VISUAL GAZE BEHAVIOUR OF SUB-ELITE CRICKET BATSMEN WHEN FACING FAST IN-SWING AND OUT-SWING BOWLING

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DECLARATION:

In accordance with Rule G4.6.3, I hereby declare that the above-mentioned treatise is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

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Date: April 2017
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ABSTRACT

The primary aim of this study was to determine the visual gaze behaviour of sub-elite cricket batsmen when facing fast in-swing and out-swing bowling. To achieve the aim of this study, two main objectives were set: (1) to describe and compare the visual gaze behaviour of sub-elite cricket batsmen for both successful and unsuccessful trials irrespective of the ball faced; and (2) to describe and compare the visual gaze behaviour of sub-elite cricket batsmen for both in-swing and out-swing bowling trials irrespective of the outcome. The gaze behaviour characteristics were described and compared in terms areas of interest (AOI), number of fixations, duration of each fixation, starting and last fixation, and order of fixations. The study was pre-experimental in nature and utilised a quantitative approach. A One group post-test only design was followed in this study. A total of 13 batsmen were tested that met the inclusion criteria and were included in the study by means of purposive sampling. Four different variables were assessed: eye dominance, visual gaze behaviour, the speed of delivery and ambient light. No significant differences were found for the mean number and duration of fixations irrespective of the stroke outcome and the ball type faced. However, significant differences were obtained when specifically looking at the stroke outcome and the ball type faced. Results suggest that the AOI, upper body, arm/ ball release and pitch are considered as task relevant cues. Information appears to be acquired from the aforementioned AOI in a sequential manner to contribute to successful batting performance. In addition, batsmen should attempt to diminish the number of blinks at the end of trials to contribute towards more successful batting performance.

Keywords: Cricket, Anticipation, Perceptual-motor skill, Batsmen, Gaze control
CHAPTER 1: PROBLEM IDENTIFICATION

1.1 INTRODUCTION

Vision is a critical source of information that affords an individual the ability to navigate through sporting environments (Cesqui, Mezzetti, Lacquaniti, d’Avella, 2015:1). Vision becomes increasingly more significant during information processing to facilitate the successful execution of fast and accurate interceptive actions like hitting a cricket ball (Cesqui et al., 2015:1). An individual’s gaze is directly influenced by the manner through which eye movements are controlled. Gaze control plays a significant role in sport as without the proper utilisation of visual strategies and effective perception, accurate and correct responses are compromised.

The spatial and temporal constraints inherent to the game of cricket in conjunction with game tactics (field placements); requires performers to accurately identify and utilise visual information from the environment to produce precise movements (Pinder, Davids, Renshaw & Araujo, 2011:1242). Cricket is a sport that requires a high level of precision from all participants; in particular, batsmen, as one performance error may subsequently result in dismissal. At the elite level cricket batting is an exceptionally difficult skill, success requiring sustained error free performance. According to Müller and Abernethy (2012:247), “cricket batting is characterised by minimal error tolerance; as one performance error, may result in dismissal.” The same sentiments were expressed earlier by Mihoces (2005), who rated hitting a ball to be one of the most difficult skills to perform in sport.

Sarpeshkar and Mann (2011:307) described batting in cricket as an ideal task to unearth the complexities involved in hitting a cricket ball when trying to conceptualise performance at the temporal and spatial limits of human performance. A prerequisite to successful batting is a tight and efficient link between the neuromuscular and visual system (Sarpeshkar & Mann, 2011:306). The ultimate goal of a batsman is to produce the most controlled, yet forceful cricket stroke possible (Sarpeshkar & Mann, 2011:307). A significant degree of spatial and temporal accuracy in coincidence timing needs to be attained to facilitate successful stroke interception.
(Weissensteiner, Abernethy & Farrow, 2011:324). This level of accuracy must be achieved under conditions that possess a considerable amount of uncertainty regarding the future position of the ball as a result of its post-bounce deceptive characteristics (Müller & Abernethy, 2012:247). Furthermore, the primary source of visual information in all striking sports generally stems from the object that must be intercepted (Müller & Abernethy, 2012:176). In addition, advance visual information can also be obtained from the subjective probabilities and kinematic properties of opponents. The aforementioned encompasses some of the constraints inherent to the game, along with sources of visual information that batsmen have to manage in an attempt to perform successfully while batting in cricket.

The compounding and accelerating spatial-temporal constraints that exist in batting appear to be very demanding, which alludes to the unanswered question: are there any gaze behaviours adopted by batsmen that assist them to perform successfully under such temporally constrained conditions? A plethora of literature exists that provides useful insight into the expert-novice differences in gaze behaviour across various sporting domains. Research that has been conducted in cricket has largely revolved around morphological and physiological factors that contribute to optimal performance (Portus, Sinclair, Burke, Moore & Farhart, 2000; Stretch, Bartlett & Davids, 2000; Noakes & Durandt, 2000; Bartlett, 2003 & Subramanian, 2014).

A wealth of literature exists examining the visual search strategies of skilled performers across various sporting modalities. Research by Williams and Davids (1998), Savelsbergh, Williams, Van der Kamp and Ward (2002) and Savelsbergh, Van der Kamp, Williams & Ward (2005), for example, assessed the visual search behaviour, in conjunction with anticipation ability amongst soccer players. Other sporting modalities in which visual search strategies were investigated are: karate (Williams & Elliot, 1999); tennis (Ward, Williams & Bennett, 2002 & Shim, Carlton & Kwon, 2006); cricket (Renshaw & Fairweather, 2000 & Müller, Abernethy & Farrow, 2006) and baseball (Takeuchi & Inomata, 2009).

Research conducted on the visual gaze behaviour or search strategies employed by batsmen has largely incorporated the use of laboratory-based experimental designs. The latter designs concentrate more on the visual component rather than on the
interaction of the visual-motor system, of which the former is inadequate for simulating the natural environment in which cricket is played.

The techniques employed during laboratory-based visual search studies include; spatial and temporal occlusion paradigms (Müller et al., 2006; & Ward, 2007; Müller & Abernethy, 2012:177), point of light displays (Abernethy & Zawi, 2007:353) and the employment of liquid crystal glasses (Müller, Abernethy, Reece, Rose, Eid, McBean, Hart & Abreu, 2009). The participants are expected to view sequences of film when the film occluded and respond appropriately once occluded. The exclusion of the natural conditions provides very little insight regarding the strategies or techniques that athletes employ to perform successfully on the pitch. The following question, therefore, remains unanswered; what are the gaze behaviours of these players and how does their search strategy enable them to perform successfully?

Vision in action research has been conducted on various sporting codes; such as baseball, ice hockey, tennis, table tennis and cricket. However, the studies that have focused on cricket included a bowling machine. The inclusion of a bowling machine brings forth a stationary visual component which does not simulate the biological motion of a bowler in the game of cricket. Research by Land and McLeod (2000); Croft, Button and Dicks (2009); Müller et al. (2009); Weissensteiner et al. (2011) and Mann, Spratford and Abernethy (2013) conducted research examining the visual search behaviours of cricket batsmen when facing a bowling machine. Conducting vision related research during more game simulated situations requires more attention, though.

To determine the gaze behaviour of cricket batsmen it is imperative to create a sporting environment that integrates both the visual and motor system. This simulated environment will lead to a more realistic and true reflection of the visual gaze behaviour strategies generated in terms of areas of interest (AOI), number, duration, starting, last and order of fixations, that batsmen employ while batting at a sub-elite level. The inclusion of actual bowlers eliminates the consistency in terms of ball location that is accompanied by the use of a bowling machine. Given the important role, batsmen play in cricket, the batsmen’s ability to control the spatial and temporal constraints required for successful execution of a cricket stroke and the
relative lack of vision-in-action cricket research justifies an investigation to answer the question of what gaze behaviour cricket batsmen of a relatively high competitive level employ when facing fast bowling. The present study was therefore designed to address this question. However, given the range of balls (fast bowling versus spin bowling) faced by batsmen, this study will limit its focus to fast in-swing and out-swing bowling.

1.2 AIM AND OBJECTIVES

The following specific aim and objectives were set for this study

1.2.1 Aim

The primary aim of this study was to determine the visual gaze behaviour of sub-elite cricket batsmen when facing fast in-swing and out-swing bowling.

1.2.2 Objectives

In order to achieve the primary aim of this study the following objectives were addressed:

- To describe and compare the visual gaze behaviour of sub-elite cricket batsmen for both successful and unsuccessful trials irrespective of the ball faced in terms of:
  - Areas of interest (AOI),
  - number of fixation,
  - duration of each fixation,
  - starting and last fixation, and
  - order of fixation

- To describe and compare the visual gaze behaviour of sub-elite cricket batsmen for both in-swing and out-swing bowling trials irrespective of the outcome in terms of:
• Areas of interest (AOI),
• number of fixations,
• duration of each fixation,
• starting and last fixation, and
• order of fixations

1.3 RESEARCH HYPOTHESES

The following research hypotheses were formulated:

• Visual gaze behaviour was different for successful and unsuccessful trials for sub-elite cricket batsmen
• Visual gaze behaviour was similar for in-swing and out-swing trials for sub-elite cricket batsmen

1.4 CONCEPT CLARIFICATION

The following concepts are clarified in order to facilitate the understanding of the research project:

• Areas of Interest (AOI) – It is an analysis method used by researchers to define areas of interest within a display and analyse only the eye movements that fall within these defined areas (Poole & Ball, 2003:10). Areas of interest will be referred to as AOI throughout the document.
• Fixation- Fixations are eye movements that stabilise the retina over a stationary object of interest to facilitate the process of encoding information (Duchowski, 2003:48 & Poole & Ball, 2003:10).
• Eye Tracker- An eye tracker is a recording device that measures an individual's point of gaze (Duchowski, 2003:99).
• Gaze- “To fix the eyes in a steady and intent look (Merriam-Webster, 2014).
• Cricket- Cricket is played on a grass wicket between two teams of 11 players, the aim of which is to outscore the opposing team (Müller & Abernethy (2012:245).
- **Pitch**- The area between the two bowling creases. At each end of the pitch are positioned two sets of three stumps which are placed 20.12m apart. The width of the pitch is 3.04m (Morrison, 1989:14).

- **Ball**- The ball is round and cased in stitched, in red leather with a circumference ranging between 22.4-22.9cm and weight ranging between 155.9-163g (Morrison, 1989:18).

- **On side**- The side of the field behind the batsman, when he assumes he’s normal stance at the crease (Morrison, 1989:28).

- **Off side**- The side of the field in front of the batsman, when he assumes he’s normal stance at the crease (Morrison, 1989:29).

- **Stroke**- “The act of swinging or striking at a ball with a bat” (Cricker, 2016).

- **Visual Search**- Is defined as a process by which one “locates a target in a cluttered scene” (Zelinsky, Rao, Hayhoe & Ballard, 1997:448).

- **Sub-elite batsman**- Croft *et al.* (2010:753) described the term “sub-elite” as someone who played competitive national league club cricket or provincial cricket. The participants in this study met the aforementioned description.

- **Visual-motor**- refers to the integration of visual perception and motor skills (Stevens & Bernier, 2013).

- **Specialist batsman**- According to Sivasamy and Anbalagan (2015:102) the term specialist batsman or batsman is generally used to describe players who specialise in batting. A cricketer contracted as a batsman and not a bowler to their respective clubs.

- **Swing**- According to Bartlett, Stockill, Elliot and Burnett (1996:416) swing refers to the lateral movement of the ball through the air.

- **In-swing**- the lateral movement of the ball through the air towards the batsman (adapted from Bartlett *et al.*, 1996:416).

- **Out-swing**- the lateral movement of the ball through the air away from the batsman (adapted from Bartlett *et al.*, 1996:416).

- **Externally paced sports situations**- According to Singer (2000a:1666), externally paced events are also known as open skills which require rapid anticipation, decision making and reactions.
• **Temporal occlusion**- According to Müller and Abernethy (2012:177), temporal occlusion paradigms control the duration of viewing time to provide visual information.

• **Spatial occlusion**- According to Müller and Abernethy (2012:177), spatial occlusion paradigms are used to determine which kinematic information is utilized for informatory purposes.

• **Point light displays**- According to Müller and Abernethy (2012:177), point light display paradigms project an opponent’s movement patterns in the form of a stick figure generated from placing reflective markers on major kinematic joints on the body. This method is used to determine the minimum visual information required for anticipation.

1.5 **SCOPE OF THE STUDY**

The study was pre-experimental in nature and utilised a quantitative approach. Participants included 20 sub-elite batsmen who were recruited using purposive sampling. All participants met the inclusion criteria relevant to this study. Due to technical difficulties experienced with the ASL mobile eye tracker only 13 batsmen’s data were analysed. The sample having met the inclusion criteria was drawn from the Nelson Mandela Metropolitan University 1st XI, Old Grey, Union and Port Elizabeth Cricket Clubs.

The testing and data collection procedure included the following: an eye dominance test, gaze behaviour assessment, speed of delivery, ambient light and a post-test questionnaire. The data collected was used to describe and compare the gaze behaviour of sub-elite cricket batsmen for both successful and unsuccessful trials when facing fast in-swing and out-swing bowling.

1.6 **SIGNIFICANCE OF THE STUDY**

The information generated from this study can potentially be used to inform and educate batsmen as well as coaches about important visual cues that must be focused on in order to perform successfully while batting in cricket. The degree of
professionalisation in sports also places a greater stress upon athletes and coaches to explore areas within the control of the athlete to achieve marginal victories. The effective use of vision is one of those areas that could potentially enhance the quality of batting and be the difference between a dismissal and the successful execution of a batting stroke.

1.7 FORMAT OF DISSERTATION

Chapter 1: Highlights the importance of the accurate and efficient acquisition of visual information in cricket and the relative lack of vision in action studies concerned with gaze behaviour of cricket batsmen.

Chapter 2: Presents an overview of literature pertaining to the demands of cricket batting in conjunction with a brief description of the intricate and complex nature of the visual system. Furthermore, anticipation is briefly elaborated on highlighting the advantage of superior anticipation ability and how this attribute contributes to successful performance in time-constrained environments.

Chapter 3: Presents the methods and procedures utilised in this study in an attempt to achieve the aim and objectives set.

Chapter 4: Describes the ambient light, ball delivery speed and eye tracking results obtained in this study.

Chapter 5: Discusses the results obtained in this study and highlights the limitations. Subsequently, recommendations for future research are also provided.

The chapter to follow will present literature reviewed to provide background to and inform the research methods and procedures employed in this study.
CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this study is to describe and compare the visual gaze behaviour of sub-elite cricket batsmen when facing fast in-swing and out-swing bowling. In order to place the focus of this study into perspective and to facilitate the discussion of the findings of this study, relevant literature is reviewed in this chapter. Three subsections are provided. The first section describes the skill of cricket batting and the associated constraints accompanying the skill. Cricket batting and bowling will be briefly discussed. The batting task will also be classified and an in-depth explanation will be provided. Secondly, the perceptual-motor skill set that is required for successful batting performance is elucidated. The visual system will include: basic anatomy of the eye, gaze control processes and the interpretation of visual information to facilitate the understanding of how vision occurs. The perceptual-motor section will discuss perception-action coupling, information processing systems, and anticipation. Anticipation is discussed in more detail in an attempt to evaluate the contribution of perceptual-cognitive skills in high time-stressed conditions.

The final section of this chapter provides a detailed overview of relevant empirical research on visual search and vision in action studies involving a variety of sporting codes.
2.2 CRICKET BATTING AND ASSOCIATED CONSTRAINTS

Cricket batting is a multifaceted skill to perform as it requires the coordination of full body movements to culminate into the production of a successful batting stroke (Sarpeshkar & Mann, 2011:306). The batting skill is also characterized by high levels of precision as one performance error can result in dismissal (Müller & Abernethy, 2006b:247). The task of a batsman in cricket is simple; to score the most runs possible. This is achieved through the production and execution of full body movements that comply with the constraints inherent to the game to produce controlled yet the most forceful batting stroke (Sarpeshkar & Mann, 2011:307). To follow is a section highlighting the skill of batting and the constraints affecting successful achievement of this interceptive task.

2.2.1 Skill of Cricket Batting

Batting in cricket is an ideal task to unearth the complexities involved in hitting a cricket ball while simultaneously trying to comprehend performance at the temporal and spatial limits of human achievement (Sarpeshkar & Mann, 2011:306). Successful batting is characterized by a high degree of temporal and spatial accuracy in coincidence timing (Müller & Abernethy 2006b:247). This degree of precision is to be achieved under conditions that possess a significant amount of uncertainty regarding the flight path of the ball, its post-bounce deceptive nature in conjunction with the bowler’s deceptive strategies (Müller & Abernethy, 2006b:247; Müller et al., 2006:2162; Sarpeshkar & Mann, 2011:306).

The level of control and prowess exhibited by skilled batsmen while executing a successful stroke, demands the intricate coordination of the visual and neuromuscular systems (Sarpeshkar & Mann, 2011:306). The objective of the visual system is to extract the required visual information from the ball and surrounding environment that necessitates appropriate motor programming. According to Pybus (2016), the first batting guideline emphasizes that the object of your attention as a batsman is the cricket ball, which should be tracked as the bowler approaches to the crease. A batsman should attempt to maintain a fairly stationary head position while simultaneously fixating on the ball as he completes the pre-determined batting
phases in an attempt to execute the desired batting stroke successfully (Hayhoe, McKinney, Chajka & Pelz, 2012:128). It has been suggested that the coupling between the performer’s head position and the object of interest may, in fact, provide a functional advantage during interceptive timing tasks (Mann, Spratford & Abernethy, 2013:2).

The batting skill can be broadly broken down into five different phases; batting stance, back-lift of the bat in preparation for movement, initiation of front foot movement and downswing of the bat, bat-ball contact and finally the follow through of the bat following bat-ball contact (Sarpeshkar & Mann, 2011:314). A batsman’s task in cricket is to intercept a 7.29 cm diameter leather ball with a 10.8 cm wide wooden bat while simultaneously avoiding dismissal (Müller et al., 2006:2163). A batsman may swing the bat either through the vertical or horizontal plane while ensuring the presentation of maximum bat width to facilitate successful interception (Müller & Abernethy, 2006b:246).

According to Müller and Abernethy (2006b:247), the batting task must be completed within the inherent constraints imposed by human reaction time and movement time latencies. Simple reaction time is the minimal amount of time it takes to identify and process a visual stimulus preceding the initiation of the desired response (Müller and Abernethy, 2006b:248). The simple reaction time delay is approximately 200 ms and during this temporal window, a batsman must identify and process a visual stimulus prior to the initiation of a movement (Müller and Abernethy, 2006b:248). The successful completion of the batting phases in conjunction with the level of control exhibited by batsmen is to a great extent dependent upon the type of bowler and the associated constraints of the bowling style.

