next logical step is training vision to provide batters with an advantage. Clear advice and identifying visual deficiencies, i.e. fixating on non-relevant locations, might be the first steps in helping batters improve their vision and ability to anticipate and watch the ball for longer periods of the ball flight. This will be discussed at greater length in the next applied implications chapter (chapter eight).

Chapter 8.0

Implications for applied practice

The following chapter will discuss how the findings from the three studies within this programme of research, alongside previous research, could be applied in the real world. The chapter starts with a discussion of how coaches and practitioners can use the findings from this programme of research to develop video-based visual perception training programmes. The chapter continues by discussing best practice and the structure that these training sessions should take. Discussions relating to the use of modern technology, specifically virtual reality, and limiting the use of traditional coaching tools (bowling machines) are also presented. The chapter concludes by providing advice to bowlers about how they can use these findings to try and deceive batters and gain an advantage.

8.1 Guided instructions to important postural locations

The use of instructions affords coaches the opportunity to guide their athlete's attention towards information rich and important cues in any given environment (Jackson & Farrow, 2005). Traditionally, researchers and practitioners have used laboratory-based video training interventions to direct athletes attention towards information rich areas of the visual scene (Abernethy, Wood & Parks, 1999; Scott, Scott & Howe, 1998; Singer, Cauraugh, Chen, Steinberg, Frehlich, & Wang, 1994; Williams, Ward & Chapman, 2003) or via video based training sessions followed by real world practice (Brenton et al., 2019; Hopwood et al., 2011; Smeeton, Hodges, Williams & Ward, 2005; Williams, Ward, Knowles & Smeeton, 2002). Research findings typically indicate that this integrated attention-guided technique leads to significant improvements in laboratory-based anticipatory tests (Memmert, 2009). More recently, the combination of video and real-world practice also shows that these improvements in laboratory anticipation tests also transfer to real-world improvements. While the consensus is that visual perception training using video footage is beneficial, how this should be implicated has been debated. The following section will discuss best practice for video based visual training interventions before highlighting how the specific findings from the current research programme can be implemented to train cricket batters.

8.1.2 Explicit, implicit and guided discovery visual training

When it comes to developing and delivering vision and perceptual skills training programmes, there are typically two main approaches: (1) Traditional or explicit training; or (2) the less prescriptive implicit training. A large amount of research has focused on the benefits and pitfalls of each method (e.g., Abernethy et al., 1999; Brenton et al., 2019; Farrow & Abernethy, 2002; Jackson & Farrow, 2005; Masters, 1992; Raab, 2003). Traditional approaches to perception training attempt to teach the athlete the importance of certain advance cues and direct the athlete attention towards these cues. Traditional perceptual training interventions (e.g., Abernethy et al., 1999; Scott et al., 1998; Singer et al., 1994; Williams et al., 2003) have proved effective, with researchers reporting an improvement in both the speed and accuracy of decision-making. Despite the interest from researchers, psychologists and coaches, only a small body of research has explored whether improvements found following perceptual-motor training can then be transferred to real world success in sport (Hopwood et al., 2011; Brenton et al., 2019). Of these few studies, the results have highlighted promising findings suggesting that improvements in these explicit videos' decision-making tasks can transfer to the real-world sporting settings that the tasks represent (Brenton et al., 2019; Hopwood et al., 2011 Scott et al., 1998; Williams, et al., 2003). A number of cricket specific studies (e.g., Brenton et al., 2019; Hopwood et al., 2011) have shown how beneficial these perception video training programmes can be for cricket performance. For example, Brenton and colleagues (2019) argued that the anticipation and ability of batters to pick up advance cues significantly improved following a four-week visual and physical training programme. Similarly, Hopwood et al., (2011), also reported that a six-week on-field and visual training programme can lead to significant improvements in fielding performance. What both of these studies highlight is that, if combined with physical on-field practice, visual perception training for cricketers can be very effective. Indeed, Brenton et al. (2019) suggested that visual motor perception training should be incorporated and a fundamental component of regular cricket practice.

In contrast to the traditional approach of explicitly guiding attention, implicit motor learning can be defined as "the acquisition of a motor skill without the concurrent acquisition of explicit knowledge about the performance of that skill" (Maxwell, Masters, & Eves, 2000, p. 111). Implicit learners typically receive little or no instruction about the skills being developed. The learning occurs when the learner is not paying specific attention to the skill or receiving any formal instruction about how to learn. Athletes usually learn subconsciously and often cannot explain how they come to learn such skills. Because learners learn implicitly, they do not receive step-by-step instructions about how to perform a skill. As such, it has been argued that by learning implicitly athletes are less likely to experience the negative consequences of learning with instruction techniques (i.e., explicit learning), which could lead to a form of paralysis by analysis (Milazzo, Farrow & Fournier, 2016). Specifically, a number of researchers have suggested that under stressful or pressurised conditions, explicit learning has the potential to lead to reinvestment of effort toward more explicitly acquired knowledge, resulting in choking (Masters, 1992; Maxwell et al., 1999). To achieve a more implicit style of learning when using video-based perceptual training, researchers have attempted to remove the overload of specific detailed verbal instructions.