2.2.2 Cricket Bowling and Its Effect on Batting

Cricket bowling is described by Renshaw and Davids (2004:94) as an activity that comprises of a run-up phase directed towards a spatial target, the bounding phase also known as the delivery position and finally the ball release phase. The bowling action is systematically broken down into four distinct phases; the run-up, the pre-delivery stride, the delivery stride and the follow through (Bartlett et al., 1996:405-
The speed of the run up along with the optimal biomechanical position of the bounding phase collectively impact on the angle of release and the velocity of the ball bowled (Renshaw & Davids, 2004:94). The speed at which the ball is delivered will classify the bowler. Bowling classifications are as follows: fast, spin, seam, and swing (Stretch et al., 2000:931). The average classification speed for spin bowlers is 70-80 km/h (Müller et al., 2009:645). A fast bowler is able to deliver a ball at speeds often exceeding 110km/h escalating to 160 km/h (Müller & Abernethy, 2006b:248; Müller et al., 2009:645; Yarrow, Brown & Krakauer, 2009:591). However, the adherent cricket enthusiast will understand that a deeper classification is needed to categorise bowler types. Therefore the speed classifications provided by Bartlett et al. (1996:416), need to be taken into consideration to provide a more cricket specific categorisation. The speed classifications are as follows: slow medium (64.8-97.2 km/h), fast medium (97.2-129.6 km/h), fast (129.6-144 km/h) and express (> 145.8 km/h).

A batsman facing a delivery bowled at 150km/h has less than 500 ms to react to the delivery from the moment of ball release till it reaches the batsman (Land & McLeod, 2000:1340; Müller & Abernethy, 2006b:248; Ranganathan & Carlton, 2007:369). The speed at which the ball is delivered determines the response time available to the batsman to select, organise motor actions and elicit the most effective response resulting in successful stroke execution (Bartlett et al., 1996:403; Ranganathan & Carlton, 2007:369; Müller et al., 2009:645). According to Bartlett et al. (1996:403), a reduction in available response time places a greater demand on the effector mechanisms responsible for affecting the most appropriate stroke. Ranganathan and Carlton (2007:369) further explain that skilled performers utilise task-relevant kinematic cues stemming from their opponents to anticipate future events in order to circumvent the inherent batting constraints. Furthermore, Land and McLeod (2000:1340) stated that successful cricket batting performance at the elite level reveals the limits of the visual-motor system.

Different types of bowlers will impose different constraints to efficient bat-ball interception (Müller et al., 2009:645). Spin bowlers pose less of a temporal threat but they adopt a slightly different approach to delude batsmen. Müller et al. (2009:645) explain that spin bowlers manipulate the trajectory of early ball flight characteristics.
to deceive the batsman’s prediction of anticipated ball bounce. The variability that exists regarding ball flight characteristics results in ball length discrepancies that ultimately influence the height of interception (Müller et al., 2009:645). The ball also deviates laterally post-bounce, due to spin being imparted onto the ball (Müller et al., 2009:645). This lateral deviation triggers incorrect spatial positioning of the bat and body that coincidently results in a decrement of the quality of bat-ball interception (Müller et al., 2009:645). The spatial and temporal characteristics of the ball together, aim to deceive and minimize prediction time of ball landing position (Müller et al., 2009:645). Research by Land and McLeod (2000:1345) revealed that early information pick-up and prediction of ball length was a key determinant of batting success in cricket.

The role of a bowler in cricket is to manipulate ball flight, swing (curvilinear flight path), speed and post-bounce characteristics with the objective of deceiving the batsman and the end goal of dismissing the batsman (Bartlett et al., 1996:403). A similar generic breakdown is provided in Figure 2.1 to assist in the understanding of the varying biomechanics underlying the phases of the bowling action.

![Figure 2.1 Cricket bowling phases (adapted from Glazier, Paradisis & Cooper, 2000:1015)]
2.2.3 The Interaction Between a Batsman and a Bowler

A batsman will typically advance or step backward in response to variations in ball length. Advancing movements arise in response to full pitched deliveries and backward movements occur as a result of short-pitched deliveries (Müller et al., 2009:649). The variability regarding the interception point alludes to the importance of meticulous foot movements. Preparatory foot movements need to be precise in order to promote the initiation of appropriate early movement preparation patterns (Müller & Abernethy, 2006a:446; Müller et al., 2009:649). The efficiency and accuracy of the movements employed by batsmen are directly dependent upon the velocity at which the ball is delivered. Corrective body positioning is deemed crucial for the attainment of efficient bat-ball interception (Müller et al., 2009:649).

The cricket batting task is characterised by minimal error tolerance in conjunction with time constraints that challenge the limits of the visual-motor system. The visual system plays a crucial role in the successful execution of these tasks. The demands placed on the visual system vary considerably depending on the nature of the task, whether it is stationary or dynamically based. The batting skill is considered to be a dynamic interceptive timing task.

2.3 GAZE CONTROL DURING INTERCEPTIVE TIMING TASKS

Hitting a cricket ball is classified as an interceptive timing task (Davids, Savelsbergh, Bennett & Van der Kamp, 2002:1). According to Montagne, Fraisse, Ripoll and Laurent (2000:60); Mann, Ho, De Souza, Watson and Taylor (2007:344) and Panchuk and Vickers (2009:1249), the successful interception of an object is dependent upon the performer’s movement complying with the informational constraints present in the environment. A high level of precision is a prerequisite for the execution of successful interceptive movements which require a limb segment or held implement to be in the right place at the right time while subsequently imparting a controlled amount of force into an intentional collision (Davids et al., 2002:1; Vickers, 2007:112; Lim, 2015:1). In this case in point, a batsman has to control his entire body as well as the bat to ensure that efficient bat-ball interception is attained in a controlled manner.
It is well established that a successful expert performer is known to possess superior visual perceptual skills which are a direct consequence of many years of extensive practice (Mann, Abernethy & Farrow, 2010:387; Giblin, Farrow, Reid, Ball & Abernethy, 2015:6). According to Lim (2015:2), visual information pertaining to the moving object is subsequently used to control the desired motor response during interceptive actions.

It appears that there are two schools of thought around how gaze is controlled during interceptive timing tasks, and these are dependent upon whether “the object's flight path is deemed predictable or not” (Vickers, 2007:112). Vickers (2007:112) suggests that successful performers have to develop the appropriate gaze control strategies in response to the two different aforementioned conditions. The predictable flight path denotes that the athlete utilises fixations or pursuit tracking from the moment of pre-release to early flight phase to extract the necessary information required to react appropriately (Vickers, 2007:112). Gaze control encompassing fixations in conjunction with pursuit tracking permits information processing. Duchowski (2003:48) defined fixations as “eye movements that stabilize the retina over a stationary object of interest”. Fixations extract detailed information from the object of interest, due to the slow rotation of the eye.

In contrast, during unpredictable flight characteristics, the athlete is subjected to use both early and late tracking in conjunction with saccades to extract the required information (Vickers, 2007:112). Pursuit eye movements are characterized by slow rotations of the eye that allow performers to maintain their gaze on a moving target of interest (Spering & Gegenfurtner, 2008:77). The intricacy of the object's flight is dependent upon the task constraints and the skill of the person pitching the object (in this case the bowler). Furthermore, it has been suggested that the most difficult object to track is one that bounces in front of the performer, as is the case in cricket (Vickers, 2007:112).

The implementation of the appropriate gaze strategy is dependent upon the efficient utilization of eye movements. Eye movements arise as a result of an inter-relationship that exists between visual processing and motor control systems, which in turn enable us to interpret and react appropriately to our surroundings. The object
of interest needs to be projected onto the retina on the fovea to extract high-quality visual information (Henderson, 2003:498; De Xivry & Lefévre, 2007:11). The fovea is responsible for resolving small details and affording us the ability to see objects clearly, as this is the region on the retina with the highest degree of visual acuity and colour sensitivity (Henderson, 2003:498; De Xivry & Lefévre, 2007:11; Vickers, 2007:18).

It is, therefore, imperative that an individual’s line of sight is aligned with the fovea, in order for an object to be viewed with acuity. Humans are capable of executing multiple rapid eye movements (three times per second); known as saccadic eye movements, that serve to correct positional errors that may occur between the performer’s eye and the tracked object (Henderson, 2003:498; De Xivry & Lefévre, 2007:11). Correctional eye movements are made to consistently align the object of interest with the fovea on the retina by directing fixations towards task-relevant cues (Henderson, 2003:498). This alignment is achieved through what is termed gaze control, which enables us to successfully navigate through a given scene.

The complexity of the temporal and spatial characteristics of the tracked object will directly influence the type of eye movements employed. These eye movements can be typically broken down into saccadic and smooth pursuit eye movements (Duchowski 2003:49; Spering & Gegenfurtner, 2008:77). Typically, humans are capable of tracking a moving target in the range of 1-100 deg/s; however, pursuit tracking may be too slow when attempting to track objects projected at great velocities, such is the case when a batsman faces a fast bowler (Spering & Gegenfurtner, 2008:77). To compensate for excessive target speeds in conjunction with the unpredictable nature of the flight path of a cricket ball; pursuit tracking is often supported by catch-up saccades to restrict large positional errors that may occur and to subsequently guard against the eye from lagging behind the ball (De Xivry & Lefévre, 2007:11).

The final fixation prior to movement initiation is thought to be particularly important as response programming occurs during this time (Lim, 2015:2). This final fixation is also known as the “quiet eye” period (Vickers, 2007:11). The quiet eye is defined as the duration of the final fixation directed towards a specific target prior to the

The quiet eye period represents cognitive processing during which a goal-directed movement is refined on the basis of force, direction and velocity (Wilson et al., 2015:22). During quiet eye periods, sensory information is integrated with the mechanisms responsible for the planning and online control of the desired response (Wilson et al., 2015:22). Furthermore, Wilson et al. (2015:20) explained that the quiet eye is linked to attentional control. The ventral and dorsal systems interact dynamically during the perception of a visual scene (Wilson et al., 2015:21). Subsequently, during the onset of attention (focused state), the ventral stream is suppressed to reduce the influence of task-irrelevant cues during information processing (Wilson et al., 2015:21). According to Wilson et al. (2015:20), the quiet eye period is guided by top-down information processing which will be discussed later in this literature review. Figures 2.2 and 2.3 illustrate the effect of the quiet eye period on motor control during the non-focused and focused state, respectively.

Figure 2.2 The effect of the quiet eye period during a non-focused state (adapted from Wilson et al., 2015:22)
The effect of the quiet eye during a non-focused state results in a more rigid control on your motor patterns. Figure 2.3 highlights a more controlled and smoother execution of the motor programme during a focused cognitive state. The more focused the performer during the quiet eye period, the more control the performer will have on the execution of the desired motor programme. This is important to remember for cricket batsmen who need to concentrate for hours on end whilst contending with the varying constraints inherent to the game.

The preceding section focused on discussing cricket batting and bowling while simultaneously highlighting the unique interaction that occurs between these two skills. Subsequently, this information portrayed the intricate nature of cricket batting. The aforementioned facilitated a greater understanding of the important contribution visual gaze behaviour has to successful performance within a time-constrained environment like cricket batting. The skill of cricket batting was classified as an interceptive timing task, which provided a deeper understanding of the different factors impacting the degree of success attained within cricket batting. The final section focused on different control mechanisms responsible for controlling gaze. The latter served as a valuable source of insight, and to focus attention on the fact that the gaze control strategy implemented is dependent on the flight characteristics of the tracked object.
In cricket, bowlers attempt to dismiss batsmen through varying ball flight characteristics through the application of swing. Batsmen, on the other hand, need to be able to identify the relevant ball flight characteristics of the bowled ball utilizing the appropriate gaze control strategy to successfully strike the ball. The literature thus far has alluded to the critical role visual gaze behaviour plays in cricket batting when facing fast bowling. In order to understand visual gaze behaviours and to provide further background to this study, an explanation of the visual system and its contribution to gaze control is addressed in the section to follow.

2.4 THE VISUAL SYSTEM

2.4.1 Introduction

The section on the visual system will be presented in four subsections. The first provides a brief explanation of the anatomy of the eye to facilitate the understanding of how light enters the eye and how an image is projected onto the retina for clear vision. Secondly, insight into the interpretation of visual information is explained. Section three discusses the two opposing theories that attempt to explain the control mechanisms responsible for executing the desired motor response. The final section explains the integral link between perception and action. Furthermore, the neural pathways responsible for the occurrence of the aforementioned function are also briefly explained.

2.4.2 Basic Anatomy of the Human Eye

Milner and Goodale (1995:5) stated that vision amongst humans has a single function; “to provide a unified internal representation of the external world”. This internal representation forms the perceptual foundation for visually based thought and action (Milner & Goodale, 1995:5). To facilitate the understanding of how vision is transformed, it is necessary to provide a brief anatomical description of the visual system.

The globed shaped eyeballs occupy the anterior part of the orbit. The orbits are conical cavities found within the skull, and retain its shape by means of fluid pressure
contained within the eye (Pirenne, 1967:1). Light enters the eye through the pupil, a narrow opening found within the iris. The iris varies in size due to expansion and constriction that occurs in response to differing light stimuli. The pupil adjusts depending on the availability of light, becoming smaller in bright light and larger in dim light (Vickers, 2007:18). The lens is adjusted by the ciliary muscles, which are smooth muscle fibers contained within the eye arranged longitudinally, circularly and radially. The contraction of these muscle fibers decreases the size of the ring formed by the ciliary body (Drake, Vogl, Mitchell & Gray, 2010:901).

The cornea is part of the outer layer of the eye and is comprised of a tough membrane, the sclera (Yarbus, 1967:5). The cornea is transparent and is not adjustable. The sclera enables the eye to maintain a constant shape while protecting its contents. When light enters the eye, it is initially bent by the curvature of the cornea and secondly by the lens. Bending the light positions objects of interest on the fovea, which is an area found at the rear portion of the eye within the retina (Vickers, 2007:18). The fovea is of greatest importance for vision, as it produces the most accurate vision of details in bright light (Pirenne, 1967:4).

The retina is located within the rear interior surface of the eye and contains light-sensitive receptors known as photoreceptors. Photoreceptors convert light energy to electrical or neural impulses (Duchowski, 2003:20). “The neural signals that originate at these receptors lead to deeper visual centers in the brain,” as proposed by Duchowski (2003:20).

Photoreceptors are classified into rods and cones. Cones are located within the fovea and respond to brighter chromatic light while simultaneously being responsible for the detection of colour and for resolving detail (Vickers, 2007:18). Rods are sensitive to dim and achromatic light and have the added function of being able to detect motion. The total rods tend to increase towards the periphery.

2.4.3 The Interpretation of Visual Information

Humans depend on the perception and utilisation of visual information arising from the environment to guide their actions (Ranganathan & Carlton, 2007:369). The
ability to effectively perceive and utilise visual information becomes increasingly more significant in activities where the temporal window available for decision making is minute; as is the case during the interception of fast moving objects (Ranganathan & Carlton, 2007:369). Sarpeshkar and Mann (2011:308) further explain that success in striking sports is dependent upon the existence of an efficient link between the perceptual and motor systems. An efficient perceptual-motor link facilitates accurate information extraction from the kinematic attributes of the opponents in conjunction with the ball (Sarpeshkar & Mann, 2011:308).

The coupling information is utilised by the performer to methodically adapt their preparatory motor programs and timing of bat swing in relation to the constantly changing informational constraints present in the environment to result in successful interception (Sarpeshkar & Mann, 2011:308). This coupling between perception and action forms an integral part of success when analysing performance at the elite level (Sarpeshkar & Mann, 2011:308). This is especially true due to the small margin of performance errors that accompany elite batting performance (Müller & Abernethy, 2006b:247). This particular study centers on the visual gaze behaviour of sub-elite cricket batsmen; therefore, the focus of this study will be to unearth and explain performance at a relatively high level. The importance of accurate motor actions has been highlighted, and therefore the control of these actions requires further explanation.

2.4.4 Prospective versus Predictive Control

Skilled movements are generally controlled in two ways; namely prospective and predictive control (Sarpeshkar & Mann, 2011:308). During prospective control, the action is continuously regulated through formulating relationships among crucial perceptual variables in the environment (Davids, Renshaw & Glazier, 2005:37; Katsumata & Russell, 2012:499). In contrast, during predictive control which is favoured during time stressed environments; the performer predicts the possible time and place of interception (Beek, Dessing, Peper & Bullock, 2003:1511; Dessing, Peper, Bullock & Beek, 2005:669; Panchuk & Vickers, 2009:1249). According to Katsumata and Russell (2012:499), this prediction is pre-programmed and can be executed instantaneously. However, a disadvantage of predictive behaviours is that
success is dependent upon the accuracy of the pre-programmed predictive movement. The accuracy of the prediction is inversely dependent on the temporal window available for prediction (Beek et al., 2003:1511). The temporal constraints inherent to the game of cricket have been previously highlighted.

In cricket batting, the prospective gaze control strategy is favoured due to the unpredictable nature of the cricket ball’s flight path. The continuous regulation of the action is characteristic of successful batting performance. Land and McLeod (2000:1343) suggest that a batsman would refine their movement to play the ball as late as possible in an effort to watch it as close as possible to the bat. This strategy is often adopted to ensure a higher percentage of successful strokes. Katsumata and Russell (2012:499) examined the control processes that underlie hitting a falling ball from varying heights with a wooden bat. The visual occlusion paradigm was implemented. The results generated from the study support batters’ use of prospective control due to the coupling of the participant’s movements with the ball’s flight characteristics (Katsumata & Russell, 2012:513).

Katsumata and Russell (2012:513) suggest that the action was continuously regulated to the moment of interception. However, the predictive control strategy played a role in initiating the bat swing during the visual occlusion conditions (Katsumata & Russell, 2012:513). An inter-relationship exists between predictive and prospective control to complete any given task. According to Katsumata and Russell (2012:499), predictive control is utilised to initiate the bat swing, and prospective control is used to guide and update the bat to near interception.

Research conducted by Panchuk and Vickers (2009) explored the control strategies of expert goaltenders in ice hockey using a spatial occlusion paradigm. The results indicated that “goaltenders used a predictive control strategy where the earlier vision of the puck in conjunction with the stick resulted in a greater percentage of saves (Panchuk & Vickers, 2009:1257). Regardless of the control mechanism used to guide successful bat-ball interception, the temporal constraints under which a batsman must perform are severe. One of the strategies employed by batsmen to surmount the posing temporal constraints is through the effective identification and interpretation of advance kinematic information inherent in the movement pattern of
their opponents (Sarpeshkar & Mann, 2011:311). An athlete’s ability to use advance postural cues is imperative in fastball sports, in particular, cricket; where the speed at which the ball is delivered dictates that decision making and response selection must be made in advance of the action (Savelsbergh et al., 2002:279).