Smeeton et al. (2005) suggested that the implicit approach is more effective and beneficial when compared to traditional explicit learning. These authors tested the decision-making abilities of tennis players following a video-based perceptual training intervention. The participants were placed into three distinct categories. The first was an explicit group, whose attention was verbally instructed to important postural cues (e.g., the shoulder) and information was provided as to how changes at this location (e.g., rotation) would alter the outcome of the shot. The second group was a guided discovery group, who received similar instruction to the explicit group [i.e., their attention was directed to a specific area (e.g., shoulder, hips, trunk, racket etc.)] but participants in this group were not told how these cues were related to shot outcome. Finally, there was a discovery group; participants in this group were not given any instruction concerning the key postural cues. Participants in this group were, however, encouraged to discover important postural cues that might be used to predict the shot location prior to the ball-racquet contact. Smeeton et al. (2005) reported no significant differences in improvement demonstrated by the three training groups from pre-test to post-test. All three groups showed significant improvement in decision-making and performance in field settings compared to the control group. However, participants in the discovery group, who were not given any instructions relating to the key postural cues, took longer to demonstrate improvements in anticipation compared to the explicit and guided discovery group. This outcome highlights promising results and benefits for all three perceptual training approaches. However, when Smeeton and colleagues tested the same participants again under an anxiety-provoking condition, a significant difference was seen in performance between the groups. Participants in the explicit group took more time to make decisions compared to the guided discovery and the discovery groups. Participants’ anticipation and decision-making in the guided discovery and discovery groups was significantly more robust under anxiety-provoking conditions when participants used more implicit methods perceptual training, compared to an explicit learning approach (Smeeton et al., 2005). Similar findings were found in handball with Abernethy, Schorer, Jackson and Hagemann (2012) suggesting that an implicit approach should be used with higher skilled athletes who are frequently subjected to high-pressure situations.

Williams et al. (2002) provide further support for the guided discovery approach, suggesting that it is just as effective as the traditional explicit instruction approach to visual perception training. The authors investigated the ability of novice performers to predict the landing location of a tennis ball from a forehand and backhand shots. Participants were divided into two distinct groups: an explicit group, and a guided discovery group. In the explicit instructions group, key postural cues were highlighted during training as well as the relationship between those postural cues and the outcome of the shot, i.e. what cues are important and why. The group who received guided discovery instructions were instructed to position their attention to potentially informative areas of the visual display, for example the trunk or hips, and then encouraged to discover meaningful relationships between various postural cues and shot outcome (Williams et al., 2002). The results from Williams et al. (2002) show that both groups, the explicit and implicit, improved decision-making performance both in the laboratory and on-field post training intervention. The guided discovery approach was as effective at improving anticipation and decision-making as the more traditional explicit approach.

Early visual perception training researchers and practitioners have relied heavily on the explicit training approach, where participants are instructed to the most important visual or postural cues and the relationship between theses cues and the outcome of the event were explained. These approaches have been very directive, with detailed instruction and information being provided to the participants. However, more recent researchers (e.g., Abernethy et al., 2012; Jackson & Farrow, 2005; Masters et al., 1999; Milazzo et al., 2016; Smeeton et al., 2005) have advocated more of a hands-off implicit approach. While truly implicit learning environments might be extremely difficult to create when presenting a visual training programme (Jackson & Farrow, 2005), guided discovery has been suggested as an appropriate method to ensure that athletes learn what cues are important without explicitly developing knowledge which could be reinvested when under pressure. Guided discovery (Smeeton et al., 2005) has shown stable and consistent improvements in anticipation and decision-making as well as effective real-world transfer. Without the specific declarative knowledge (gained through explicit training programmes), athletes are unable to reinvest effort toward more explicitly acquired knowledge, thus are less likely to choke under pressure (Masters, 1992; Maxwell et al., 1999). Although explicit approaches may facilitate short-term solutions and benefits, and results may be obtained at a quicker pace, they may not be as beneficial to the long-term development of the athlete, especially when the athlete finds themselves in a pressure situation. Also, because the prescriptive approach does not allow the athlete the opportunity to explore different solutions to the problem at hand when presented with a novel situation or when facing an opposition with an abnormal bowling action, this approach may inadvertently inhibit performance. The growing body of evidence therefore highlights that a guided approach, advocating less explicit instruction and more discovery of the importance of the postural cues, is likely to be the most beneficial for long-term visual development.

8.1.3 Developing guided discovery visual training in cricket

One of the key messages emerging from past research, is that when attempting to develop a guided discovery visual perception training programme, athletes should be directed toward "information rich" areas of the visual scene (Williams et al., 2003). By directing attention to these information rich areas but not expanding on their importance, it allows information to be acquired more implicitly through guided discovery. Detailed information about why these areas are important and how they impact the outcome of the skill should be avoided. However, in order to avoid time-consuming and completely inefficient search strategies, some guidance to information rich areas or zones should be presented. Cricketers should also be encouraged to discover meaningful relationships between various postural cues and the outcome of the delivery.

Based on the data gathered within this programme of research, a potential example of a perceptual training programme that may be suitable for cricket batting would involve the presentation of video footage of a bowler alongside information about key postural areas. This video footage should include footage of different types of deliveries from the batsman's perspective. Video footage of these deliveries should be edited and occluded at different time points before and after the ball is released (e.g., 60ms before release, at ball release, 60ms after ball release and 120ms after release). The batter should then predict the outcome of the delivery (i.e., the speed type and landing location of the delivery) and respond with a shadow shot of what shot they would play to that delivery. The logic underpinning this training is that the early occlusion of the delivery forces the batter to learn to respond to the bowler's pre-delivery movement pattern as early as possible (Hopwood et al., 2011). Following the occluded video footage, the full outcome of the video should be presented to the batters in order for them to gain full information about the outcome of the delivery. Rather than being informed about why certain cues are important and how they impact the outcome of the delivery, batters should be merely directed to focus on potential areas of interest. For example, under an explicit training programme, cricket batters might be instructed to look at the ball/bowling hand of the athlete and try to see the direction of the seam and which way the shiny side of the ball is facing. They would be told that this information will impact which way the ball will swing in the air; if the shiny side is on the left as you look at it and the seam is pointed towards the slips, then the ball will swing away from you in the air. In a guided discovery visual perception training programme, batters will be instructed to focus on the ball and hand and encouraged to make discoveries for themselves about how watching the ball can impact the outcome of the delivery.