2.4.5 Perception-Action Coupling

Perception is described by Dehaene, Changeux, Naccache, Sackur and Sergent (2006:204) and Milner and Goodale (2008:775) as the conscious experience of seeing; which refers to the visual information obtained from a given scene. The definition of perception can be further extended to memory or abstract representations that could potentially reach conscious awareness (Milner & Goodale, 2008:775). In contrast, “action” refers to the programming and real-time control of movements (Milner & Goodale, 2008:776).

The difference between “vision for action” and “vision for perception” insinuates that visual information is transformed in different ways dependent upon its purpose (Milner & Goodale, 2008:775). According to several researchers: Ranganathan and Carlton (2007:370); Milner and Goodale (2008:775) and Katsumata and Russell (2012:500) the two cortical pathways (streams) responsible for visual processing are the ventral and dorsal streams.

According to Milner and Goodale (2008:774) and Katsumata and Russell (2012:501), the ventral stream is essentially responsible for the visual perception that enables us to identify objects in the environment. The information supplied by the ventral “action” stream not only serves to identify an object of interest but also assists in selecting an appropriate course of action to deal with the stimulus (Milner & Goodale, 2008:775). Conversely, Milner and Goodale (2008:774) state that the dorsal stream plays an interceding role between visually guided actions directed at objects of interest in the environment; for example, reaching and grasping for a cup (Milner & Goodale, 2008:775).

The dorsal stream plays a role in the implementation and regulation of the selected response (action) and can also process object acceleration (Katsumata & Russell,
Goodale and Westwood (2004:204) explain that “the retina sends projections to the dorsal part of the lateral geniculate nucleus of the thalamus (LGNd), which projects in turn to the primary visual cortex. The ventral stream arises from early visual areas and projects to regions in the occipitotemporal cortex. The dorsal stream also arises from early visual areas but projects instead to the posterior parietal cortex. The posterior parietal cortex also receives visual input from the superior colliculus through the pulvinar. A graphical representation of the two streams of visual processing in the human cerebral cortex can be seen in Figure 2.4.

Figure 2.4 Graphical representation of the ventral and dorsal contributions to visual processing in the human cerebral cortex (adapted from Goodale & Westwood, 2004:204)

The section thus far presented the intricate nature of the batting skill along with the constraints that are inherent to the game. The interceptive nature of the batting task was described in conjunction with how gaze is controlled during the execution of interceptive movements. The visual system with specific focus on prospective and predictive control mechanisms was elucidated upon. Finally, the critical link between perception and action was presented. This link is often the most important to consider when analysing the batting skill, as the batsman’s perception in conjunction with the implementation of the appropriate motor response will determine the
success of the batting stroke executed. Details pertaining to the theories behind perceptual-motor control will be attended to in the succeeding section.

2.5 PERCEPTUAL-MOTOR CONTROL THEORIES

2.5.1 Introduction

Perception refers to the visual scene, and motor refers to the response or motor plan. The section to follow aims to provide an overview of the current information processing theories that attempt to explain the occurrence of the control mechanism utilised by skilled performers. Two opposing theories will be briefly elaborated on. Subsequently, a brief explanation of attention and the role attention plays in perceptual-motor control will be elucidated. A limiting factor to performance and particularly to the perceptual process is the amount of information a performer can attend to at a time. Details pertaining to this constraint will also be attended to in this section.

2.5.2 Information Processing Theory

There are two opposing theoretical approaches regarding how the information processing system operates; ecological psychology and cognitive psychology. Ecological psychology was founded by Bernstein (1967) and Gibson (1979). Michaels and Carello (1979:2) explains that ecological psychology is also referred to as direct perception, which is the detection of information. Ecological theorists believe that this detection of information occurs unaided by inference, memories or other neural representations (Michaels & Carello, 1979:2).

According to McMorris (2004:17), there are two major contributing theories governing ecological psychology; the action systems theory and the dynamical systems theory. Ecological psychologists believe that the environment dictates how humans are able to react in any given situation (McMorris, 2004:18). The opportunity for action that an environment affords an individual has been defined by Gibson as “affordances” (McMorris, 2004:18).
To facilitate the understanding of affordances, soccer will be used as the context. In a two versus one attacking scenario, the player on the left is marked but the player on the right is unmarked. The “affordance” or opportunity provided by the environment is, therefore, to pass the ball to the player on the right. Ecological theorists, therefore, believe that the environment must be actively searched to uncover affordances; this active search is termed direct perception (McMorris, 2004:18).

Ecological theorists view perception and action as a direct link unaffected by memory representations to perform accordingly. McMorris (2004:19) explains that the perception-action coupling within any given task is situation specific and is directly influenced by the task-specific goals that need to be met. Furthermore, the role of the central nervous system is to decide what course of action to take in an effort to bring out the desired response.

According to Sternberg and Sternberg (2011:3), “cognitive psychology is defined as the study of how people perceive, learn, remember and think about information”. As opposed to ecological psychology which involves direct perception; the act of perceiving involves the intervention of memories and knowledge representations stored in the brain (Michaels & Carello, 1979:2; Vickers, 2007:4).

The present study is focused on the information processing theory as it relates to cognitive psychology; and hence, it will be further elucidated. According to Stelmach (1982:64), the theory of human information processing describes humans as a processor of information. Stelmach (1982:64) proposed that “an organism has both receptors and effectors in conjunction with an intervening control system”. The control system plays an instrumental role in the sequential steps that are followed to firstly, process information; and secondly, to facilitate the successful completion of the desired movement outcome. Information processing is a reflection of the efficiency of the control system to sense, attend to, transform, retain and transmit information (Stelmach, 1982:64). Information processing forms an integral part of how humans successfully interact in the environment.
The stages of the information processing system can be broadly broken down into detection, recognition and memory (Stelmach, 1982:65). McLeod (2008) explains that humans are information processors who can only process a limited amount of information. The information processing model involves three main stages; input, storage, and output. The input refers to the analysis of the stimuli; storage is concerned with the internal coding and manipulation of the stimuli within the central nervous system, and the output stage is responsible for executing the desired motor action (McLeod, 2008). Figure 2.5 provides a simple graphical illustration of the information processing system.

![Information processing system](figure25.png)

**Figure 2.5 Information processing system (adapted from McMorris, 2004:13)**

Information processing theorists refer to incoming information stemming from the environment or scene display as the input (McMorris, 2004:14). The perception of the input plays a crucial role regarding how information from the environment is interpreted (McMorris, 2004:15). The scene display encompasses both task-relevant and irrelevant cues that the performer must “filter” to process only task-relevant cues. The information from the scene is relayed to the central nervous system for analysis and interpretation (McMorris, 2004:15). Processing task-relevant cues in interceptive timing tasks will be a large contributor to successful performance. Selective attentional strategies are often employed to filter task-relevant from task-irrelevant cues, where the influence of memory largely dictates the filtering process (McMorris, 2004:15).
The information processing model places great emphasis on the impact of memory representations on perception and the selective attentional ability of a performer. Memory represents information that is retained and processed for future use (Schmidt & Lee, 2011:88). As an individual is presented with information, it is stored in the short-term sensory store. The short-term sensory store is able to hold vast amounts of information but for only for a limited duration (Schmidt & Lee, 2011:90). A component of short-term memory is working memory; that plays a role in retrieving information from both short-term and long-term memory that is stored and used for further processing, depending on the requirements of the processing system (Schmidt & Lee, 2011:92). The short-term memory contains information that is being actively used (Matlin, 2005:10). Long-term memory has a large capacity as it holds limitless amounts of information. The information stored within long-term memory is permanent (Matlin, 2005:10). A graphical illustration of the interplay that exists between visual search (perception) and selective attention during information processing can be seen in Figure 2.6 and 2.7.
Figure 2.6 Two-stage model of visual search and selective attention (adapted from Abernethy, 1988:207)
According to McLeod (2009), short-term memory has the following three components: limited capacity, limited duration, and encoding ability. The short-term sensory store has the capability of storing an average of seven items at any one time. The duration of the stored information is very limited; 90% of all information entering the short-term memory is lost within 10 s and rehearsal, incorporating both physical and mental, is the only determining factor that influences the degree of information that is retained (McMorris, 2004:119).

Information that is received is stored in short-term memory and then it is transferred to long-term memory. The short-term memory deals with perceiving incoming information, and the role of long-term memory is to facilitate the initiation of the desired response to be carried out (McMorris, 2004:15). The interplay that exists between short-term and long-term memory is known as working memory. Once a decision has been decided upon, the central nervous system organizes the movement, known as an efferent organization (McMorris, 2004:15). The information is then sent to the peripheral nervous system for the movement to be carried out. The feedback process only occurs when the action is performed. Actions that are
characterized by slow movements use feedback to constantly refine the action (McMorris, 2004:16). Feedback regarding the success or failure of the action is stored in long-term memory and is used as a learning cue for future performances see Figure 2.7, (McMorris, 2004:16).

As information is passed through the processing system, the order of processing stages is invariant (Stelmach, 1982:65). The cognitive psychologist’s central assumptions underlying information processing are (Stelmach, 1982:66):

1. Various processing stages occur between stimulus and response
2. The sequence of processing stages is initiated by stimulus presentation
3. Each stage operates only on information available to it
4. Each stage transforms the information supplied to it, an event which requires time for accomplishment
5. Upon completion of processing performed at one stage, the transformed information is made available to the next stage of processing.

For the purpose of the present study the information processing model is favoured as a theoretical frame for the research, as the influence of memory representations and feedback might be utilised to guide the online adaptation of a performer’s movement pattern. The preceding literature provides useful insight into the manner in which the desired response is executed. Furthermore, the control systems allude to the sequential processes that are undertaken to process visual information received at the sensory receptors. A determining factor concerning the amount of information passed through the system is attention. Humans have an innate ability to only attend to a limited amount of information. The succeeding section discusses attention and how “filtering” mechanisms are employed to differentiate between task-relevant and irrelevant cues.

2.5.3 The Role of Attention

Attention is defined as “selectivity” during scene perception; whereby an organism intentionally focuses their attention on task-relevant cues, while purposefully excluding task-irrelevant cues (Bundesen, 2001:878). The amount of time that
necessitates successful information processing is dependent upon the complexity of
the information presented, previous exposure to the information and whether we
have learned to attend to task specific cues or not (Vickers, 2007:54). The process of
selectively filtering out task-irrelevant cues while processing relevant information is
known as attention (Vickers, 2007:54). Humans possess a limited processing
capacity; therefore, we can only concentrate on small amounts of information at any
given time (Vickers, 2007:54). During interceptive timing tasks, an athlete may be
presented with endless amounts of visual information. A prerequisite for successful
performance in all sporting scenarios requires athletes to possess an efficient ability
to orientate their attention and gaze simultaneously (Vickers, 2007:54).

Erickson (2007:20) presented an information processing model adapted from
Welford (1960) for sports performance. This model proposes that skilled motor
performance is the result of three processing mechanisms; perceptual, decision and
the effector mechanisms. These mechanisms function in a sequential manner.
Furthermore, this model denotes a significant consideration of the influence of
intrinsic and extrinsic feedback in conjunction with memory (Erickson, 2007:21).

According to Erickson (2007:21) and McMorris (2004:15), the perceptual mechanism
receives an immense amount of information stemming from a diverse collection of
sensory receptors (vision, vestibular, tactile and auditory) within the central nervous
system. The information, once received, is transported for interpretation via the
sensory channel which has a limited processing capacity. This limited capacity to
process information demands the implementation of selective attention. Selective
attention improves the filtering of task-irrelevant cues and the selection of task-
relevant cues for visual information processing (Erickson, 2007:21). Erickson
(2007:21) explains that the effectiveness of the filtering of information is largely
influenced by the performers’ sport-specific knowledge and past experience. The
perceptual mechanism is responsible for organizing and interpreting the information
that passes through the system in a manner that facilitates optimal performance
(Erickson, 2007:21).

The processed sensory information is transmitted to a decision mechanism to
determine the most appropriate motor response in relation to the received stimuli
Erickson (2007:21) explains that the neural commands that produce the desired response are organized and sent to the appropriate brain centers for the execution of the action where the entire motor response is controlled by the effector mechanism. The high degree of motor control is a reflection of the effectiveness of the perceptual and decision mechanisms in controlling both internal and external information sources. There is constant interaction between the internal and external information systems (Erickson, 2007:21). This model provides a simple understanding of the processes involved when an athlete is required to react to sensory information in a sporting scenario (Erickson, 2007:21).

Vickers (2007:54) proposed that the processing of visual information is dependent upon whether the bottom-up or top-down processing methodology is followed. Bottom-up information processing refers to the processing of information without the influence of feedback (Vickers, 2007:54). The characteristics (colour, motion, textures) and degree of saliency of the object within the visual scene are subconsciously perceived and these perceptual representations are used to direct motor behaviour (Vickers, 2007:54).

In contrast, top-down information processing refers to the flow of information from higher to lower cortical brain areas influenced by the knowledge base (as a result of previous experience) of the performer (Vickers, 2007:55). According to Vickers (2007:55), top-down processing is affected by the following factors: memory, individual goals, and expectations, the amount of knowledge and experience the individual possesses with a given scenario. Furthermore, top-down information processing attaches a deeper understanding of motor control that assists in conceptualizing sports performance across various domains. According to Vickers (2007:55), factors like anticipation, expectations, goals and intentions collectively influence the manner in which information is processed following the top-down approach.

Broadbent (cited in McLeod, 2008) proposed the first modern theory of attention, known as the filter theory. McLeod (2008) explains that Broadbent's, Treisman's and Deutsch and Deutsch's late selection filter models are collectively known as
“bottleneck” theories of attention. These theories were developed on the premise that there is a limited capacity for paying attention (McLeod, 2008).

According to Shiffrin and Schneider (1977:177), Broadbent’s selective attention model (1971) has two basic selective processes. The first arising from the physical input referred to as the “filtering or stimulus set”; and the second coming from the internal response also known as the “response set” (Shiffrin & Schneider, 1977:177). As information enters the system (input), it is accepted in a parallel manner through a very brief short-term sensory information store that acts like a buffer (Shiffrin & Schneider, 1977:177).

Shiffrin and Schneider (1977:177) suggest that the duration of the buffer is 1 s. The filter then selects information from the buffer after which it proceeds through a limited capacity channel (Broadbent, 1958:42; Shiffrin & Schneider, 1977:177). Broadbent’s (1958) theory stated that the filter only allows one source of information to pass through the system at any given time (Shiffrin & Schneider, 1977:177). An example of the filter theory can be seen in Figure 2.8 below.

**Figure 2.8 Broadbent’s filter theory of attention**
(adapted from Bundesen, 2001:878)
Information processing in conjunction with selective attention, explains the system processes involved in acquiring information from a visual scene and the sequential manner that information is processed, in an attempt to elicit an appropriate response.

Information is received via the sense organs and stored for a brief period in the short-term sensory store. However, the sensory store has a limited capacity. This limited capacity is an indirect consequence of our attention capabilities. To circumvent this limited capacity, information needs to be filtered out on the basis of task-relevant and irrelevant cues. This is the premise of the inter-relationships that exists between information processing and the role of attention.

Anticipation plays a significant role in information processing. The ability to anticipate allows the performer to not only predict the likely outcome of an event, but it affords the performer the innate ability to programme their motor programme earlier and bypass some of the processing operations. In time-constrained environments, this is seen as a pre-requisite to success. The beneficial effect of anticipation during information processing can be viewed in Figure 2.9. When an individual does not anticipate, they go through the normal pre-determined information processing stages. However, anticipation affords the performer the added advantage of bypassing the response selection stage and initiates an earlier response programming stage. The aforementioned reduces the response time of a performer. In time-constrained events, this ability is crucial for successful performance.
The preceding section presented the perceptual-motor control theories. These theories served to highlight the different ways in which organisms perceive, process and react to the stimuli presented. Additionally, the sequential order through which information is processed was elucidated upon. Furthermore, the role of attention specifically highlighting how the performer purposefully distinguishes between task-relevant and irrelevant cues was briefly described. Information processing appears to be a time-consuming process. The temporal constraints inherent to the game of cricket may suggest that anticipation may play a crucial role in the successful execution of interceptive actions. The critical contribution of anticipation and how superior anticipation ability may be used to bypass some of the information processing stages was briefly alluded to.
The subsequent section aims to elucidate the techniques employed to measure anticipation and the influence thereof on performance. Furthermore, characteristics of the elite to sub-elite performers, along with the cognitive processes involving anticipation are briefly explained.

2.6 ANTICIPATION AND TECHNIQUES EMPLOYED TO MEASURE ANTICIPATION

The chapter thus far presented literature on cricket batting and the associated constraints inherent to the game that a performer must contend with in order to perform successfully. Furthermore, the visual system was introduced, specifically highlighting the crucial contribution of vision to successful performance. The researcher acknowledges that anticipation and expertise have been investigated using numerous different tasks; however, this section is dedicated specifically to interceptive timing tasks as it has a more direct link to the current study.

The constraints that one has to contend with in interceptive timing tasks appear to have many similarities. The following constraints collectively impact on the performance environment: visual cues encompassing both informative and deceptive information; the induced time pressure due to the velocity of the game; the precision with respect to temporal and spatial accuracy that must be attained; and finally, the spatial uncertainty concerned with the flight path along with post-bounce deceptive properties of the desired object of interest (Müller et al., 2006:2161; Müller & Abernethy, 2012:176). According to Müller & Abernethy (2012:176), the primary source of information in striking sports; in particular, cricket, stems from the object that must be intercepted; in this case a cricket ball. However, a multitude of advance visual information arising from the subjective probabilities and the kinematic properties of opponents can be very useful to the performer.

It is evident that cricket batting defies the very limits of human performance in a severely constrained spatial and temporal performance environment. The ability to accurately identify essential contextual information stemming from the kinematic characteristics of the bowler forms an integral part of successful batting. This ability facilitates the accurate anticipation of future sporting events, which serves a
contributing factor towards continuous successful batting performance (Müller et al., 2006:2163; Sarpeshkar & Mann, 2011:311).

Anticipation is defined as the ability to predict the likely outcome of an event prior to the occurrence of the event itself (Piras, Lobietti & Squatrito, 2014:1). The ability to anticipate is pivotal as the speed at which certain sports are played often dictates that decision making needs to occur in advance of an opponent’s action (Piras et al., 2014:1). Anticipation ability becomes increasingly more critical in sports that require the interception of objects that travel at high velocities. The ability to anticipate allows expert performers to react in domain specific scenarios with seeming time to spare (Yarrow et al., 2009:591). Accurate anticipation is pre-eminent to successful batting performance in cricket, as the temporal constraints that batsmen have to contend with are severe (Müller et al., 2009:644). Anticipation not only affords the batsman an added advantage of conquering these constraints but also provides a means for the performer to safeguard against deceptive strategies employed by an opponent. According to Abernethy and Zawi (2007:353) and Jackson and Mogan (2007:341), as well as Williams, Ford, Eccles and Ward (2011:433), early and accurate anticipation ability affords the athlete additional time to interpret, formulate and execute the most appropriate response.