Following the video-based occlusion training, batters should be afforded the opportunity to face a similar real bowler (preferably the same bowler that they viewed in the video if possible) in order to strengthen the linkage between the connections that they have developed. This is a crucial stage that is often overlooked, however, recent research (Brenton et al., 2019), has demonstrated that in order to see transfer from video-based training to the real world, a combination of video and motor training should be employed. Batters could easily incorporate a 20-30 minute guided discovery occlusion decision-making training programme prior to their regular batting practice. Indeed, this could be set up via projection screens, at any indoor cricket school (common training environments for professional clubs) or in the clubhouse at most local cricket grounds.

The data collected from this programme of research suggest that there are a number of key postural locations where the batter's vision should be directed towards when the bowler is approaching the crease. These locations include the ball and hand of the bowler and the head. These locations were consistently fixated upon by all participants across the three studies. Batters, specifically amateur batters, should be encouraged to discover for themselves why these locations are important and how they impact the outcome of the delivery. By directing their attention to the meaningful areas, this would have an additional benefit of reducing the non-relevant locations attended to by the amateur batters. One of the key findings from the data that has emerged during this research programme and one of the main recommendations for amateur batters is to reduce the amount of time fixating on non-relevant locations. These non-relevant locations were deemed as a potential difference between amateur and elite batters. By providing alternative areas to for the batters to focus on and discover for themselves, this should happen automatically. It is expected that by providing these guided discovery visual perception training programmes, batters will enhance their visual and perceptual abilities. These training programmes have the potential to improve batters' ability to pick out early information and improve their pattern recognition skills, both of which are crucial for anticipation in fast moving sports such as cricket (Cotterill & Discombe, 2016). While these suggestions are logical based on the findings from the programme of research, it should be stressed that further research is needed to determine whether these recommendations would be effective. Logic dictates that removing the amount of non-relevant information fixated upon pre-delivery and fixating upon locations that could aid in anticipating the outcome of the deliver would be an effective strategy and intervention. However, the aims of the three experiments within this programme of research was not to explore the effectiveness of these suggestions, therefore, the researcher cannot categorically state that they would be effective.

8.2 Video based or Virtual Reality for vision training

To date, research exploring methods to enhance cue utilisation and thus anticipation, has highlighted the benefits of using video-based occlusion training programmes. However, the advancement in modern technology raises the question as to whether this technology is the most realistic (task representative) or beneficial method available to us. In 2016, multiple virtual reality (VR) systems were released to the public by a range of companies including: Oculus, HTC, Sony, Google, and Samsung (Bird, 2019). Access to VR content has therefore grown significantly as VR has become readily available (Lin, 2017; Bird, 2019). This relatively modern technology has the potential to be used in the sporting world and is quickly opening the door for new and exciting methods of developing vision and perception training. Discussions relating to VR in sport have focused on two differing approaches. The first is the traditional virtual reality, where software developers create an immersive virtual environment and present this experience via a stereoscopic Head Mounted Display (Craig, 2014). This approach allows the current head position and orientation of the athlete to be recorded instantly so that the position of the participant within the display can be updated to correspond to the position and orientation within the virtual environment (Craig, 2014). This means that you can interact, move and even play sports in the virtual world. A batter, therefore, would be able to face a virtual bowler running in and bowling at them and respond to the deliver i.e. swing the bat and intercept the ball. When the systems are designed well, they have the ability to engage users and bring a sense of excitement to the situation in ways that traditional video presentations cannot (Edsall & Larson, 2006). These virtual environments are, at least to the present generations of users, still novel and exciting. While seen by some as a game or novelty, it is believed that this technology has the ability to make a significant improvement in the development of decision-making. There are, however, a number of drawbacks with using virtual reality in the applied world of sport. The first is the cost and expertise needed to develop realistic virtual environments. Indeed, some argue (Cipresso, Serino, & Riva, 2016) that it is extremely rare that effective VR environments can be developed without the aid of specialised software engineers. The realism of virtual environments has also been questioned and it has been argued (Miles, Pop, Watt, Lawrence, & John 2012; Slater & Sanchez-Vives, 2016) that if the environments are not representative of the real world it can lead to incorrect learning.

As developing effective and realistic environments is beyond the expertise of many people, practitioners and researchers have advocated presenting 360-degree video in the VR head mounted displays (VR HMDs) (Bird, 2019; Craig, 2014). As previously discussed, video-based training methods have been widely used to try to enhance the visual and perceptual skills of athletes. However, there are several limitations with using traditional video footage, the main one being the 2D nature means it is difficult to extract stereoscopic information (Mann et al., 2010; Vignais, Kulpa, Brault, Presse, & Bideau, 2015). Indeed, the data from the present programme of research highlights that while the pre-delivery gaze behaviour of the batters was similar when facing 2D video footage compared to real bowlers, the ball flight data varied significantly. This suggests that the batters found it difficult to track the ball (i.e. an object moving towards them) and thus 2D video might not be task-representative of the real ball flight. The use of 360-degree video footage may overcome this issue and 360 cameras can be positioned to record footage from the perspective of the athlete. This means that video footage similar to that used in the 2D virtual training can be recorded in 360-degrees and presented back via a VR HDM, creating a potentially more immersive and ecological experience. One company at the forefront of this method of training is STRIVR. Derek Belch, the founder of STRIVR, wanted to create a training programme for American football quarterbacks that was more representative of the real match environment. He set up the company STRIVR and recorded numerous 360-

videos of specific plays from the point of view of the quarterback. The quarterback then was able to watch these plays at their convenience and complete what Derek and STRIVR termed 'mental reps'. STRIVR are now working with numerous professional teams in American football, ice hockey, baseball and basketball and have received a large amount of attention from the media in America. An example of how impactful this approach can be, came from Cronin (2018) an ESPN reporter. Cronin highlighted how quarterback Case Keenum from the Minnesota Vikings watched over 2,500 plays using a VR HMD during the 2017 season and attributed much of his success to the work completed with STRIVR (Bird, 2019).