Anticipation is a fundamental perceptual-motor skill that is crucial in order to perform at the elite level. Therefore, it is imperative for athletes to acquire the necessary skill set in order to succeed. The acquisition of differing skill sets affords them the opportunity to develop knowledge structures and cognitive processes that allow them the ability to anticipate effectively (Williams et al., 2011:432). A defining characteristic of all expert performers is their ability to rapidly retrieve and encode large quantities of information (Singer, 2000b:223; Williams, 2000:738). According to Williams (2000:739) and Yarrow et al. (2009:591), this ability is of a direct consequence of knowledge structures developed over many years of extensive practice, which may subsequently result in the earlier onset of the desired response. The perceptual part of anticipation was initially thought to include key factors as depicted in Figure 2.10.
The process of anticipation arises as a result of a performer’s ability to identify, interpret and utilise advance postural cues to their distinct advantage. Advance cue utilisation is defined by Williams (2000:739) as the ability to make predictions of the likely outcome of a scenario based on the kinematic properties of the opponent. Williams et al. (2011:433) further explained that the processes underpinning anticipation include: recognising and using task-relevant kinematic characteristics of opponents, recognising familiarity and structure in the patterns of others and utilising probabilities and expectations within a given scenario. According to Müller et al. (2006:2164), this early identification and utilisation of advance visual information form an integral part of skilled batting performance in cricket.

Temporal and spatial occlusion paradigms are often implemented to lure out the mechanisms underlying the extraction and utilisation of visual information in interceptive timing tasks (Müller et al., 2006; Williams & Ward, 2007; Müller & Abernethy, 2012:177). The amount of visual information comprising of both advance, as well as ball flight information available to the performer, is altered during these occlusion conditions to determine which phase of the visual stimuli or task is
considered to be critical for the extraction of needful visual information to subsequently result in accurate anticipation and to further facilitate successful performance. The intricate relationship that exists between perception and action with a specific focus on the cognitive and motor elements that collectively aid in the execution of the most appropriate response can be seen in Figure 2.11.

Figure 2.11 Cognitive and motor elements involved in creating and generating an effective movement response in externally paced situations (adapted from Singer, 2000b:223)

The typical intertwined cognitive and motor elements involved in externally paced sports situations are presented in Figure 2.11 above. The performer is presented with a sporting scenario; in this case, the performance situation. The initial step is to visually search (measured with the eye tracker in the current study) for task-relevant cues (postural and from the ball). This step is supported by anticipation (prediction of what will happen). Accurate anticipation ability is critical, as this directly influences
subsequent processing stages. The acquired information is simultaneously used to influence rapid decision making and appropriate response selection. The final step is to initiate and regulate the movement up to the point of completion (measured as stroke outcome in the current study). Anticipation appears to be pivotal to success; as inaccurate anticipation will foster incorrect decision making, movement initiation, and completion. Anticipation ability is to some degree supported by the performer’s visual search behaviour, the interpretation of situational probability information and recognising familiarity patterns (recall). The following section will provide details on how these factors contribute to accurate anticipation. The section to follow will present current literature on the methods employed to lure out the processes that facilitate accurate anticipation ability.

2.6.1 Visual Search Behaviours and Advance Cue Utilisation

The manner in which the eyes are controlled to extract task-relevant visual information from the environment is defined as visual search, which allows us to navigate effectively and react appropriately to the stimuli presented (Williams, 2000:741; Williams, Janelle & Davids, 2004a:302). Portable head mounted eye movement registration systems are often employed to assess the visual strategies of performers while executing the desired task. The aforementioned provides useful insight into the mechanisms underpinning successful performance, specifically during interceptive timing tasks with a specific focus on information pertaining to point of gaze, eye movements and fixations (Williams et al., 2004a:301; Müller & Abernethy, 2012:179). A typical experimental setup employed by researchers to examine the visual search characteristics of performers can be seen in Figure 2.12. The diagram illustrates a participant wearing an eye tracker connected to a laptop while watching a video based stimuli projected onto a screen. The participant will then be required to respond accordingly while the eye tracker records the participant’s eye movements.
The effectiveness of the motor programme executed is largely determined by the application of visual attention (Williams et al., 2004a:301). A typical model highlighting the different factors influencing visual attention is illustrated in Figure 2.13.
Visual information is received via the short-term sensory store. This information undergoes a filter where the information is broken up into task-relevant and irrelevant cues. The process of receiving visual stimuli and the filtering of the stimuli occurs during the pre-attentive and attentive stages. The aforementioned stages signify the point whereby a performer will begin to shift their attention to focus entirely on relevant cues (attentive stage). The task-relevant cues are then subsequently passed through the system onto the decision making and response selection stage. The selective attention, decision making, and response selection stages are influenced by memory (acquired knowledge). Memory representation occurs as a result of previous exposure to a given stimulus. This previous exposure guides the filtering process to ensure a more efficient control system. The more efficient the control system, the faster the appropriate response is selected and implemented. Research has revealed that expert performers utilise situational probability information to increase the speed of decision-making. Extensive sport-specific knowledge has largely led to this occurrence. The section to follow will present literature on the contribution of visual search and advance cue utilisation to successful performance.

Figure 2.13 Cognitive model of visual attention (adapted from Williams et al., 2004a:303)
Savelsbergh et al. (2002) assessed the visual search behaviour among soccer goalkeepers. A group of experts and novices wearing the ASL 4000 SU mobile eye tracker had to anticipate the direction of penalty kicks when viewing a temporally occluded video. The players were to try and disguise the intended direction of these kicks. Experts were significantly more accurate in predicting penalty kick height and direction; made fewer corrective movements and when corrective movements were made, they initiated these movements later than novices (Savelsbergh et al., 2002:283). Moreover, experts not only made fewer fixations of longer duration; but also extracted more information from the kicking leg, non-kicking leg, and ball regions in comparison with novices who fixated on the trunk, arm and hip regions. In a follow-up study, Savelsbergh et al. (2005) used a successful and unsuccessful expert group and yielded similar results to the expert group of Savelsbergh et al. (2002). Successful experts fixated more time on the non-kicking leg; in contrast to the unsuccessful experts, who fixated on the head. No significant differences were found for fixation duration, number and number of areas fixated per trial. The authors suggested that the determining factor in saving a penalty may be a combination of when to initiate a response and attention directed towards the non-kicking leg.

In a similar study, Dicks et al. (2010) examined visual gaze behaviours under in situ and video simulation using the same experimental set-up as Savelsbergh et al. (2005). A group of experts had to anticipate penalty kick direction while viewing penalty kicks under five different experimental conditions; which included verbal and movement responses. The performance was significantly better during the in situ-movement compared to video simulation conditions. Interestingly, goalkeepers did not fixate on the ball until the final 500 msec of the penalty takers approach during video simulation verbal, video simulation movement and in situ-verbal. In contrast, during in situ-interception, the ball was fixated upon earlier and for a longer duration more than any other viewing condition. The goalkeepers also made more saves during the movement and interception conditions in comparison to non-movement responses. Similarly, Shim, Carlton, Chow and Chae (2005:173) also found that experts reacted faster than novices at anticipating the type and direction of tennis strokes when viewing the live hitter in comparison to a ball machine. The authors suggested that visual gaze behaviours may be dependent upon the demands presented to the performer (Dicks et al., 2010:717).
McRobert et al. (2009) investigated how advance cue utilisation contributes to anticipation in a video-based cricket task. Participants also viewed video stimuli similar to Dicks et al. (2010:708). The results revealed that more fixations were directed at the ball-hand location by both skilled and less skilled participants. Furthermore, skilled batters viewed the bowling arm, head-shoulder, trunk-hips and predicted ball release area more compared to less skilled batters (McRobert et al., 2009:479). Interestingly, skilled participants viewed more fixation locations than less skilled counterparts (McRobert et al., 2009:480), in contrast to the results obtained by Savelsbergh et al. (2002:283). The ball-hand region appeared to be the primary source of information when facing spin deliveries and central body regions provided additional information that batsmen utilised to perform successfully when facing fast deliveries (McRobert et al., 2009:482). The authors concluded that visual search behaviour would be dependent upon the task constraints in conjunction with the skill level of the performer (McRobert et al., 2009:481).

The preceding section discussed empirical literature concerned with the methodologies employed to lure out the visual gaze behaviour characteristics of performers of differing skill levels. The research suggests that the visual gaze behaviour exhibited by performers may be dependent upon the task constraints; for example, different responses occur when executing a simple joystick movement in contrast to completing a full body movement to intercept a target. More specifically, the methodology used should attempt to replicate the natural task environment as much as possible.

The section to follow will present current literature on the methods employed to lure out the processes that facilitate accurate anticipation ability. Abernethy, Gill, Parks and Packer (2001:233) investigated the expert-novice difference in information pick up in squash. Experts and novices predicted ball landing position when viewing the film and point light display stimuli through the implementation of a temporal occlusion design. Overall, as expected, experts outperformed novices across all viewing and occlusion conditions (Abernethy et al., 2001:238). Interestingly, experts were able to pick up information between the 160 ms to racquet-ball contact temporal window, in contrast to novices who could not. Furthermore, both skill groups attained higher prediction accuracies when viewing the film, as opposed to point-light displays.
(Abernethy et al., 2001:239). This finding concurs with Shim et al. (2005:173), who found that skilled performers reacted faster to film as opposed to point light display stimuli. The authors concluded that the difference between experts and novices may be due to the experts’ ability to make associations between the kinematics contained in the visual stimuli.

In experiment two, Abernethy et al. (2001:243) set to determine if the results obtained in experiment one would extend to the natural squash environment. An expert and the less skilled group were to play normal squash strokes on court wearing PLATO liquid crystal occlusion goggles following a temporal occlusion design. The authors concluded that the expert advantage may be as a result of their unique ability to identify and interpret kinematic information (see also Shim et al., 2005). Furthermore, this advantage may be attributable to experts’ ability to utilise probability information to supplement decision making (Abernethy et al., 2001:247; Farrow & Reid, 2012; Mann, Schaefers & Cañal-Bruland, 2014).

Shim et al. (2006) investigated (in experiment two) the contribution of specific body segments to anticipation in tennis. Highly skilled and less skilled tennis players viewed film and point light displays while wearing PLATO liquid crystal goggles that occluded the clips. Occluding the racquet and forearm drastically decreased anticipation accuracy, as opposed to occluding other body segments (Shim et al., 2006:334; Jackson & Mogan, 2007:346; Williams, Huys, Cañal-Bruland & Hagemann, 2009:367). Moreover, Williams et al. (2009:367) also found that less skilled participants suffered a decrement in performance with the occlusion of this body segment. This finding substantiates the importance of this region to facilitate successful performance and specifically concurs with extensive research highlighting experts’ ability to utilise kinematic information. The authors concluded that the relative motion of the racquet and forearm provides additional information for perceiving anticipated outcomes (Shim et al., 2006:338).

Müller et al. (2006) examined the ability of cricket batsmen of different skill levels to identify and utilise advance visual information to anticipate ball type and length for swing and spin bowlers. In experiment one; skilled, intermediate and low skilled cricket players viewed film sequences that were temporally occluded. Skilled players
were significantly more accurate at predicting ball type and length than low skilled players at front foot impact (Müller et al., 2006:2168). Furthermore, highly skilled players were able to pick up information from the pre-release period (Müller et al., 2006:2171). This finding coincides with that of Abernethy et al. (2001:239) and Müller et al. (2009:648). Müller et al. (2006:2171), in experiment two, aimed to determine if any reductions in prediction accuracy were as a direct consequence of the occlusion of specific cues. The same participant group and the procedure were used as experiment one following the spatial occlusion design. The results reveal that none of the spatial occlusion conditions resulted in a prediction error for ball type and length for the swing bowler (Müller et al., 2006:2171). The authors suggest that the prediction of ball length and type can be derived from multiple sources and not merely one isolated body segment (Müller et al., 2006:2174). This finding is somewhat at odds with those of Shim et al. (2006:338), who found that the motion of the hand and racquet provided additional information regarding the possible outcome of the action.

McRobert et al. (2009) examined how advance cue information influences anticipation using a simulated cricket batting task. Skilled and less skilled male cricket players viewed film stimuli and were required to intercept the ball while wearing an ASL 5001 eye tracker. The skilled group displayed lower errors when anticipating ball location. Visual search data indicated that skilled players spent more time on the ball-hand and bowling arm location, which previous research by Shim et al. (2006) has identified as crucial to anticipation. Furthermore, less skilled players also fixated on the ball-hand location, but this was supported by unclassified locations. Interestingly, the authors suggested that skilled batters may, in fact, use a more systematic search strategy supplemented by prior knowledge and experience to direct their gaze towards additional task-relevant sources of information (McRobert et al., 2009:481).

2.6.2 Situational Probabilities

It is well established that elite athletes use situational probability information to facilitate or accelerate the anticipation process (Williams et al., 2011:435). Research by Farrow and Reid (2012) sought to determine the contribution of situational
probability information to the anticipatory responses of skilled tennis players. An elite group consisting of an older and younger sub-group viewed tennis serves on a plasma screen with the influence of situational probability. Older players were able to identify this probability, in contrast to the younger players who could not (Farrow & Reid, 2012:371). The presence of situational probability also allowed the older players to initiate their movement responses earlier. The authors concluded that the speed at which tennis serves are presented at the younger level, may not necessitate the utilisation of probability information; and hence, may have resulted in the younger players not being able to identify probability information (Farrow & Reid, 2012:372).

Although Farrow and Reid (2012) found that skilled performers can identify situational probability information, but whether or not this information is advantageous or detrimental to performance, is still in question. Mann et al. (2014) found that situational probability information may in fact only be advantageous when the actual outcome is consistent with the expectations created by the performer (Mann et al., 2014:6). In contrast, when the outcome is inconsistent, it may subsequently result in a decrement in performance.

It appears that situational probability information is used by skilled performers in an advantageous manner to initiate their movement responses earlier which is a key factor in time-constrained environments. It is important to remember that the situational advantage may only be true if the outcome matches the expectation.

2.6.3 Recognising Familiar Patterns

Another element contributing to anticipation is stimulus recall and recognition. This paradigm has often been implemented to lure out the familiarity processes that are utilised by skilled performers (North, Ward, Ericsson & Williams, 2011:156; Williams, Ward & Smeeton, 2004b). A graphical illustration of the different information processing mechanisms involved during the anticipation process can be seen in Figure 2.14.
Anticipation is influenced by attention and memory; which in turn, is influenced by your visual abilities, decision making, and perceptual-cognitive skills. The relative contributions of the aforementioned factors are dependent on their respective subsections. The arrows indicate the direction of flow of the inter-relationships that exist between factors that collaboratively influence anticipation. Empirical evidence on the contribution of recognising familiar patterns and the methods employed to examine this skill will be presented.

North et al. (2011) investigated anticipation and pattern recall where skilled and less skilled soccer players viewed point light display and dynamic video stimuli and had to anticipate pass direction. The occlusion design was implemented and participants underwent an anticipation test, recognition test and provided retrospective verbal reports (North et al., 2011:161). Skilled participants maintained their advantage over
less skilled counterparts during the anticipation test (North et al., 2011:162). The recognition test revealed that skilled participants were better able to distinguish between previously seen and novel stimuli across presentation formats (North et al., 2011:165). Furthermore, verbal report data revealed that skilled participants made more evaluations and made more predictive judgments than less skilled counterparts (North et al., 2011:163). The authors concluded that skilled performers’ sport-specific knowledge base, in conjunction with their ability to rapidly encode and decode a vast quantity of information, may contribute to anticipation (North et al., 2011:166).

The in-depth knowledge advantage displayed by skilled performers (North et al., 2011:166) was further elucidated by Gorman, Abernethy and Farrow (2013), who had a group of expert and novice basketball players complete a pattern recall task. The recall error for the expert group was significantly lower than that of novices. More apparent differences were found during the anticipatory recall task; extending experts’ superiority over novices. Interestingly, although experts were found to be superior to novices; novices still showed some degree of anticipation (Gorman et al., 2013:2227). Furthermore, both groups suffered a decrement in recall when viewing moving images in comparison to static images (Gorman et al., 2013:2229). The authors concluded that traditional approaches for measuring pattern recall may not entirely evoke the intricate contribution of anticipation (Gorman et al., 2013:2234).

In a similar study, Gorman, Abernethy and Farrow (2015) further investigated the processes underpinning pattern recall and decision-making by experts. The participants and test procedure were the same as that of Gorman et al. (2013), but the ASL 6000 mobile eye tracker was included. Participants first completed the pattern recall task before the decision-making task. The recall task required players to recall the position of the ball carrier and the stimuli was presented in static and moving blocks; for example, the static pattern recall block was followed by the moving recall block (Gorman et al., 2015:1816). The same procedure was followed for the decision-making task. The pattern recall and decision-making results were synonymous with that of Gorman et al. (2013), highlighting experts’ superiority in comparison with novices. Gaze data revealed that more fixations occurred during the static display and a greater number of fixations occurred during the pattern recall test in comparison with the decision-making test (Gorman et al., 2015:1822).
Furthermore, longer fixation durations occurred during the moving display in comparison with the static display. Moreover, the decision-making test also had a longer fixation duration than the recall test (Gorman et al., 2015:1823). Interestingly, no differences were found between the two skill groups concerning the visual search data. The visual search data revealed that recall and decision-making tasks involve different processes. The authors concluded that recall skill may be one of many skills that contribute to experts’ ability to select the most effective motor response in sports situations (Gorman et al., 2015:1828). The results from the study reiterate the assumption that different perceptual processes are evoked when faced with different task constraints.

Loffing, Stern and Hagemann (2015) had a group of experienced and novice volleyball players predict the type of shot viewed on video stimuli, which were occluded before ball-hand contact. Volleyball players’ prediction accuracy was higher in congruent compared to incongruent trials (Loffing et al., 2015:48), whereas novices only performed better during congruent trials (Loffing et al., 2015:48). The authors found that when the outcome of a target trial was congruent to the preceding trial pattern, prediction accuracy increased and response time decreased. However, the results also suggest that experts may be more susceptible to the congruence effect than novices (Loffing et al., 2015:50). This finding concurs with the results obtained; suggesting that contextual information may only be beneficial if it corresponds with the actual outcome, but may be detrimental if it does not (Mann et al., 2014:6).

The preceding section highlighted the role of recognising familiar patterns and how skilled performers utilise this information to facilitate appropriate decision making and response programming. Similar to situational probability information, the advantage in the use of recall information is directly related to the correctness of the anticipated outcome.