While there are currently companies and athletes using the 360-video method of visual training, there are still a number of drawback and potential issues. The first is that very little empirical evidence has been produced to determine whether this method is beneficial at improving decision-making or performance. The second and most obvious disadvantage of 360-video when compared to immersive VR is that athletes are not able to move or interact within the environment when viewing 360-degree video footage. Instead, athletes are active observers as the environment does not update or move as the participant moves (Craig, 2014). However, while this is a disadvantage when compared to immersive VR, the use of 360-video seems like a significant improvement compared to traditional 2D video presentations. Coaches, specifically those working within professional cricket, could purchase a 4k 360-video camera for under a thousand pounds, record footage from a batter's point of view and present this back via a guided discovery visual perception programme with the use of commercially available VR machines. Indeed, this idea could potentially offer a unique selling point to sport psychology practitioners working within cricket or other similar interceptive sports such as tennis, badminton, squash etc. Practitioners could set up a company and follow a similar model of STRIVR. This is something that has yet to be attempted in the UK. Either through immersive VR or 360-degree video, this is an exciting area which has the potential to enhance decision-making, anticipation and visual perception. While this is an exciting area, more empirical research is needed to develop the best methods of implication within sport and cricket.

8.3 Limiting bowling machine use

A key finding from each of the three studies within this programme of research is that batters fixate on very similar body locations pre-delivery when facing the varying types of bowlers, most noticeably on the ball/bowling hand and the head, as well as the point of release. The pre-delivery gaze behaviours of the participants can therefore be considered consistent, learned and a fundamental source of information for batters to utilise in order to anticipate what type of delivery will be bowled. Removing this information in any way could therefore have a detrimental impact on the performance of the batter, particularly in relation to their decision-making and anticipatory abilities.

Unfortunately, one of the most common training tools used to practice batting in cricket is the bowling machine. Bowling machines are readily available at an affordable price and the market leader, BOLA Bowling Machines, can be seen in all professional clubs and most amateur clubs and schools within the UK. The vast majority of cricket coaches consistently rely on bowling machines as one of their key coaching tools. However, there have been calls for some time now from professional players and coaches to be wary about the overreliance of bowling machines. For example, Greg Chappell, a former Australian cricket batsman who scored 24 test hundreds and averaged over 53 in his cricket career describes his view of bowling machines:

> What my intuition told me for years was that the bowling machine was a totally different exercise from batting against the bowler. From my own personal experience of batting against the bowling machine, it wasn't a great experience because once I've done it a few times I decided that it wasn't going to help me with batting. I was better off not to bat at all than to go and bat on a bowling machine because the activity is so different. [In an actual cricket match] you know the bowler's preparation to bowl; you know everything - all of the cues and clues that you're getting from the bowler is [sic] really important to get into the rhythm of the bowler and to get the timing of your movements. You take the bowler out of the equation, you stick a machine there that spits balls out at you and you've lost all those cues and clues. What I've subsequently found is that research is telling us what my intuition and my experience was telling me. The other thing is that the research into expertise tells you that experts are better at picking up the cues and clues than the average player. So why take it away from everyone and stop them from developing the things that will help them get better? (Renshaw & Chappell, 2010)

Robert Key, the former England international batsman, also has concerns about the impact that bowling machines are having on the development of young batters:

> Batting, and cricket in general, is about making the right decisions time and time again and if you do 90 per cent of your winter practice without facing bowlers - because bowlers don't like bowling indoors due to the risk of getting injured - you're stopping yourself from being able to learn the decision-making process that batting is…I think at times where people should be doing 50 per cent bowling machine, 50 per cent against bowlers, it is probably more 80-20 (in favour of the

> bowling machine). They are an excellent tool but coaches just have to be careful about how they use them. (Key, 2018)

The scientific literature suggests that batting against a bowling machine is completely different, particularly pre-ball release, compared to facing a bowler (Bartlett, 2003), as using bowling machines completely disregards the pre-delivery information that is available to the batters in a naturalistic environment. The findings from this programme of research highlights the importance of pre-delivery cues and adds weight to the arguments that current methods of training (e.g., cricket batters using bowling machines) may not benefit the athlete and could potentially harm the development of cricketers (Pinder et al., 2009). Specifically, the removal of pre-delivery information can alter the movement pattern and execution of batters. For example, Pinder et al. (2009) reported that while batting against a medium-fast pace bowling machine compared to a bowler of the same speed, batters produced significant adaptations to their movement, timing and coordination. Davids et al. (2005) provided similar results and highlight that when facing a real bowler compared to a bowling machine, they found that overall movement time was shorter, the batters backswing started later, initiation foot movement occurred earlier, the downswing of the bat occurred later, and the peak bat height was higher. This research taken together with the aforementioned research again highlights the potential pitfalls of overusing bowling machines. Thus, coaches should limit the use of bowling machines whenever possible and where possible provide real bowlers for batters to face. Coaches and players need to be wary that practicing with ball machines can potentially lead to the formation of inappropriate information movement couplings and inhibit the anticipation and the decision-making capabilities of their batters (Renshaw et al., 2007)

8.4 Advice for bowlers

Deception (i.e. the purposeful presentation of false visual cues) and disguise (i.e. delaying the onset of an informative cue) are important techniques used by skilled bowlers to minimise batters ability to anticipate the delivery and increase the chances of inducing a mistake in batters (Brault et al., 2010; Jackson et al., 2006; Rowe, et al., 2009). In cricket, bowlers often achieve this outcome by hiding the ball, or disguising the type of delivery (in or away swing, slower ball, etc.) that they are preparing to bowl. This programme of research has highlighted that both elite and amateur batters fixate upon the ball more than any other location during the bowlers run up. It has also been demonstrated within previous occlusions studies (e.g., Müller et al., 2006; Tayler & McRobert, 2004) that the presence of the ball and bowling hand is crucial for batters to be able to predict the line and length (landing location) of the delivery. When the ball/bowling hand is occluded, batters are unable to predict the landing location of the delivery. Therefore, in order to anticipate the type of ball delivered by the bowler, cricket batters need to extract information from the bowling hand/ball. The ball is considered a important postural cue for cricket batters because it provides information on how the bowler grips the ball, as well as the position of the seam (which dictates the amount and type of movement that is produced) and the type of ball that will be bowled (McRobert, 2009). It therefore seems logical that if batters find this location a valuable source of information, bowlers should attempt to hide the ball during the run up. There are a number of methods that could potentially be utilised to achieve this. The bowler could run in and hide the ball with their other hand, or they could run in with the ball behind their back. Both strategies would make sure the ball is not visible to the batter. Another strategy that has recently been employed by Wahab Riaz in the ICC 2019 world cup, is bowling around the wicket and running in for the majority of the run up behind the umpire. This means that the batter would have very limited visibility of the bowler on the approach to the crease. At the last moment, Wahab then darted out from behind the bowler and delivered the ball. This would be considerably different to what the batsmen is used to facing (i.e., watching the bowler the whole way from the top of his bowling mark to delivery). The removal of most pre-delivery information using this tactic could impact the batter's normal gaze behaviour and ability to anticipate the delivery. Another potential strategy is to swap (twist the ball around or swap the ball from non-bowling to bowling hand) the ball at the last minute as the bowler approaches the crease. Swapping the ball last minute would not only limit the information gained from this area but could potentially draw the attention away from other crucial postural locations e.g. non-bowling arm. Swapping the ball at the last minute may also impede the batter's ability to see the seam position of the ball and predict which way the ball will swing. Bowlers should be encouraged to develop strategies to limit the pre-delivery information of the batter, potentially developing a number of differing strategies so that batters cannot consistently reproduce the same gaze behaviour delivery after delivery. Changing the presentation of pre-delivery information during the run up and approach to the crease would likely mean that the batter needs to alter their visual strategies in accordance.

The majority of the fixation location data from this programme of research has highlighted that elite batters' fixations were mainly on the upper body when facing spin, medium-paced and fast bowling. Elite batters spent longer fixating upon the upper body compared to the amateur batters and when facing spin and medium-paced bowling. They also spent a significant smaller percentage of pre-delivery fixating upon the lower body when facing spin bowling. These results suggest that the majority of important pre-delivery information comes from the upper body. From a bowling perspective, delivering a slower ball and or disguised delivery without altering any upper body movements in the run up or during the delivery may therefore be extremely beneficial. If the bowler can deliver a slower ball without changing or altering the movements of the upper body, this is much more likely to confuse the batter and has the potential to lead to a poor decision-making or reduced anticipation. Bowlers could potentially achieve this by bowling from further back than they usually would. This would mean that the action of the bowler is the same, the ball leaves the hand of the bowler at the same velocity but arrives to the batter a fraction of a second later. This makes it exceptionally difficult for the batter to judge the landing location and time and may enforce a mistake. Bowling from half a metre or one metre further away from the batter would achieve a subtle 'slower delivery' without altering any of the bowling action or upper body movements. The data collected in this programme of research suggests that batters may not be aware of this subtle change as all batters shifted their vision to the point of release when the bowler was in their delivery stride. No batter made a fixation towards the landing location of the bowler. This bowling strategy is something that is not regularly used by bowlers either at the elite or amateur level, however, this has recently been employed by Kieran Pollard bowling in the 2019 Indian Premier League for the Mumbai Indians. According to the laws of the game, as long as the bowler is in front of the umpire they can bowl from as far back as they wish. Bowlers should practice bowling from a slightly longer distance, so they are familiar with the change and are able to bowl the desired line and length from the new delivery location. This would ensure they have an additional strategy to try and deceive the batter.

The modern game of cricket with the increasing success and popularity of the shorter version of the game (e.g., twenty-20 cricket) and the introduction of an even shorter game called the hundred (one hundred deliveries per team), has encouraged accelerated developments in batting styles and the introduction of new shots. Batters such as Tillakaratne Dilshan, Jos Buttler, M.S. Dhoni and Kevin Pietersen have continually advanced the game and developed new and creative ways of batting and scoring runs. These players have developed shots which have not been seen before. For example, the 'dilscoop' was named after Tillakaratne Dilshan, who got down on one knee against a fast bowler and scooped the ball over his head and the wicket keeper. Likewise, Kevin Pietersen's switch hit was something that had not been seen previously. While the bowler ran in, Kevin switched his stance from a right-handed stance to a left-handed stance in order to hit the ball in the free space on the field. However, with the exception of the increased number of slower balls being delivered, bowlers have been less inventive, specifically when it comes to trying to disguise or hide the pre-delivery information available to batters. Novel attempts to hide the bowling action, the ball or disguise and distract the batsmen are rare in the game of cricket, however, they are likely to have a negative impact on the batters ability to predict the line and length of the ball. It is also likely that these disguise deliveries will become even more important as the game becomes shorter. Bowlers should also continue to develop strategies to alter the delivery velocity or type of delivery without altering upper body movements.