In summary, this section focused on anticipation and the methodologies used to measure anticipation in conjunction with other contributing perceptual-cognitive skills. Collectively, the aforementioned provided useful insight into the perceptual-cognitive skills displayed by a performer. The anticipation section highlights the
significant contribution that accurate decision making plays in time-constrained environments. Furthermore, the perceptual-cognitive skills (visual search behaviours, situational probabilities and recognizing familiar patterns) were briefly elucidated on, highlighting the essential role and contribution made by each. As previously mentioned, the contributing factors influence one another directly and ultimately combine to impact on the performers overall perceptual skill. The information provides useful insight into the complex nature of perceptual skills and the many different cognitive processes that necessitate the successful execution of an appropriate motor response. Expert performers’ unique ability to adapt and improve the efficiency of the control mechanisms needed to elicit an appropriate response, is remarkable.

A table consisting of empirical literature reviewed is presented in Appendix D. The literature explores the two different methodologies employed to extract the perceptual skill information displayed by performers in a given sporting scenario. The two methodologies are visual search and vision in action. Visual search studies refer to the paradigm employed to lure out the visual search strategies employed by skilled performers. The visual search paradigm is characterized by a video-based simulation experimental set-up where a performer is expected to respond in accordance to the scene stimuli. Vision in action paradigms are characterised by experimental set-ups that require the performer to physically intercept a moving target. There is a set outcome that needs to be achieved. The succeeding section will present the methods and procedure employed in this study.

2.7 CHAPTER OVERVIEW

This chapter presented detailed literature on mechanisms responsible for generating the most effective gaze strategy employed in cricket batting. The chapter commenced by focusing on the skill of cricket batting and the interplay that exists between batsmen and bowlers. This interplay highlighted the different roles bowlers have; the strategies employed by bowlers to overthrow batsmen, in conjunction with the temporal and spatial constraints that batsmen have to conquer.
The visual motor system is extensively elaborated on. Initially, the anatomical description of the eye is presented in order to facilitate a basic understanding of how the eye functions. Succeeding this description, the mechanisms that are used to control gaze for information extraction is briefly discussed. Cricket batting is the activity used through which the gaze control processes are scrutinized.

The final section of this chapter is subdivided into three subsections. The first broadly explores the opposing information processing theories that control the basis of how a motor response is initiated and executed with an emphasis on the theoretical framework underpinning the present study. The second section analyses the contribution of attention and anticipation to successfully execute the desired action. Furthermore, the techniques employed to measure anticipation ability are discussed in detail. The final section of this chapter presents recent research on visual search and vision in action studies. These studies served to highlight relevant research methodologies used and background for the interpretation of the present study’s results.

The following chapter provides a very detailed description of the methods and procedures used to collect, capture and analyse data in order to achieve the aim and objectives of this study.
CHAPTER 3: METHODS AND PROCEDURES

3.1 INTRODUCTION

In order to determine the visual gaze behaviour of sub-elite cricket batsmen when facing fast bowling, visual data were collected from batsmen in the top cricket clubs in the Eastern Province.

The focus of this chapter is on providing details of the methods and procedures used to achieve the aim of this study. More specifically, it provides details on the research design and participants selected, measuring instruments used as well as the process of data collection and subsequent statistical analyses conducted.

3.2 RESEARCH DESIGN

The study was pre-experimental in nature and utilised a quantitative approach. A One group post-test only design was followed in this study. The former was deemed pre-experimental because it did not meet scientific standards of experimental designs according to the criteria depicted by De Vos, Strydom, Fouché & Delport (2011:145).

Pre-experimental designs are not characterized by random sampling and do not include a control group. The strength of the proposed research namely to uncover the causal nature of a given relationship is therefore compromised due to the lack of randomization and control groups (De Vos et al., 2011:145). According to De Vos et al. (2011:145), pre-experimental designs are helpful for formulating tentative hypotheses that should be followed up with more controlled studies.

The one group post-test only design is one that is often implemented to determine whether an event had any effect on a group of participants (De Vos et al., 2011:146). The dependent variable, in this case, visual gaze behaviour characteristics, is measured once and conclusions are then drawn from the results.
3.3 PARTICIPANTS AND SAMPLING TECHNIQUE

A participant in the sample relevant to this study had to meet the following inclusion criteria and be:

- a male cricket player
- a specialist batsman
- a member of the Nelson Mandela Metropolitan University 1st xi or Old Grey or Union and Port Elizabeth Cricket Club
- injury free.

Due to the fact that gender and specialized skill differences pertaining to visual gaze behaviours during cricket batting is unknown, it was decided to focus on one gender, namely male batsmen. It was furthermore assumed that sub-elite batsmen could exhibit different visual gaze behaviours compared to non-elite batsmen and non-specialist batsmen. Therefore, the relevant participant selection is justified. The four clubs from whom specialist batsmen were selected comprise of the four top clubs in the Nelson Mandela Bay Metro super league grand challenge club competition. The super league grand challenge club competition is the highest competing club level cricket league in Port Elizabeth. The participants selected are considered to be of the top batsmen in the province and hence are considered to be sub-elite batsmen.

A total of 20 batsmen were tested that met the aforementioned criteria. Due to technical difficulties experienced while calibrating the ASL Mobile Eye Tracker, three participant’s data had to be discarded. In addition, a total of 4 participants withdrew due to international/ national cricket commitments and hence were unavailable for a retest following an incomplete scheduled testing session. Therefore, the final number of participants was 13. The loss of the international and national batsmen is the reason why the participants are referred to as sub-elite (provincial batsmen). The sampling technique implemented was non-probability sampling, in particular, purposive sampling. According to De Vos et al. (2005:232), purposive sampling is entirely based on the judgment of the researcher and a particular case is included due to having attributes that are of interest to the researcher; and in this case being sub-elite batsmen.
3.4 MEASURING INSTRUMENTS

Four different measuring instruments were employed in order to facilitate the successful execution of this study. The following components were assessed: eye dominance, visual gaze behaviour, the speed of delivery and ambient light. Details pertaining to how each of these components was assessed will be discussed in the following subsections.

3.4.1 Eye Dominance

**Purpose:** To test for ocular dominance.

**Equipment:** The Hole in the Card test (Dolman Method) was employed. Figure 3.1 illustrates the Dolman Hole in the Card Test.

![Figure 3.1 Dolman Hole in the Card test](image)

**Method:** The card used in this test has size dimensions of 13x20 cm and contains a round hole in the center of the card with a diameter of 3 cm. The participants were required to hold the card with both hands at full arm’s length. The participants had to view a distant target 6 m away through the hole in the center of the card with both eyes open. The participant then alternated between closing each eye in order to determine the dominant viewing eye. Upon closing each eye alternately, the participant had to continually fixate upon the distant object without moving their hands to accommodate the object.
**Scoring**: The dominant eye is the eye through which the distant object can be viewed while the card is held at full arm’s length in front of the observer without manipulating the position of the hands.

**Validity and Reliability**: Face validity was accepted for this test. According to Rice, Leske, Smestad and Holmes (2008:367), the reliability coefficient of the Dolman Hole in the card test is 0.77.

### 3.4.2 Visual Gaze Behaviour

**Purpose**: To determine visual gaze behaviour in terms of AOI, the number of fixations, the duration of each fixation, the starting and last fixation and the order of fixations.

**Equipment**: ASL Mobile Eye Tracker was employed. The Mobile Eye Tracker is a head mounted monocular eye tracking system that computes the point of gaze within a scene through calculation of the vector (angle and distance) between the participant’s pupil and cornea (Dicks, Button & Davids, 2010:709). Figure 3.2 illustrates the ASL Mobile eye tracker.

*Figure 3.2 Batsman wearing ASL mobile eye tracker*
Method:

Eye tracker fitment:

All participants were required to wear full cricket protective gear to simulate match conditions. The helmet or hat was not included due to possible interference with the optical lens of the mobile eye tracker. The omission of the helmet minimized disturbance during recording.

Once the mobile eye tracker was fitted to the batsman he was given 12 “practice trials” by the researcher. The practice trials served two main purposes. Firstly, these served as a means for the participant to get accustomed to wearing the mobile eye tracker. Furthermore, the practice trials allowed the batsman to get his eye in (adjusted to the circumstances).

After the practice trials were administered, the eye tracker along with the recording device was connected via an electronic cable to a laptop. The participant was now ready for the calibration of the equipment. Calibration is a two-step process encompassing firstly calibrating the position of the eye and secondly calibrating the eye’s fixation points to known points in the scene.

Calibration of the eye:

Calibration is the process of aligning the monocle (optical lens) with the pupil of the participant’s eye in order to track eye movement. The recording device has a display screen upon which the participant’s eye can be viewed. Three white dots can be seen on the display screen, the goal of which was to try and align the white dots with the participant’s pupil. This alignment was attained through the manipulation of the monocle (optical lens). The alignment allowed the infra-red beams to reflect off the cornea and record the movements made by the eye. Step one of the calibration process was now complete and one could proceed to calibrate the scene.
Calibration of the scene:

Each batsman assumed their standard batting stance in the upright position when calibrating the scene. The batsmen viewed the calibration screen from a side on position in order to simulate the nature of the batting skill.

The participants were required to fixate on pre-determined points that served to define the boundaries of possible AOI for a particular participant, while the tracking system observed the pupil position. The batsmen stood on a mark 10.06 m away from the calibration wall. This distance was the equidistant length of a standard cricket pitch of 20.12m (Zhang, Unka & Liu, 2011:1022).

According to the Applied Science Laboratories (ASL) mobile eye operation manual (2008:19) to ensure the best accuracy for calibration; it is suggested that calibration is done at an intermediate distance of any given task. The dimensions of the cricket of the cricket wicket are illustrated in Figure 3.7 (a graphical illustration). The pre-determined calibration points were projected onto a wall via a data projector connected to a laptop, and contained 10 fixation points. Each point illuminated for 10 seconds before its disappearance and illumination of the next fixation point. The batsmen were required to fixate upon each mark for the entire duration. The duration of the calibration process was approximately 3 minutes.

The calibration area had a height of 2.7 m and covered a width of 3.04 m. The mean average ball release height (cm) of fast bowlers is 201.3±10.6 cm (Wormgoor, Harden & Mckinon, 2010:962). The calibration screen, therefore, aimed to cover all possible AOI that a batsman may fixate upon in an attempt to play a stroke while batting. The width is the exact width of a standard cricket pitch. Figure 3.3 illustrates the calibration screen.
At the conclusion of the calibration process, the participant was now ready to commence with the testing procedure. Details of the latter are described later under the heading of “Data Collection Procedure”.

**Scoring**: Upon completion of the calibration process, the mobile eye tracker was ready to record frame by frame visual and scene data. The following data were collected from the mobile eye tracker: the AOI visited, the number of fixations, duration of fixations, start, last and order of fixations.

**Accuracy of the Eye Tracker**: The ASL mobile eye tracker has an accuracy of $0.5^\circ$ (ASL mobile eye-xg manual, 2013). Face validity was accepted for this measuring instrument.

### 3.4.3 Speed of Delivery

**Purpose**: to calculate the speed at which the ball travelled towards the batsmen.

**Equipment**: The original equipment of choice was the Jugs Professional Sports Radar Gun. However, due to technical difficulties experienced with the equipment the researcher had to use an alternative method of calculating the speed. The Sony DCR-SR68 60X optical zoom handy cam was therefore employed. Additionally, the Dart Fish ProSuite software version 5.5 was utilised to analyse the videos in order to calculate the speed of each respective delivery.
**Method:** The video clip was manually downloaded from the Sony DCR-SR68 60X optical zoom handy cam video recorder onto a laptop. The video clip was then analysed using DartFish ProSuite version 5.5 Software. The process comprised of the frame by frame analysis in an attempt to determine the moment of ball release as well as point of bat-ball contact.

The respective time frames of the aforementioned phase were recorded for each delivery. The respective time frames were then exported and tabulated in Microsoft Excel (see Appendix A) in order to be converted into the correct units (Kilometres/hour) for each delivery bowled. The average was calculated after the conversion to serve as the average speed of the deliveries that each batsman faced during their scheduled testing session. Figures 3.4 and 3.5 illustrate the two respective phases used to calculate the speed of delivery.

![Figure 3.4 Moment of ball release](image-url)
Scoring: The time interval between the moment of ball release and bat ball interception was recorded.

Validity and Reliability: Face validity was accepted for this measurement. An inter-rater reliability test was conducted for frame by frame analysis directly after the pilot test in order to calculate the reliability of the assessment outcome.

3.4.4 Ambient Light

Purpose: To quantify light readings for the testing environment.

Equipment: The Gossen Lunasix 3 light meter was employed. Figure 3.6 illustrates the light meter.
**Method**: The light meter operates with an automatic switch to generate the light reading. A switch is present on the right-hand side of the light meter. Holding the light meter at full arm’s length in front of the operator, the latter should assume a position where they would like to take the reading and press the switch. Light readings were measured and recorded at the stumps at the bowler’s end, the batsman’s end and at the equidistant mark of the total length of the pitch prior to the delivery of the first ball that each respective batsman received.

**Scoring**: The light readings were recorded prior to the delivery of the first ball faced per batsman. Light readings were taken at the following areas: the batsman’s end, the bowler’s end and the equidistant length of the pitch. See Figure 3.7 for a graphical illustration of the experimental setup. The average light reading from each of the three points was used as the final light reading for that particular batsman.

**Validity and Reliability**: Face validity was accepted for this measurement. The researcher was unable to uncover the validity and reliability of this equipment. The light reading was measured at three different places on the pitch and only differed by 0.2 lux Ca. The measurements were consistently above 14.0 lux Ca. The light reading and subsequent lighting conditions were considered consistent and reliable.
3.5 **ASSISTANTS**

All assistants present on the day were briefed prior to the testing date on their respective duties that needed to be carried out. The assistants comprised of one masters student and a co-supervisor. All assistants were from the department of Human Movement Science and have also been previously exposed to working with the eye tracker, which justified their inclusion. The assistants were trained before and during the pilot study. Each assistant was allocated a designated task. Their ability to execute this task was examined by both the researcher as well as the co-supervisor. The pilot study also served as a training opportunity for the assistants.

3.6 **DATA COLLECTION AND TESTING PROTOCOL**

Testing took place at the Eastern Province indoor cricket facility, Axxess St Georges Park, Port Elizabeth. Upon arrival, the participants were welcomed and formally introduced to the assistants on hand. Post-welcoming, the participants completed the informed consent forms, underwent the eye dominance test and finally fitted their cricket gear along with the mobile eye tracker.

The succeeding section will provide details of the pre-data-collection protocol and data collection procedure.

3.6.1 **Pre-Data Collection Protocol:**

Each participant was allocated a 1-hour time interval and arrived at the Eastern Province Indoor Cricket Grounds on their specified day and assigned time slot. The one-hour time slot encompassed the completion of informed consent form (see Appendix B) and data capturing template (see Appendix C). Upon arrival, participants were welcomed and formally introduced to the researcher and assistants present on the day. The researcher explained the informed consent form which the participants completed and provided a brief overview of the testing session.

The two right-handed fast bowlers included in this study had the following attributes: in-swinger and out-swinger bowling ability. The artificial indoor cricket facility
accommodated the bowler’s full length run up on a standardized cricket wicket. The bowler’s run-up ranged between three and ten meters. The bowlers were instructed to bowl with the intent of dismissing the batsmen as they would under match conditions.

The batsmen entered the testing venue one at a time. The rest of the batsmen scheduled for testing on the same day were not allowed to enter the testing area until the researcher allowed them to enter. Their presence within the testing area could influence the results of the study and hence the afore-mentioned decision. Similarly, participants who had completed the test were asked not to liaise with other future participants regarding the testing procedure.

The batsmen were instructed to play with the same intent that they would display under match conditions until told to stop. A 45-minute window period was allocated to each batsman for the batting duration. A graphical illustration of the experimental set-up is provided below in Figure 3.7.

![Figure 3.7 Experimental set-up (Dell, 2012)](image-url)
3.6.2 Data Collection Procedure

The cricket data capturing template (see Appendix C) was used to determine both the successful and unsuccessful trials for each batsman and was completed by the researcher. The researcher was only concerned with obtaining 5 successful and 5 unsuccessful batting trials; these trials did not have to be in succession. The batsmen were unaware of this as test criterion. Only one batsman did not achieve this within-test criterion, as a result of not receiving a complete set of unsuccessful in-swinger trials during his testing session. The aforementioned resulted in 124 unsuccessful in-swinger trials instead of the equivalent 130 successful trials.

Each batsman received 12 practice trials to get accustomed to wearing the eye tracker. A typical batsman could face up to 48 deliveries (8 overs) before the test was terminated. The test was terminated to minimize the influence of fatigue on the bowlers, which could possibly influence the quality of the data collected.

A batting stroke was deemed successful if bat-ball contact was made and if the ball travelled to the intended location. A batting stroke was deemed unsuccessful if: it was missed or if bat-ball contact was made but the ball did not travel to the intended location. It is important to note that a delivery that was left alone is neither successful nor unsuccessful because no batting stroke was offered; therefore it was not recorded based on the definition of a batting stroke. The test was terminated once the in-test criterion was achieved for each batsman.

3.7 CODING AND EXTRACTION

The initial step of the coding process was to download the video from start to finish of each respective batsman from the eye tracker software. The coding process was performed on a programme called INTERACT version 8.7.0. Various pre-defined AOI were created within interact in order to describe what each batsman fixated upon during successful and unsuccessful shot execution. The eight AOI selected for this study are listed in Table 1.1.1.
The AOI upper body was coded from the waist up to the head. The AOI lower body was coded from the waist down to the toes. The AOI ball was coded when the fixation point occurred on the ball. The AOI pitch was coded when the fixation point occurred on the pitch. The AOI arm/ ball release was coded when the fixation point occurred at the anticipated release point region prior to ball release. The AOI other/ off target was coded when the fixation did not occur at any of the above-presented AOI. The AOI ball trajectory was coded when the fixation occurred ahead of the AOI ball. Finally, the AOI blink occurred when no crosshair was found evident within a given scene indicating that the participant blinked.

The second step was to analyse each video clip frame by frame (25 frames per second) using INTERACT to determine the AOI that each batsman fixated upon, the frequency of those fixations, duration of those fixations and the start and end points of the respective fixations in conjunction with time intervals for each fixation. This was done for 5 successful and 5 unsuccessful trials for each of the batsmen.

An example of a frame examination using INTERACT can be seen in Figure 3.8. The coding process is subject to experience and interpretation. It is worth noting that INTERACT has the ability to zoom in order to get a clear image of the fixation point. In order to ensure the optimal reliability of the coding process, an inter-rater reliability test was conducted for a subset of the data with a dual-coder and achieved a correspondence index of 83.3%. Furthermore, the researcher has five years’ experience as a batsman himself at senior club level.
In Figure 3.8, the batsman is fixating on the bowlers’ head during the initial part of the bowlers’ run-up. It is important to note, that figure 3.8 is a still image to provide further insight into the coding process. Furthermore, if a coder was unsure of one particular frame then using the previous as well as the following frame helped indicate the fixation point for the frame of interest. At the completion of the coding process, a thorough check in respect of corresponding time intervals, commas, and semi-colons were done. Group 1 refers to each batsman individually. Set 1 refers to each delivery faced and coded according to ball type and stroke outcome. Lastly, each event within each set is a different AOI fixated upon. Each code has a start and end time code to determine the duration. An example of the coding process can be seen in Figure 3.9.
The information was then systematically broken down to produce the necessary data for the number of fixations, duration, starting, last and order of fixations. The final step of the coding process was to transfer each participant’s information from interact into a template created in Microsoft Excel for the purpose of further analyses.

3.8 ETHICS CONSIDERATIONS

According to De Vos et al. (2011:114), ethics is a set of principles that govern behaviour in human relations. These principles ensure no harm to involved participants. Ethics clearance was obtained from the Health Science’s Faculty Research Technology and Innovation committee (FRTI) and the Research Ethics Committee (Human) (Rec-H) at NMMU during September 2014 (Ethics reference: H14-HEA-HMS-011). All participation in this study was voluntary and all participants completed informed consent forms prior to their participation in the current study (see Appendix B). The researcher ensured all the participants understood the requirements to be fulfilled even after informed consent was provided.
3.9 DATA ANALYSIS

The assistance of a qualified statistician was enlisted to assist with the analysis of the data. Descriptive statistics such as the mean, median, standard deviation, and frequency distribution were used to describe the number of fixations, duration of each fixation for all AOI visited, starting and last fixations and the order of fixations. Analysis of variance (ANOVA) was used to compare successful and unsuccessful and in-swing and out-swing trials. Statistical significance was set at p<.05 and where ANOVA did indicate statistical significance posthoc analyses consisting of Scheffé tests and Cohen's d statistics were conducted to determine the statistical and practical significance of individual between group differences. A two sample t-test was conducted to assess the significance between the speeds of the stroke outcome and the ball type faced.

Inferential statistics could not be done on the lighting conditions and eye dominance. Descriptive statistics only were reported for the order of fixations section as the lack of appropriate statistical tests made it impossible to obtain inferential statistics. The Chi² test could not be utilised as the test requires that the observations for the frequency table for which the test is to be conducted must be independent. This requirement is not met for the tables here as a result of multiple entries per participant and therefore a ranking system was employed. The ranking system was employed in order to classify the AOI in order of importance.

The rankings reported in Chapter 4 were obtained as follows:

Step 1: The AOI's were sorted in descending sequence on the observed percentages;

Step 2: The AOI with the largest observed percentage was ranked 1;

Step 3: All the AOI's with observed percentages within 5% of the percentage of the first AOI were also ranked 1. The 5% increment was used to highlight a significant difference among AOI that further served to rank AOI in terms of importance.
Step 4: The first AOI with observed percentage more than 5% less than the first AOI ranked 1 was ranked 2;

Step 5: All the AOI’s with observed percentages less than and within 5% of the percentage of the AOI ranked 2 were also ranked 2;

Step 6: Steps 4 and 5 were used in a similar way to rank the remaining AOI’s.

The chapter to follow will outline the results obtained for this study.
CHAPTER 4: RESULTS

4.1 INTRODUCTION

The purpose of this study was to identify and characterise the visual gaze behaviour of sub-elite cricket batsmen when facing fast in-swing and out-swing bowling. The focus of this chapter is on reporting the results generated from this study. To facilitate the understanding of the contents of this chapter, the results are presented in two main sections namely: factors that were controlled for during the testing; and visual gaze behaviour of batsmen. The factors that were controlled for during the testing of visual gaze behaviours are: eye dominance, the speed of delivery and lighting conditions during the testing.

The second main category of results displays the visual gaze behaviour. These results are reflected in the following five subsections: number of fixations, duration of fixations, starting fixation, last fixation and order of fixations. Within each of these subsections, the results are discussed in terms of AOI for: successful and unsuccessful trials irrespective of ball faced; and in-swing and out-swing trials irrespective of the stroke outcome, to specifically address the objectives of this study. If a variable displayed significant differences, the statistical and practical significance statistics are provided and these are highlighted in red. Where it was impossible to determine the statistical significance of results, the following percentage differences were considered to be of practical significance:

- For percentage differences between AOI: 5%
- For percentage differences related to ball type and stroke outcome: 1%

The percentage differences for all frequency tables were calculated by subtracting the percentage value of successful trials (B) from the value of unsuccessful trials (A). The positive differences observed are as a result of the number of fixations for unsuccessful trials being greater than that of successful trials per AOI. Contrary, the negative differences observed are as a result of the number of fixations for successful trials being greater than that of unsuccessful trials per AOI.
4.2 FACTORS CONTROLLED FOR DURING TESTING

The following section highlights the factors that were controlled for throughout the study to ensure that the results obtained were valid.

4.2.1 Eye Dominance

The eye dominance of the 13 participants used within the study had the following respective characteristics: nine were right eye dominant and four were left eye dominant.

4.2.2 Speed of Delivery

The results from the inter-rater reliability test revealed a correlation coefficient of 0.73. However, average speed readings pertaining specifically to the stroke outcome and the ball type faced can be seen in Table 4.1.1. No significant difference ($t=0.07$, $p=.946$) was found comparing successful ($113.11\pm5.03$ km/h) and unsuccessful ($113.07\pm4.33$ km/h) trials. However, a significant difference ($t=-8.43$, $p<.0005$, $d=1.06$) was found when comparing in-swinger ($110.16\pm4.86$ km/h) and out-swinger ($115.22\pm4.71$ km/h) trials.

Table 4.1.1: Speed classifications

<table>
<thead>
<tr>
<th>Classification</th>
<th>Average speed readings (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful trials</td>
<td>113.11±5.03</td>
</tr>
<tr>
<td>Unsuccessful trials</td>
<td>113.07±4.33</td>
</tr>
<tr>
<td>In-swinger trials</td>
<td>110.16±4.86</td>
</tr>
<tr>
<td>Out-swinger trials</td>
<td>115.22±4.71</td>
</tr>
</tbody>
</table>
4.2.3 Lighting Conditions During Eye Tracking

The average light readings obtained from the three areas on the pitch over the 19 days when testing took place can be seen in Table 4.2.1. Overall, the light readings varied between 14.0 and 14.2 lux on the light scale. Although inferential statistics has not been completed on this particular data set, the average light readings across all areas were very close to one another possibly suggesting that no significant difference would have been obtained.

Table 4.2.1: Light readings

<table>
<thead>
<tr>
<th>Areas of the pitch</th>
<th>mean (lux Ca)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowlers end</td>
<td>(14.05±0.09)</td>
</tr>
<tr>
<td>Equi-distant length of the pitch</td>
<td>(14.12±0.10)</td>
</tr>
<tr>
<td>Batsman’s end</td>
<td>(14.06±0.09)</td>
</tr>
</tbody>
</table>
4.3 VISUAL GAZE BEHAVIOUR

The following section presents the results on the visual gaze behaviour characteristics of the batsmen.

4.3.1 Number of Fixations

Table 4.3.1 reflects the descriptive statistics for the number of fixations per area of interest (nAOI) for all trials, the stroke outcome (successful and unsuccessful) and the ball type faced (in-swing and out-swing).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>Minimum</th>
<th>Quartile 1</th>
<th>Median</th>
<th>Quartile 3</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Trials</td>
<td>254</td>
<td>8.45</td>
<td>2.89</td>
<td>4.00</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Successful</td>
<td>130</td>
<td>8.23</td>
<td>2.96</td>
<td>4.00</td>
<td>6.00</td>
<td>7.50</td>
<td>10.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Unsuccessful</td>
<td>124</td>
<td>8.71</td>
<td>2.80</td>
<td>4.00</td>
<td>7.00</td>
<td>8.50</td>
<td>10.00</td>
<td>18.00</td>
</tr>
<tr>
<td>In-Swinger</td>
<td>124</td>
<td>8.36</td>
<td>2.80</td>
<td>4.00</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Out-Swinger</td>
<td>130</td>
<td>8.58</td>
<td>2.97</td>
<td>4.00</td>
<td>6.25</td>
<td>8.00</td>
<td>10.75</td>
<td>18.00</td>
</tr>
</tbody>
</table>

According to Table 4.3.1, no significant differences were found between successful and unsuccessful trials for number of fixations (F= 1.936, df=1;51, p=.172). A higher mean number of fixations were observed for unsuccessful trials (8.71±2.80) than successful trials (8.23±2.96). No significant differences were found between in-swing and out-swing trials for number of fixations (F=0.424, df=1;51, p=.519). A higher mean number of fixations were observed for out-swing trials (8.58±2.97) than in-swing (8.36±2.80) trials.
Table 4.3.2 reflects the mean number of fixations per AOI with related inferential statistics for the differences between unsuccessful and successful trials.

### Table 4.3.2: Number of fixations per AOI by stroke outcome

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Unsuccessful</th>
<th>Successful</th>
<th>ANOVA Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean  S.D.</td>
<td>Mean  S.D.</td>
<td>F-value</td>
</tr>
<tr>
<td>Upper body</td>
<td>1.79 0.69</td>
<td>1.63 0.78</td>
<td>2.151</td>
</tr>
<tr>
<td>Lower body</td>
<td>0.68 0.57</td>
<td>0.77 0.74</td>
<td>1.078</td>
</tr>
<tr>
<td>Ball</td>
<td>1.55 0.39</td>
<td>1.52 0.45</td>
<td>0.073</td>
</tr>
<tr>
<td>Pitch</td>
<td>1.18 0.89</td>
<td>1.26 0.90</td>
<td>1.045</td>
</tr>
<tr>
<td>Arm/ ball release</td>
<td>1.16 0.56</td>
<td>1.00 0.30</td>
<td>3.829</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td><strong>1.45 0.78</strong></td>
<td><strong>1.15 0.62</strong></td>
<td><strong>4.219</strong></td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>0.55 0.35</td>
<td>0.59 0.26</td>
<td>0.358</td>
</tr>
<tr>
<td>Blink</td>
<td>0.34 0.38</td>
<td>0.31 0.32</td>
<td>0.269</td>
</tr>
<tr>
<td>Overall number</td>
<td>8.71 2.80</td>
<td>8.23 2.96</td>
<td>1.936</td>
</tr>
</tbody>
</table>

According to Table 4.3.2, the successful stroke revealed a significantly lower mean number of fixations (1.15±0.62) than the unsuccessful stroke (1.45±0.78); (p= .047, d=0.44) for the AOI other/ off-target. Interesting to note, was the almost significant (p=0.58) difference for the AOI arm/ ball release. A greater number of fixations on this AOI were observed for an unsuccessful stroke outcome.

The highest mean number of fixations was observed for both successful (1.63±0.78) and unsuccessful (1.79±0.69) trials for the AOI upper body. The lowest mean number of fixations was observed for both successful (0.31±0.32) and unsuccessful (0.34±0.38) trials for the AOI blink.
Table 4.3.3 reflects the frequency distribution per AOI for unsuccessful and successful trials.

The percentage differences for all frequency tables are calculated by subtracting the percentage value of successful trials (B) from the value of unsuccessful trials (A). The positive differences observed are as a result of the number of fixations for unsuccessful trials being greater than that of successful trials per AOI. Contrary, the negative differences observed are as a result of the number of fixations for successful trials being greater than that of unsuccessful trials per AOI.

**Table 4.3.3: Frequency distribution of fixations per AOI by stroke outcome**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>A</th>
<th>B</th>
<th>Total</th>
<th>A-B Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>222</td>
<td>212</td>
<td>434</td>
<td>0.8%</td>
</tr>
<tr>
<td>Ball</td>
<td>194</td>
<td>198</td>
<td>392</td>
<td>-0.5%</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>174</td>
<td>149</td>
<td>323</td>
<td>2.2%</td>
</tr>
<tr>
<td>Pitch</td>
<td>146</td>
<td>164</td>
<td>310</td>
<td>-1.8%</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>137</td>
<td>130</td>
<td>267</td>
<td>0.6%</td>
</tr>
<tr>
<td>Lower body</td>
<td>89</td>
<td>100</td>
<td>189</td>
<td>-1.1%</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>71</td>
<td>77</td>
<td>148</td>
<td>-0.6%</td>
</tr>
<tr>
<td>Blink</td>
<td>43</td>
<td>40</td>
<td>83</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

According to Table 4.3.3, practical significant differences were observed for the AOI other/off-target, pitch and lower body. Higher other/off-target percentages were observed for the unsuccessful stroke outcome. Furthermore, higher pitch and lower body percentages were observed for the successful stroke outcome.
Table 4.3.4 reflects the number of fixations per AOI with related inferential statistics for in-swing and out-swing balls bowled.

### Table 4.3.4: Number of fixations per AOI by ball type faced

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>In-swing Mean</th>
<th>In-swing S.D.</th>
<th>Out-swing Mean</th>
<th>Out-swing S.D.</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen’s D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>1.71</td>
<td>0.82</td>
<td>1.72</td>
<td>0.66</td>
<td>0.002</td>
<td>.964</td>
<td>n/a</td>
</tr>
<tr>
<td>Lower body</td>
<td>0.69</td>
<td>0.61</td>
<td>0.76</td>
<td>0.70</td>
<td>0.722</td>
<td>.401</td>
<td>n/a</td>
</tr>
<tr>
<td>Ball</td>
<td>1.50</td>
<td>0.38</td>
<td>1.57</td>
<td>0.46</td>
<td>0.495</td>
<td>.486</td>
<td>n/a</td>
</tr>
<tr>
<td>Pitch</td>
<td>1.21</td>
<td>0.87</td>
<td>1.23</td>
<td>0.93</td>
<td>0.065</td>
<td>.800</td>
<td>n/a</td>
</tr>
<tr>
<td>Arm/ ball release</td>
<td>1.14</td>
<td>0.53</td>
<td>1.02</td>
<td>0.35</td>
<td>1.954</td>
<td>.171</td>
<td>n/a</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>1.27</td>
<td>0.65</td>
<td>1.32</td>
<td>0.78</td>
<td>0.108</td>
<td>.745</td>
<td>n/a</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>0.52</td>
<td>0.31</td>
<td>0.62</td>
<td>0.30</td>
<td>2.238</td>
<td>.143</td>
<td>n/a</td>
</tr>
<tr>
<td>Blink</td>
<td>0.31</td>
<td>0.33</td>
<td>0.34</td>
<td>0.36</td>
<td>0.193</td>
<td>.663</td>
<td>n/a</td>
</tr>
<tr>
<td>Overall number</td>
<td>8.36</td>
<td>2.80</td>
<td>8.58</td>
<td>2.97</td>
<td>0.424</td>
<td>.519</td>
<td>n/a</td>
</tr>
</tbody>
</table>

According to Table 4.3.4, none of the differences between in-swing and out-swing trials was found to be statistically significant. The highest mean number of fixations was observed for both in-swing (1.71±0.82) and out-swing (1.72±0.66) trials for the AOI upper body. The lowest mean number of fixations was observed for both in-swing (0.31±0.33) and out-swing (0.34±0.36) trials for the AOI blink.
Table 4.3.5 reflects the frequency distribution of the total number of fixations per AOI for in-swing and out-swing trials.

Table 4.3.5: Frequency distribution of fixations per AOI by ball type faced

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>A In-swing</th>
<th>B Out-swing</th>
<th>Total</th>
<th>A-B Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>211 20.5%</td>
<td>223 20.0%</td>
<td>434 20.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Ball</td>
<td>188 18.3%</td>
<td>204 18.3%</td>
<td>392 18.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>151 14.7%</td>
<td>172 15.4%</td>
<td>323 15.1%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Pitch</td>
<td>150 14.6%</td>
<td>160 14.3%</td>
<td>310 14.4%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>134 13.0%</td>
<td>133 11.9%</td>
<td>267 12.4%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Lower body</td>
<td>90 8.7%</td>
<td>99 8.9%</td>
<td>189 8.8%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>67 6.5%</td>
<td>81 7.3%</td>
<td>148 6.9%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Blink</td>
<td>39 3.8%</td>
<td>44 3.9%</td>
<td>83 3.9%</td>
<td>-0.2%</td>
</tr>
</tbody>
</table>

According to Table 4.3.5, practical significant differences were only found for the AOI arm/ball release. Higher arm/ball release percentages were observed for in-swing ball type faced.
### 4.3.2 Duration of Fixations

Table 4.4.1 reflects the descriptive statistics for the duration of fixations (dAOI) per AOI (nAOI) for all trials by stroke outcome (successful and unsuccessful) and ball type (in-swing and out-swing) and all trials.

Table 4.4.1: Duration of fixations (sec) by stroke outcome and ball type faced

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>Minimum</th>
<th>Quartile 1</th>
<th>Median</th>
<th>Quartile 3</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Trials</td>
<td>254</td>
<td>2.30</td>
<td>0.17</td>
<td>2.00</td>
<td>2.24</td>
<td>2.28</td>
<td>2.32</td>
<td>4.48</td>
</tr>
<tr>
<td>Successful</td>
<td>130</td>
<td>2.29</td>
<td>0.13</td>
<td>2.00</td>
<td>2.24</td>
<td>2.28</td>
<td>2.32</td>
<td>3.56</td>
</tr>
<tr>
<td>Unsuccessful</td>
<td>124</td>
<td>2.30</td>
<td>0.21</td>
<td>2.08</td>
<td>2.24</td>
<td>2.28</td>
<td>2.32</td>
<td>4.48</td>
</tr>
<tr>
<td>In-Swinger</td>
<td>124</td>
<td>2.31</td>
<td>0.21</td>
<td>2.08</td>
<td>2.24</td>
<td>2.28</td>
<td>2.32</td>
<td>4.48</td>
</tr>
<tr>
<td>Out-Swinger</td>
<td>130</td>
<td>2.28</td>
<td>0.13</td>
<td>2.00</td>
<td>2.24</td>
<td>2.28</td>
<td>2.32</td>
<td>3.56</td>
</tr>
</tbody>
</table>

According to Table 4.4.1, no significant differences were found between successful and unsuccessful trials (F=0.200, df=1;51, p=.660). A higher mean duration of fixations were observed for unsuccessful (2.30±0.21) trials than successful (2.29±0.13) trials. No significant differences were found between in-swing and out-swing trials (F=2.000, df=1;51, p=.165). A higher mean duration of fixations was observed for in-swing (2.31±0.21) trials than out-swing (2.28±0.13) trials.
Table 4.4.2 reflects the mean duration of fixations per AOI for unsuccessful and successful trials.