8.5 Vision testing and monitoring

It is widely accepted by academic experts, researchers and the general public, that vision is the most powerful sense and the visual system provides us with an extraordinary amount of information (Williams et al., 2000). The vast majority of the information that we received comes via our visual system. Indeed, it has been estimated that between 85 and 90% of sensory information regarding the external environment is obtained via our visual system (Loran & MacEwen, 1995). Therefore, without the visual system, humans find interpreting the world around them extremely challenging and if vision were to become impaired then even the simplest of tasks becomes laborious. In sport, where participants and objects frequently move on complex and rapid trajectories, the need for efficient vision is self-evident (Williams et al., 2000).

A large focus of research within the field of sport vision has compared the differences in visual ability between elite and amateur performers. These studies have mainly focused on testing visual abilities between sports experts and novices (e.g., visual acuity, colour vision, and depth perception etc.). The findings from this research is somewhat inconclusive. Most research testing the basic visual functioning (e.g., visual acuity, colour vision, and depth perception etc.) suggests that there are no differences between elite and amateur athletes (for an overview, see Williams & Ford, 2008; Williams & Grant, 1999). When testing basic visual functioning, most tend to agree with the statement by Eccles (2006, p. 1103) regarding the state of research on basic perception capabilities: "The findings from over a decade of research on expertise within and beyond sports have provided limited support for the existence of differences between expert and less skilled performers in terms of basic visual and neural systems".

However, when testing more dynamic and sport specific visual functions such as: dynamic visual acuity (Barns & Schmid, 2002; Junyent et al., 2011); peripheral vision and awareness (Ghasemi et al., 2009; Ryu et al., 2013; Zweirko, 2008); speed of recognition (Ghasemi et al., 2009; Isaacs & Finch, 1983); and saccadic eye-movements (Ghasemi et al., 2009); it seems that experts are superior when compared to their novice counterparts. It has also been reported that various sports require different visual abilities (Dogan, 2009), and the visual demands faced by athletes who play in varying positions within the same sport often differs (Wimshurst et al., 2012). Taking this into account, the visual demands of a batter may differ from those needed by a specialist bowler. What is clear, from this programme of research and previous research focused on vision and visual perception, is that vision is a fundamental component needed in the vast majority of sports. While elite athletes' basic visual functioning may not differ from amateurs, research has shown that experts have better sport specific visual abilities and visual perceptual abilities. This programme of research has highlighted that there are differences in gaze behaviour between elite and amateur players and that any changes in the gaze behaviour of athletes could potentially impact decision-making and ultimately have an impact on batting performance. With such a strong understanding of how important vision is, it is the author's belief that vision and visual perceptual training should receive far more attention in the applied world of cricket and sport in general. Both elite and amateur level cricketers should be aware and have access to sport vision training. Not only should athletes have regular eye checks, they should also train their perceptual and anticipatory abilities, sport specific vision and be made aware of potential anomalies of visual defects (such as fixating on non-relevant areas when the bowler is running in) that might impact performance. Professional clubs should spend more of their financial budgets on vision experts to improve this fundamentally vital component of the sport.

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Cotterill, S. T., & Discombe, R. M. (2016). Enhancing decision-making during sport performance: Current understanding and future directions. *Sport & Exercise Psychology Review, 12*(1), 54–68.

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Discombe, R. M., Cotterill, S. T., Randell, J., & Batten, J. (In Press). An Exploration of Cricket Batters Visual Search Strategies While Facing Different Types of Delivery. *International Journal of Sport Psychology.*

Conference proceedings:

Discombe, R. M., & Cotterill, S. (2015). An exploration of cricket batsmen's visual search strategies while batting against spin, medium paced, and fast paced bowling. 14th European Congress of Sport Psychology, Bern, Switzerland, 14th-19th July.

Cotterill, S., Edgar, G., Catherwood, D., Davis, S., & Discombe, R. M. (2013). An exploration of decision-making preferences amongst cricketers. Expertise and Skill Acquisition Network Annual Conference. Liverpool, UK, 3-4th April.

Appendices

Appendix A – Information sheet study one

An exploration of cricketers' visual search strategies and gaze behaviours while batting against spin, medium pace and fast paced bowling.

Dear Participant,

Thank you for showing an interest in taking part in this study. This sheet will tell you a little more about the study and what we would like you to do. Please read it carefully.

What is the project about?

The study has been designed to investigate the visual search strategies, and gaze behaviours of cricket batsmen when presented with video footage of human bowlers of varying speeds and bowling styles. This will include slow bowling/conventional off spin bowling, medium pace bowling, and fast paced bowling. It is the aim of the research project to answer the following questions:

1. What information do batsmen gather, and what do batsmen fixate on during the bowlers run up?
2. Is there a significant difference in visual search strategies prior to ball release, when batsmen view bowlers of varying speeds?
3. What method do cricket batsmen use to follow the ball during flight when viewing video clips of varying speeds (I.e. a spin bowler, medium pace bowler, and fast bowler)?
4. Is there a significant difference in the way batsmen follow the ball during its flight when viewing bowlers of differing speeds?

Who is taking part in the study?

The participants within this experiment will be the University of Winchester cricket squad. All participants will have taken part in There will be between 6-12 participants. In order to ensure that you are currently active within the sport, it is a requirement that you have played some form of cricket within the last 12 months (this can include net practice, indoor cricket etc.).

What will I be asked to do?