Table 4.4.2: Duration of fixations (sec) per AOI by stroke outcome

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Unsuccessful</th>
<th>Successful</th>
<th>ANOVA Results</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Upper body</td>
<td>1.10</td>
<td>0.40</td>
<td>1.11</td>
<td>0.39</td>
</tr>
<tr>
<td>Lower body</td>
<td>0.12</td>
<td>0.12</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>Ball</td>
<td>0.36</td>
<td>0.09</td>
<td>0.36</td>
<td>0.10</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.18</td>
<td>0.42</td>
<td>0.18</td>
<td>0.39</td>
</tr>
<tr>
<td>Arm/ ball release</td>
<td>0.24</td>
<td>0.13</td>
<td>0.22</td>
<td>0.12</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>0.23</td>
<td>0.25</td>
<td>0.20</td>
<td>0.25</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Blink</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>Overall duration</td>
<td>2.30</td>
<td>0.09</td>
<td>2.29</td>
<td>0.06</td>
</tr>
</tbody>
</table>

According to Table 4.4.2, none of the differences between successful and unsuccessful trials were found to be statistically significant. The highest mean duration of fixations were observed for both successful (1.11±0.39) and unsuccessful (1.10±0.40) trials for the AOI upper body. The lowest mean duration of fixations were observed for both successful (0.03±0.06) and unsuccessful (0.02±0.02) trials for the AOI blink.
Table 4.4.3 reflects the percentage of time spent per trial by AOI with related inferential statistics for unsuccessful and successful trials.

**Table 4.4.3: Percentage of time spent per AOI by stroke outcome**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Unsuccessful Mean Values (%)</th>
<th>Successful Mean Values (%)</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>47.59</td>
<td>48.21</td>
<td>0.099</td>
<td>.755</td>
<td>n/a</td>
</tr>
<tr>
<td>Lower body</td>
<td>5.28</td>
<td>6.54</td>
<td>1.495</td>
<td>.229</td>
<td>n/a</td>
</tr>
<tr>
<td>Ball</td>
<td>15.64</td>
<td>15.51</td>
<td>0.084</td>
<td>.773</td>
<td>n/a</td>
</tr>
<tr>
<td>Pitch</td>
<td>7.97</td>
<td>7.93</td>
<td>0.004</td>
<td>.953</td>
<td>n/a</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>10.37</td>
<td>9.69</td>
<td>0.657</td>
<td>.423</td>
<td>n/a</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>10.08</td>
<td>8.61</td>
<td>0.995</td>
<td>.325</td>
<td>n/a</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>2.29</td>
<td>2.39</td>
<td>0.064</td>
<td>.802</td>
<td>n/a</td>
</tr>
<tr>
<td>Blink</td>
<td>0.77</td>
<td>1.13</td>
<td>0.603</td>
<td>.443</td>
<td>n/a</td>
</tr>
</tbody>
</table>

According to Table 4.4.3, none of the differences between successful and unsuccessful trials were found to be significant. The highest mean percentage of time was observed for both successful (48.21%) and unsuccessful (47.59%) trials for the AOI upper body. The lowest mean percentage of time was observed for both successful (1.13%) and unsuccessful (0.77%) trials for the AOI blink.
Table 4.4.4 reflects the mean duration of fixations per trial by AOI for in-swing and out-swing trials.

### Table 4.4.4: Duration of fixations (sec) per trial per AOI by ball type faced

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>In-swing</th>
<th>Out-swing</th>
<th>ANOVA Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
</tr>
<tr>
<td>Upper body</td>
<td>1.09</td>
<td>0.42</td>
<td>1.12</td>
</tr>
<tr>
<td>Lower body</td>
<td>0.12</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ball</td>
<td>0.37</td>
<td>0.11</td>
<td>0.34</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.19</td>
<td>0.42</td>
<td>0.18</td>
</tr>
<tr>
<td>Arm/ ball release</td>
<td>0.25</td>
<td>0.14</td>
<td>0.21</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>0.22</td>
<td>0.27</td>
<td>0.20</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Blink</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Overall duration</td>
<td>2.31</td>
<td>0.21</td>
<td>2.28</td>
</tr>
</tbody>
</table>

According to Table 4.4.4, the AOI that were found to be significantly different when comparing in-swing and out-swing trials in terms of duration of fixations were ball (F=7.606, p=.009, d=0.29) and arm/ ball release (F=4.795, p=.035, d=0.33). Higher mean fixation duration was observed for the in-swing group for both AOI that were found to be statistically significant. The highest mean duration of fixations was observed for both out-swing (1.12±0.36) and in-swing (1.09±0.42) trials for the AOI upper body. The lowest mean duration of fixations was observed for both in-swing (0.02±0.02) and out-swing (0.03±0.06) trials for the AOI blink.
Table 4.4.5 reflects the percentage of time per trial by AOI for in-swing and out-swing trials.

**Table 4.4.5: Percentage of time per trial per AOI by ball type faced**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Mean Values (%)</th>
<th>ANOVA Results</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-swing</td>
<td>Out-swing</td>
<td>F-value</td>
</tr>
<tr>
<td>Upper body</td>
<td>46.82</td>
<td>48.98</td>
<td>1.233</td>
</tr>
<tr>
<td>Lower body</td>
<td>5.31</td>
<td>6.52</td>
<td>1.375</td>
</tr>
<tr>
<td>Ball</td>
<td>16.12</td>
<td>15.04</td>
<td>5.426</td>
</tr>
<tr>
<td>Pitch</td>
<td>8.11</td>
<td>7.79</td>
<td>0.144</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>10.88</td>
<td>9.18</td>
<td>4.121</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>9.66</td>
<td>9.03</td>
<td>0.185</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>2.32</td>
<td>2.35</td>
<td>0.006</td>
</tr>
<tr>
<td>Blink</td>
<td>0.79</td>
<td>1.11</td>
<td>0.509</td>
</tr>
</tbody>
</table>

According to Table 4.4.5, significant differences were found between in-swing and out-swing trials for the AOI ball (F=5.426, p=.025, d=0.26) and arm/ball release (F=4.121, p=.050, d=0.31). A higher mean percentage of time was observed for the in-swing group for both AOI that were found to be statistically significant. The highest mean duration of fixations was observed for both in-swing (46.82%) and out-swing (48.98%) trials for the AOI upper body. The lowest mean duration of fixations was observed for both in-swing (0.79%) and out-swing (1.11%) trials for the AOI blink.
4.3.3 Starting Fixations

This section reflects results for the starting fixations. The results will be presented per AOI, followed by two, three and four AOI pattern combinations. The practical significance ranking is based on the differences between observed frequencies. The minimum percentage difference deemed practically significant was 5%. However, when practical significance for differences between ball type and between stroke outcome were respectively considered a one (1) percent (%) threshold was used.

Table 4.5.1 reflects the frequency distribution of the number of fixations per AOI at the start of trials for all trials (successful, unsuccessful, in-swing, and out-swing). The AOI that display no numerical value will be omitted from all the relevant tables in the remainder of this section.

Table 4.5.1: Number of starting fixations per AOI

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Total Fixations</th>
<th>Rank*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>142 55.9%</td>
<td>1</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>48 18.9%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body</td>
<td>40 15.7%</td>
<td>2</td>
</tr>
<tr>
<td>Pitch</td>
<td>15 5.9%</td>
<td>4</td>
</tr>
<tr>
<td>Blink</td>
<td>9 3.5%</td>
<td>4</td>
</tr>
</tbody>
</table>

*Based on the practical significance of the percentage differences, i.e. a difference of at least 5%

According to Table 4.5.1, the AOI that accumulated the most number of fixations at the start of trials was the AOI upper body (55.9%) and the AOI that accumulated the least number of fixations was the AOI blink (3.5%) and pitch (5.9%). The ranking that was found to be practically significant was rank 1, AOI upper body. The AOI can be broken up into three groups based on the practical significance of the percentage (%) differences. The AOI upper body is ranked first because the difference between 55.9% and 18.9% is greater than 5%. The AOI other/ off-target and lower body receive the ranking of second because the difference between 18.9% and 15.7% does not exceed 5%. The AOI pitch and blink received the ranking of fourth because
the difference between 15.7% and 5.9% is greater than 5% and because the difference between 5.9% and 3.5% does not exceed 5%.

Table 4.5.2 reflects the mean number of fixations per AOI at the start of trials for unsuccessful and successful trials.

Table 4.5.2: Number of starting fixations per AOI by stroke outcome

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Unsuccessful Mean</th>
<th>S.D.</th>
<th>Successful Mean</th>
<th>S.D.</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>0.57</td>
<td>0.35</td>
<td>0.57</td>
<td>0.35</td>
<td>0.000</td>
<td>1.000</td>
<td>n/a</td>
</tr>
<tr>
<td>Lower body</td>
<td>0.14</td>
<td>0.16</td>
<td>0.17</td>
<td>0.25</td>
<td>0.443</td>
<td>.510</td>
<td>n/a</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.06</td>
<td>0.22</td>
<td>0.05</td>
<td>0.21</td>
<td>0.156</td>
<td>.695</td>
<td>n/a</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>0.18</td>
<td>0.25</td>
<td>0.19</td>
<td>0.21</td>
<td>0.071</td>
<td>.792</td>
<td>n/a</td>
</tr>
<tr>
<td>Blink</td>
<td>0.05</td>
<td>0.11</td>
<td>0.02</td>
<td>0.08</td>
<td>2.441</td>
<td>.127</td>
<td>n/a</td>
</tr>
</tbody>
</table>

According to Table 4.5.2, none of the differences between successful and unsuccessful trials was found to be significant. The highest mean number of fixations observed at the start of trials was identical (0.57±0.35) for both successful and unsuccessful trials for the AOI upper body. The Lowest mean number of fixations at the start of trials was observed for both successful (0.02±0.08) and unsuccessful (0.05±0.11) trials for the AOI blink.
Table 4.5.3 reflects the frequency distribution of fixations per AOI at the start of trials for unsuccessful and successful trials.

**Table 4.5.3: Frequency distribution per AOI start of trials by stroke outcome**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>A. Unsuccessful</th>
<th>B. Successful</th>
<th>Total</th>
<th>A - B Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>68 54.8%</td>
<td>74 56.9%</td>
<td>142 55.9%</td>
<td>-2.1%</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>23 18.5%</td>
<td>25 19.2%</td>
<td>48 18.9%</td>
<td>-0.7%</td>
</tr>
<tr>
<td>Lower body</td>
<td>18 14.5%</td>
<td>22 16.9%</td>
<td>40 15.7%</td>
<td>-2.4%</td>
</tr>
<tr>
<td>Pitch</td>
<td>8 6.5%</td>
<td>7 5.4%</td>
<td>15 5.9%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Blink</td>
<td>7 5.6%</td>
<td>2 1.5%</td>
<td>9 3.5%</td>
<td>4.1%</td>
</tr>
</tbody>
</table>

According to Table 4.5.3, practical significant differences were found for all AOI except the AOI other/off-target. Higher upper body and lower body percentages were observed for the successful stroke outcome. Furthermore, higher pitch and blink percentages were observed for the unsuccessful stroke outcome.
Table 4.5.4 reflects the statistics for the number of the most common AOI and two, three and four element pattern fixations at the start of each trial according to the outcome of the trial.

**Table 4.5.4: The most common AOI and 2, 3 and 4 element fixations at the start of each trial by stroke outcome**

<table>
<thead>
<tr>
<th>AOI/Pattern</th>
<th>Mean Values</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsuccessful</td>
<td>Successful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper body</td>
<td>0.57</td>
<td>0.57</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release</td>
<td>0.19</td>
<td>0.31</td>
<td>6.401</td>
<td>.016</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball</td>
<td>0.12</td>
<td>0.23</td>
<td>7.299</td>
<td>.010</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>0.06</td>
<td>0.10</td>
<td>1.473</td>
<td>.233</td>
</tr>
</tbody>
</table>

According to Table 4.5.4, upper body was the most common AOI at the start of each trial. The mean (0.57±0.35) number of fixations for both unsuccessful and successful trials was identical. The most common two element AOI fixation at the start of trials was upper body & arm/ ball release. The highest mean (0.31±0.27) occurred during successful trials and was found to be significantly greater than the corresponding value (0.19±0.21) for unsuccessful trials (F=6.401, p=.016, d=0.48).

The most common three element AOI fixation at the start of trials was upper body & arm/ ball release & ball. The highest mean (0.23±0.24) occurred during successful trials and was found to be significantly greater than the corresponding value (0.12±0.18) for unsuccessful trials (F=7.299, p=.010, d=0.51).

The most common four element AOI fixation at the start of trials was upper body & arm/ ball release & ball & ball trajectory. The highest mean (0.10±0.16) occurred
during successful trials in comparison with unsuccessful (0.06±0.13) trials. This difference was found to be not significant (F=1.473, p=.233).

Table 4.5.5 reflects the mean number of fixations per AOI at the start of trials for in-swing and out-swing ball types respectively.

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>In-swing</th>
<th>Out-swing</th>
<th>ANOVA Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
</tr>
<tr>
<td>Upper body</td>
<td>0.62</td>
<td>0.37</td>
<td>0.52</td>
</tr>
<tr>
<td>Lower body</td>
<td>0.15</td>
<td>0.23</td>
<td>0.15</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.07</td>
<td>0.25</td>
<td>0.05</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>0.14</td>
<td>0.22</td>
<td>0.23</td>
</tr>
<tr>
<td>Blink</td>
<td>0.02</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

According to Table 4.5.5, none of the differences between in-swing and out-swing trials was found to be statistically significant. The highest mean number of fixations at the start of trials was observed for both in-swing (0.62±0.37) and out-swing (0.52±0.32) trials for the AOI upper body. The lowest mean number of fixations at the start of trials was observed for both in-swing (0.02±0.05) and out-swing (0.05±0.12) trials for the AOI blink.
Table 4.5.6 reflects the frequency distribution per AOI at the start of trials for in-swinger and out-swinger ball type trials.

**Table 4.5.6: Frequency distribution per AOI start of trials by ball type faced**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>A. In-swinger</th>
<th>B. Out-swinger</th>
<th>Total</th>
<th>A - B Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>75</td>
<td>67</td>
<td>142</td>
<td>8.9%</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>18</td>
<td>30</td>
<td>48</td>
<td>-8.6%</td>
</tr>
<tr>
<td>Lower body</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>0.7%</td>
</tr>
<tr>
<td>Pitch</td>
<td>9</td>
<td>6</td>
<td>15</td>
<td>2.6%</td>
</tr>
<tr>
<td>Blink</td>
<td>2</td>
<td>7</td>
<td>9</td>
<td>-3.8%</td>
</tr>
</tbody>
</table>

According to Table 4.5.6, practical significant differences were observed for all AOI except the AOI lower body. Higher upper body and pitch percentages were observed for the in-swinger ball type faced. Furthermore, higher other/off-target and blink percentages were observed for the out-swinger ball type faced.
Table 4.5.7 reflects the descriptive statistics of the number of the most common AOI and two, three and four element pattern fixations at the start of each trial for in-swing and out-swing trials.

**Table 4.5.7: Number of the most common AOI and 2, 3 and 4 element fixations at the start of each trial by ball type faced**

<table>
<thead>
<tr>
<th>AOI/Pattern</th>
<th>Mean Values</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-swing</td>
<td>Out-swing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper body</td>
<td>0.62</td>
<td>0.52</td>
<td>3.302</td>
<td>.077</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release</td>
<td>0.25</td>
<td>0.25</td>
<td>0.012</td>
<td>.913</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball</td>
<td>0.17</td>
<td>0.18</td>
<td>0.193</td>
<td>.663</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>0.07</td>
<td>0.09</td>
<td>0.575</td>
<td>.453</td>
</tr>
</tbody>
</table>

According to Table 4.5.7, upper body was the most common AOI at the start of each trial. A higher mean (0.62±0.37) number of fixations occurred at the start of trials for in-swing trials than out-swing (0.52±0.32) trials. However, no statistically significant differences were found for the AOI upper body (F=3.302, p=0.77).

The most common two element AOI fixation at the start of trials was upper body & arm/ ball release. The mean (0.25±0.26) number of fixations for both in-swing and out-swing was identical and obviously, no significant difference was found when comparing in-swing and out-swing trials (F=0.012, p=.913) in this respect. The most common three element AOI fixation at the start of trials was upper body, arm/ ball release & ball. The mean number of fixations was (0.17±0.20) for in-swing trials and (0.18±0.25) for out-swing trials and again no significant difference was
found (F=0.193, p=.663). The most common four element AOI fixation at the start of trials was upper body & arm/ ball release & ball & ball trajectory. The highest mean number of fixations occurred for out-swing trials (0.09±0.16) than in-swing (0.07±0.13) trials. However, this difference was also not statistically significant (F=0.575, p=.453).

4.3.4 Last Fixations

The following section will present data on the last fixations. The data will be presented per AOI, followed by two, three and four AOI pattern combinations. The practical significant ranking is based on the differences between observed frequencies. The minimum percentage difference deemed significant was 5%. However, when practical significance for differences between ball type and between stroke outcome were respectively considered a one (1) percent (%) threshold was used.

Table 4.6.1 reflects the frequency distribution of the number of fixations per AOI at the end of trials for all trials (successful, unsuccessful, in-swing, and out-swing).

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Total Fixations</th>
<th>Rank*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>167</td>
<td>66%</td>
</tr>
<tr>
<td>Blink</td>
<td>30</td>
<td>12%</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>28</td>
<td>11%</td>
</tr>
<tr>
<td>Ball</td>
<td>20</td>
<td>8%</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>9</td>
<td>4%</td>
</tr>
</tbody>
</table>

*Based on the practical significance of the percentage differences, i.e. a difference of at least 5%

According to Table 4.6.1, the AOI that accumulated the most number of fixations at the end of trials was the AOI pitch (66%) and the AOI that accumulated the least number of fixations at the end of trials was the AOI ball trajectory (4%). The ranking that was found to be practically significant was rank 1, AOI pitch. According to table
4.6.1, the categories that differed significantly can be broken up into three groups based on the practical significance of the percentage (%) differences. The AOI, pitch, is ranked first because the difference between pitch and blink exceeded the 5% threshold. Furthermore, blink, other/off-target and ball, received the ranking second as all these AOI are within the 5% threshold. In addition, ball trajectory received the ranking of five.

Table 4.6.2 reflects the mean number of fixations per AOI at the end of trials for unsuccessful and successful trials.

**Table 4.6.2: Number of fixations per AOI at the end of trials by stroke outcome**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Unsuccessful Mean</th>
<th>Unsuccessful S.D.</th>
<th>Successful Mean</th>
<th>Successful S.D.</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>0.64</td>
<td>0.38</td>
<td>0.68</td>
<td>0.29</td>
<td>0.592</td>
<td>.447</td>
<td>n/a</td>
</tr>
<tr>
<td>Blink</td>
<td><strong>0.17</strong></td>
<td><strong>0.27</strong></td>
<td><strong>0.07</strong></td>
<td><strong>0.11</strong></td>
<td><strong>0.012</strong></td>
<td><strong>.047</strong></td>
<td><strong>0.51</strong></td>
</tr>
<tr>
<td>Other/off-target</td>
<td>0.10</td>
<td>0.21</td>
<td>0.12</td>
<td>0.18</td>
<td>0.127</td>
<td>.724</td>
<td>n/a</td>
</tr>
<tr>
<td>Ball</td>
<td>0.05</td>
<td>0.09</td>
<td>0.11</td>
<td>0.22</td>
<td>2.387</td>
<td>.131</td>
<td>n/a</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>0.05</td>
<td>0.14</td>
<td>0.02</td>
<td>0.07</td>
<td>1.050</td>
<td>.312</td>
<td>n/a</td>
</tr>
</tbody>
</table>

According to Table 4.6.2, the unsuccessful group revealed a significantly higher number of fixations at the end of trials (0.17±0.27) than the successful group (0.07±0.11); (F=0.012, p=.047, d=0.51) for the AOI blink. The highest mean number of fixations at the end of trials was observed for both successful (0.68±0.29) and unsuccessful (0.64±0.38) trials for the AOI pitch. The lowest mean number of fixations at the end of trials was observed for both successful (0.02±0.07) and unsuccessful (0.05±0.14) trials for the AOI ball trajectory.
Table 4.6.3 reflects the frequency distribution of the number and subsequent percentage of fixations per AOI at the end of trials for unsuccessful and successful trials.

Table 4.6.3: Frequency distribution per AOI end of trials by stroke outcome

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>A. Unsuccessful</th>
<th>B. Successful</th>
<th>Total</th>
<th>A - B Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>78</td>
<td>62.9%</td>
<td>89</td>
<td>68.5%</td>
</tr>
<tr>
<td>Blink</td>
<td>21</td>
<td>16.9%</td>
<td>9</td>
<td>6.9%</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>13</td>
<td>10.5%</td>
<td>15</td>
<td>11.5%</td>
</tr>
<tr>
<td>Ball</td>
<td>6</td>
<td>4.8%</td>
<td>14</td>
<td>10.8%</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>6</td>
<td>4.8%</td>
<td>3</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

According to Table 4.6.3, practical significant differences were found for all AOI. Higher blink and ball trajectory percentages were observed for the unsuccessful stroke outcome. Furthermore, higher pitch, other/ off-target and ball percentages were observed for the successful stroke outcome.
Table 4.6.4 reflects the statistics for the number of the most common AOI and two, three and four element pattern fixations at the end of each trial according to the outcome of the trial.

Table 4.6.4: Number of the most common AOI and 2, 3 and 4 element fixations at the end of each trial by stroke outcome

<table>
<thead>
<tr>
<th>AOI/Pattern</th>
<th>Mean Values</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsuccessful</td>
<td>Successful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitch</td>
<td>0.64</td>
<td>0.68</td>
<td>0.592</td>
<td>.447</td>
</tr>
<tr>
<td>Ball &amp; Pitch</td>
<td>0.48</td>
<td>0.45</td>
<td>0.255</td>
<td>.617</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball &amp; Pitch</td>
<td>0.15</td>
<td>0.16</td>
<td>0.034</td>
<td>.855</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Pitch</td>
<td>0.11</td>
<td>0.11</td>
<td>0.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

According to Table 4.6.4, pitch was the most common AOI at the end of each trial. A higher mean (0.68±0.29) number of fixations occurred at the end of trials for successful trials than unsuccessful (0.64±0.38) trials. The difference between these mean values was found to be not significant (F= 0.592, p= .447). The most common two element AOI fixation at the end of trials was ball & pitch. The highest mean occurred during unsuccessful (0.48±0.35) and successful (0.45±0.28) trials. However, no significant differences were found when comparing unsuccessful and successful trials (F=0.255 p=.617) in this regard.

The most common three element AOI fixation at the end of trials was ball trajectory & ball & pitch. The highest mean occurred during successful (0.16±0.17) trials than unsuccessful (0.15±0.25) trials. However, no significant differences were found (F=0.034, p=.855) in this regard. The most common four element AOI fixation at the end of trials was upper body & arm/ ball release & ball & pitch. The shared mean (0.11) was the number of fixations for both successful (0.11±0.15) and unsuccessful (0.11±0.19) trials and obviously, no significant difference was found (F=0.000, p=...
1.000) in this regard. Overall, no significant differences were found for one, two, three and four element fixation patterns for stroke outcome.

Table 4.6.5 reflects the mean number of fixations per AOI at the end of trials for in-swinger and out-swinger trials.

**Table 4.6.5: Number of fixations per AOI at the end of trials by ball type faced**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>In-swinger</th>
<th>Out-swinger</th>
<th>ANOVA Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.66</td>
<td>0.35</td>
<td>0.66</td>
</tr>
<tr>
<td>Blink</td>
<td>0.12</td>
<td>0.21</td>
<td>0.12</td>
</tr>
<tr>
<td>Other/ off-target</td>
<td>0.11</td>
<td>0.19</td>
<td>0.11</td>
</tr>
<tr>
<td>Ball</td>
<td>0.05</td>
<td>0.11</td>
<td>0.10</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>0.05</td>
<td>0.14</td>
<td>0.02</td>
</tr>
</tbody>
</table>

According to Table 4.6.5, none of the differences between in-swinger and out-swinger trials was found to be statistically significant in respect of the mean number of fixations at the end of trials. The highest mean number of fixations at the end of trials was observed for both in-swinger (0.66±0.35) and out-swinger (0.66±0.33) trials for the AOI pitch. The lowest mean number of fixations at the end of trials was observed for both in-swinger (0.05±0.14) and out-swinger (0.02±0.05) trials for the AOI ball trajectory.
Table 4.6.6 reflects the number of fixations and subsequent percentage frequency distribution per AOI at the end of trials for in-swinger and out-swinger trials.

Table 4.6.6: Frequency distribution of number of fixations per AOI at the end of trials by ball type faced

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>A. In-swinger</th>
<th>B. Out-swinger</th>
<th>Total</th>
<th>A - B Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>81 65.3%</td>
<td>86 66.2%</td>
<td>167 65.7%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Blink</td>
<td>15 12.1%</td>
<td>15 11.5%</td>
<td>30 11.8%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>14 11.3%</td>
<td>14 10.8%</td>
<td>28 11.0%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Ball</td>
<td>7 5.6%</td>
<td>13 10.0%</td>
<td>20 7.9%</td>
<td>-4.4%</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>7 5.6%</td>
<td>2 1.5%</td>
<td>9 3.5%</td>
<td>4.1%</td>
</tr>
</tbody>
</table>

According to Table 4.6.6, practical significant differences were found for the AOI ball and ball trajectory. Higher ball percentages were observed for the out-swinger ball type faced. Furthermore, higher ball trajectory percentages were observed for the in-swinger ball type faced.
Table 4.6.7 reflects the statistics for the number of the most common AOI and two, three and four element pattern fixations at the end of each trial according to the outcome of the trial.

**Table 4.6.7: Number of the most common AOI and 2, 3 and 4 element fixations at the end of each trial according to ball type faced**

<table>
<thead>
<tr>
<th>AOI/Pattern</th>
<th>Mean Values</th>
<th>F-value</th>
<th>p (df=1;51)</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-swinger</td>
<td>Out-swinger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitch</td>
<td>0.66</td>
<td>0.66</td>
<td>0.002</td>
<td>.964</td>
</tr>
<tr>
<td>Ball &amp; Pitch</td>
<td>0.44</td>
<td>0.48</td>
<td>0.436</td>
<td>.513</td>
</tr>
<tr>
<td><strong>Ball trajectory &amp; Ball &amp; Pitch</strong></td>
<td><strong>0.12</strong></td>
<td><strong>0.20</strong></td>
<td><strong>4.119</strong></td>
<td><strong>.050</strong></td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Pitch</td>
<td>0.12</td>
<td>0.10</td>
<td>0.179</td>
<td>.675</td>
</tr>
</tbody>
</table>

According to Table 4.6.7, pitch was the most common AOI at the end of each trial. The mean (0.66) number of fixations for both in-swinger and out-swinger trials was identical. The most common two element AOI fixation at the end of trials was ball & pitch. The highest mean (0.48) occurred during out-swinger trials and was found to be not significant when compared to the corresponding value (0.44) for in-swinger trials (F=0.436, p=.513).

The most common three element AOI fixation at the end of trials was ball trajectory & ball & pitch. The highest mean (0.20) occurred during out-swinger trials and was found to be significantly greater than the corresponding value (0.12) for in-swinger trials (F=4.119, p=.050, d=0.41).

The most common four element AOI fixation at the end of trials was upper body & arm/ ball release & ball & pitch. The highest mean (0.12) occurred during in-swinger trials in comparison with out-swinger (0.10) trials. This difference was found to be not significant (F=0.179, p=.675).
4.3.5 Order of Fixations

This section presents results for the order in which AOI fixation patterns were observed. Descriptive statistics only will be reported as the lack of appropriate tests makes it impossible to obtain inferential statistics. The Chi² test could not be utilised as the test requires that the observations for the frequency table for which the test is to be conducted must be independent. This requirement is not met for the reason that multiple entries per participant were entered.

It needs to be noted that in this section the same ranking system as was used to describe percentage results in other sections was applied here as well (see chapter 3 data analysis).

Tables 4.7.1 and 4.7.2 reflect the descriptive statistics of the number of fixations per AOI for successful and unsuccessful trials respectively.

**Table 4.7.1: Frequency distribution per AOI for successful trials**

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>212</td>
<td>19.8%</td>
<td>1</td>
</tr>
<tr>
<td>Ball</td>
<td>198</td>
<td>18.5%</td>
<td>1</td>
</tr>
<tr>
<td>Pitch</td>
<td>164</td>
<td>15.3%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>149</td>
<td>13.9%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>130</td>
<td>12.1%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body</td>
<td>100</td>
<td>9.3%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>77</td>
<td>7.2%</td>
<td>3</td>
</tr>
<tr>
<td>Blink</td>
<td>40</td>
<td>3.7%</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 4.7.2: Frequency distribution per AOI for unsuccessful trials

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>222</td>
<td>20.6%</td>
<td>1</td>
</tr>
<tr>
<td>Ball</td>
<td>194</td>
<td>18.0%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>174</td>
<td>16.2%</td>
<td>1</td>
</tr>
<tr>
<td>Pitch</td>
<td>146</td>
<td>13.6%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>137</td>
<td>12.7%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body</td>
<td>89</td>
<td>8.3%</td>
<td>3</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>71</td>
<td>6.6%</td>
<td>3</td>
</tr>
<tr>
<td>Blink</td>
<td>43</td>
<td>4.0%</td>
<td>3</td>
</tr>
</tbody>
</table>

According to Tables 4.7.1 and 4.7.2, the AOI upper body and ball were ranked similarly for both successful and unsuccessful trials. However, the AOI pitch was ranked first in successful trials, but ranked second in unsuccessful trials. Interestingly, AOI other/off-target was ranked first and registered more frequent fixations during unsuccessful trials.
Tables 4.7.3 and 4.7.4 reflect the descriptive statistics of the number of fixations per AOI for in-swinger and out-swinger trials respectively.

Table 4.7.3: Frequency distribution per AOI for in-swinger trials

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>211</td>
<td>20.5%</td>
<td>1</td>
</tr>
<tr>
<td>Ball</td>
<td>188</td>
<td>18.3%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>151</td>
<td>14.7%</td>
<td>2</td>
</tr>
<tr>
<td>Pitch</td>
<td>150</td>
<td>14.6%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>134</td>
<td>13.0%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body</td>
<td>90</td>
<td>8.7%</td>
<td>3</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>67</td>
<td>6.5%</td>
<td>3</td>
</tr>
<tr>
<td>Blink</td>
<td>39</td>
<td>3.8%</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 4.7.4: Frequency distribution per AOI for out-swinger trials

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body</td>
<td>223</td>
<td>20.0%</td>
<td>1</td>
</tr>
<tr>
<td>Ball</td>
<td>204</td>
<td>18.3%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target</td>
<td>172</td>
<td>15.4%</td>
<td>1</td>
</tr>
<tr>
<td>Pitch</td>
<td>160</td>
<td>14.3%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release</td>
<td>133</td>
<td>11.9%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body</td>
<td>99</td>
<td>8.9%</td>
<td>3</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>81</td>
<td>7.3%</td>
<td>3</td>
</tr>
<tr>
<td>Blink</td>
<td>44</td>
<td>3.9%</td>
<td>4</td>
</tr>
</tbody>
</table>

According to Tables 4.7.3 and 4.7.4, the AOI upper body and ball were ranked similarly for both in-swinger and out-swinger trials. However, the addition of other/off-target was ranked first in out-swinger trials. All other AOI were ranked exactly the same per ranking for ball type.
Tables 4.7.5 and 4.7.6 reflect the descriptive statistics of the number of fixations per two element AOI fixations for successful and unsuccessful trials respectively.

Table 4.7.5: Frequency distribution per 2 AOI pattern for successful trials

<table>
<thead>
<tr>
<th>2 AOI Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release</td>
<td>108</td>
<td>11.5%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball</td>
<td>96</td>
<td>10.2%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Pitch</td>
<td>87</td>
<td>9.3%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body</td>
<td>69</td>
<td>7.3%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory</td>
<td>55</td>
<td>5.9%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body</td>
<td>50</td>
<td>5.3%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target</td>
<td>48</td>
<td>5.1%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball</td>
<td>43</td>
<td>4.6%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Lower body</td>
<td>37</td>
<td>3.9%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Other/off-target</td>
<td>31</td>
<td>3.3%</td>
<td>2</td>
</tr>
<tr>
<td>Pitch &amp; Ball</td>
<td>27</td>
<td>2.9%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Pitch</td>
<td>25</td>
<td>2.7%</td>
<td>2</td>
</tr>
<tr>
<td>Pitch &amp; Lower body</td>
<td>21</td>
<td>2.2%</td>
<td>2</td>
</tr>
<tr>
<td>Blink &amp; Other/off-target</td>
<td>20</td>
<td>2.1%</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 4.7.6: Frequency distribution per 2 AOI pattern for unsuccessful trials

<table>
<thead>
<tr>
<th>2 AOI Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release</td>
<td>103</td>
<td>10.8%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball</td>
<td>91</td>
<td>9.6%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Pitch</td>
<td>84</td>
<td>8.8%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body</td>
<td>64</td>
<td>6.7%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body</td>
<td>63</td>
<td>6.6%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target</td>
<td>62</td>
<td>6.5%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory</td>
<td>53</td>
<td>5.6%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Lower body</td>
<td>41</td>
<td>4.3%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball</td>
<td>41</td>
<td>4.3%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Other/off-target</td>
<td>36</td>
<td>3.8%</td>
<td>2</td>
</tr>
<tr>
<td>Pitch &amp; Ball</td>
<td>26</td>
<td>2.7%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Arm/ball release</td>
<td>25</td>
<td>2.6%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Ball</td>
<td>23</td>
<td>2.4%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Pitch</td>
<td>20</td>
<td>2.1%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release &amp; Upper body</td>
<td>19</td>
<td>2.0%</td>
<td>2</td>
</tr>
</tbody>
</table>

According to Tables 4.7.5 and 4.7.6, the AOI upper body and arm/ball release; arm/ball release and ball; ball and pitch; lower body and upper body were ranked similarly for both successful and unsuccessful trials. However, the addition of other/off-target and upper body and other/off-target was ranked first during unsuccessful trials. All other AOI received the same ranking for stroke outcome.
Tables 4.7.7 and 4.7.8 reflect the descriptive statistics of the number of fixations per two element AOI fixations for in-swingers and out-swingers trials respectively.

**Table 4.7.7: Frequency distribution per 2 AOI pattern for in-swingers trials**

<table>
<thead>
<tr>
<th>2 AOI Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release</td>
<td>105</td>
<td>11.6%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball</td>
<td>96</td>
<td>10.6%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Pitch</td>
<td>80</td>
<td>8.8%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body</td>
<td>65</td>
<td>7.2%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target</td>
<td>56</td>
<td>6.2%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory</td>
<td>50</td>
<td>5.5%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body</td>
<td>45</td>
<td>5.0%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Lower body</td>
<td>34</td>
<td>3.8%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Other/off-target</td>
<td>32</td>
<td>3.5%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball</td>
<td>32</td>
<td>3.5%</td>
<td>2</td>
</tr>
<tr>
<td>Pitch &amp; Ball</td>
<td>25</td>
<td>2.8%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Arm/ball release</td>
<td>23</td>
<td>2.5%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Pitch</td>
<td>22</td>
<td>2.4%</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 4.7.8: Frequency distribution per 2 AOI pattern for out-swing trials

<table>
<thead>
<tr>
<th>2 AOI Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release</td>
<td>106</td>
<td>10.8%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball</td>
<td>91</td>
<td>9.2%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Pitch</td>
<td>91</td>
<td>9.2%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body</td>
<td>68</td>
<td>6.9%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body</td>
<td>68</td>
<td>6.9%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory</td>
<td>58</td>
<td>5.9%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target</td>
<td>54</td>
<td>5.5%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball</td>
<td>52</td>
<td>5.3%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Lower body</td>
<td>44</td>
<td>4.5%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Other/off-target</td>
<td>35</td>
<td>3.5%</td>
<td>2</td>
</tr>
<tr>
<td>Pitch &amp; Ball</td>
<td>28</td>
<td>2.8%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Ball</td>
<td>24</td>
<td>2.4%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Pitch</td>
<td>23</td>
<td>2.3%</td>
<td>2</td>
</tr>
<tr>
<td>Blink &amp; Other/off-target</td>
<td>23</td>
<td>2.3%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Arm/ball release</td>
<td>20</td>
<td>2.0%</td>
<td>2</td>
</tr>
</tbody>
</table>

According to Tables 4.7.7 and 4.7.8, the AOI upper body and arm/ball release; arm/ball release and ball; ball and pitch; and lower body and upper body, were ranked similarly for both in-swing trials and out-swing trials. However, the addition of other/off-target and upper body; and ball and ball trajectory were ranked first during out-swing trials. All other AOI were ranked exactly the same per ranking for ball type.
Tables 4.7.9 and 4.7.10 reflect the descriptive statistics of the number of fixations per three element AOI fixations for successful and unsuccessful trials respectively.

**Table 4.7.9: Frequency distribution per 3 AOI fixation pattern for successful trials**

<table>
<thead>
<tr>
<th>3 AOI Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball</td>
<td>83</td>
<td>10.2%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>41</td>
<td>5.1%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Lower body &amp; Upper body</td>
<td>32</td>
<td>4.0%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Pitch</td>