If you volunteer for this study, you will need to complete an eye-tracking experiment, which will last approximately 20-30 minutes. During the task you will be asked to view numerous clips of cricket bowlers (ranging from spin to pace), while having your gaze tracked using the Universities desk mounted eye tracker (the Eye-Link 1000).

Directly following each delivery you will be asked to make a selection regarding the shot you would have played to the ball you have just view. The decision will simply be attack or defend. You will not be asked to verbalise this decision, instead you will tap with your left hand to defend, and your right hand to attack.

Before any data collection you will be presented with two overs of video clips so you can acclimatise to the laboratory, get use to the lighting in the room, the eye-tracking technology, and the correct way to respond to the delivery seen on the screen etc. If you wish you can repeat this process until you become comfortable with the environment. Only when you have confirmed that you are comfortable will the data collection start.

Do I have to take part?

No, taking part in this study is entirely your choice. Moreover, if you do choose to take part in the study, you still remain free to withdraw from it at any point and any data collected will not be used within the study.

What will you do with the information?

All the information will be collected and securely stored on a password protected private computer. The results will only be seen by the research team, and there will be not data or information that might reveal your identity within the final article. The aim is to publish the findings in an academic paper/journal in the future.

Thank you for your time,

Project lead:

Russell Discombe

PhD Student

University of Winchester

Email: Russell.Discombe@unimail.winchester.ac.uk

Appendix B – Consent form study one

THE UNIVERSITY OF WINCHESTER

An exploration of cricketers' visual search strategies and gaze behaviours while batting against spin, medium pace and fast paced bowling.

I have been informed that Russell Discombe, a PhD student within the sports department, is completing a study to investigate the gaze behaviours of cricket batsmen.

I understand that I will need to complete an eye-tracking experiment, which will last approximately 20-30 minutes. During the task I will be asked to view numerous clips of cricket bowlers, while having my gaze tracked using the Universities desk mounted eye tracker (the Eye-Link 1000).

I understand that the results of the experiment will be kept confidential and that my involvement in the study will not be revealed to any one beyond the research team. I also acknowledge that although the information gained from the study will be disseminated to the wider community, my identity will not be revealed in doing so.

I have been informed that any questions I have regarding this study will be answered by the Russell Discombe at (Russell.Discombe@unimail.winchester.ac.uk).

I have read the above information and understand fully the nature of the study and my role within it. I therefore sign this consent form knowing that I still may withdraw from the study at any point.

Participant signature:

Date:

Appendix C – Information sheet study two

An exploration of cricketers' visual search strategies and gaze behaviours while batting against spin and medium-paced bowling.

Dear Participant,

Thank you for showing an interest in taking part in this study. This sheet will tell you a little more about the study and what we would like you to do. Please read it carefully.

What is the project about?

The study has been designed to investigate the visual search strategies, and gaze behaviours of cricket batsmen in their natural environment when facing bowlers of varying speeds and bowling styles. This will include slow bowling/conventional off spin bowling, medium pace bowling, and fast paced bowling. It is the aim of the research project to answer the following questions:

1. What eye-movements do batters produce and do these eye movement differ prior to the release of the ball when facing human spin, medium pace, and fast paced bowlers in situ?
2. Do batters produce significantly different eye-movements prior to the release of the ball when batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
3. Do batters produce significantly different eye-movements prior to the release of the ball when they successfully execute a shot compared to when they fail to execute the shot successfully?
4. Is there a significant difference in the method for tracking the ball (pursuit tracking vs. predictive saccades) and the timing/onset of saccades and pursuit tracking, when batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection? Or when they execute a shot successfully compared to an unsuccessful shot?

Who is taking part in the study?

The participants within this experiment (both the bowlers and batsmen) will be selected from an amateur university or cricket club. There will be between 6-10 participants in total. In order to ensure that you are currently active within the sport, it is a requirement that you have played some form of cricket within the last 12 months (this can include net practice, indoor cricket etc.).

What will I be asked to do?

If you volunteer for this study, you will need to complete an eye-tracking experiment, which will last approximately 20-30 minutes. During the task you will be asked bat in the nets against a spin bowler, a medium paced bowler and a fast pace bowler while wearing the SMI eye-tracking glasses. You will be asked to bat in your conventional manner as if you were batting in a match situation. You will be read a match brief before you start the experiment. Before any data collection you will be required to go through a calibration and validation phase. This is an easy process (lasting approximately 5 minutes) where you will be required to look at certain points around the sports hall. You will also be afforded the chance to bat with the eye-tracking glasses in order to familiarise yourself with the equipment. Once you feel comfortable with the process, situation and what is required the data collection will begin.

Do I have to take part?

No, taking part in this study is entirely your choice. Moreover, if you do choose to take part in the study, you still remain free to withdraw from it at any point and any data collected will not be used within the study. If you feel uncomfortable facing any of the different types of bowlers you are completely free to withdraw at any time.

What will you do with the information?

All the information will be collected and securely stored on a password protected private computer. The results will only be seen by the research team. The aim is to publish the findings in an academic paper/journal in the future, however no information or data that might reveal your identity will be included within and drafts or the final article.

Thank you for your time, if you have any information please feel free to ask.

Project lead:

Russell Discombe

PhD Researcher & Part-Time lecturer

University of Winchester

Email: Russell.Discombe@winchester.ac.uk

Appendix D – consent form study two

An exploration of cricketers' visual search strategies and gaze behaviours while batting against spin and medium-paced paced bowling.

I have been informed that Russell Discombe, a PhD. student within the sports department, is completing a study to investigate the gaze behaviours of cricket batsmen.

I understand that I will need to complete an eye-tracking experiment, which will last approximately 20-30 minutes. During the task I will be asked to bat against a spin bowler, a medium paced bowler, and a fast pace bowler while wearing the SMI 2.0 eye-tracking glasses. Although I will be wearing all of the protective equipment I regularly wear, I understand that when batting in cricket there is always a possible chance of getting hit by the ball. I accept this possibility, I am happy that there will be an individual trained in first aid present and I agree to participate.

I understand that the results of the experiment will be kept confidential and that my involvement in the study will not be revealed to any one beyond the research team. I also acknowledge that although the information gained from the study will be disseminated to the wider community, my identity will not be revealed in doing so.

I have been informed that any questions I have regarding this study will be answered by the lead researcher Russell Discombe at (Russell.Discombe@winchester.ac.uk). I also understand that I have the right to withdraw from this study at any time.

I have read the above information and understand fully the nature of the study and my role within it. I therefore sign this consent form knowing that I still may withdraw from the study at any point.

Participant signature: Date:

Appendix E – Information sheet study 3

A comparison of elite and amateur cricketers visual search strategies and gaze behaviours while batting against spin and medium-paced bowling.

Dear Participant,

Thank you for showing an interest in taking part in this study. This sheet will tell you a little more about the study and what we would like you to do. Please read it carefully.

What is the project about?

The study has been designed to investigate the visual search strategies, and gaze behaviours of both elite and amateur cricket batsmen in their natural environment when facing bowlers of varying speeds and bowling styles. This will include slow bowling/conventional off spin bowling and medium-fast bowling. It is the aim of the research project to answer the following questions:

1. Is there a significant difference between elite vs. amateur batter's eye-movement and gaze behaviour differ prior to the release of the ball when facing human spin and medium-fast paced bowlers in situ?
2. Is there a significant difference between elite vs. amateur batters eye-movements and gaze behaviour prior to the release of the ball when batters make a correct decision regarding shot selection compared to when they make an incorrect decision regarding shot selection?
3. Is there a significant difference between elite vs. amateur eye-movements and gaze behaviour prior to the release of the ball when they successfully execute a shot compared to when they fail to execute the shot successfully?
4. Is there a significant difference in the method for tracking the ball (pursuit tracking vs. predictive saccades) and the timing/onset of saccades and pursuit tracking between elite vs. amateur batters.
5. Is there a difference between amateur and elite batters method of tracking the ball (pursuit tracking vs. predictive saccades and the timing/onset of saccades and pursuit tracking) when batters make a correct decision regarding shot selection

compared to when they make an incorrect decision regarding shot selection? Or when they execute a shot successfully compared to an unsuccessful shot?

Who is taking part in the study?

The participants within this experiment (both the bowlers and batsmen) will be both amateur and professional cricketers. The amateur cricketers will be selected from a University or amateur cricket team. The professionals will be from a first-class cricket county or individuals involved within the national set up. There will be between 10-20 participants in total. In order to ensure that you are currently active within the sport, it is a requirement that you have played some form of cricket within the last 12 months (this can include net practice, indoor cricket etc.).

What will I be asked to do?

If you volunteer for this study, you will need to complete an eye-tracking experiment, which will last approximately 20-30 minutes. During the task you will be asked bat in the nets against a spin bowler, and a medium-fast paced bowler while wearing the SMI eye-tracking glasses. You will be asked to bat in your conventional manner as if you were batting in a match situation. You will be read a match brief before you start the experiment. Before any data collection you will be required to go through a calibration and validation phase. This is an easy process (lasting approximately 5 minutes) where you will be required to look at certain points around the sports hall. You will also be afforded the chance to bat with the eye-tracking glasses in order to familiarise yourself with the equipment. Once you feel comfortable with the process, situation and what is required the data collection will begin.

Do I have to take part?

No, taking part in this study is entirely your choice. Moreover, if you do choose to take part in the study, you still remain free to withdraw from it at any point and any data collected will not be used within the study. If you feel uncomfortable facing any of the different types of bowlers you are completely free to withdraw at any time.

What will you do with the information?

All the information will be collected and securely stored on a password protected private computer. The results will only be seen by the research team. The aim is to publish the findings in an academic paper/journal in the future, however no information or data that might reveal your identity will be included within and drafts or the final article.

Thank you for your time, if you have any information please feel free to ask.

Project lead:

Russell Discombe
PhD Researcher & Part-Time lecturer
University of Winchester
Email: Russell.Discombe@winchester.ac.uk

Appendix F – consent form study 3

THE UNIVERSITY OF WINCHESTER

A comparison of elite and amateur cricketers visual search strategies and gaze behaviours while batting against spin and medium-paced bowling.

I have been informed that Russell Discombe, a PhD. student within the sports department, is completing a study to investigate the gaze behaviours of cricket batsmen.

I understand that I will need to complete an eye-tracking experiment, which will last approximately 20-30 minutes. During the task I will be asked to bat against a spin bowler and a medium-fast bowler while wearing the SMI 2.0 eye-tracking glasses. Although I will be wearing all of the protective equipment I regularly wear, I understand that when batting in cricket there is always a possible chance of getting hit by the ball. I accept this possibility, I am happy that there will be an individual trained in first aid present and I agree to participate.

I understand that the results of the experiment will be kept confidential and that my involvement in the study will not be revealed to any one beyond the research team. I also acknowledge that although the information gained from the study will be disseminated to the wider community, my identity will not be revealed in doing so.

I have been informed that any questions I have regarding this study will be answered by the lead researcher Russell Discombe at (Russell.Discombe@winchester.ac.uk). I also understand that I have the right to withdraw from this study at any time.

I have read the above information and understand fully the nature of the study and my role within it. I therefore sign this consent form knowing that I still may withdraw from the study at any point.

Participant signature:

Date: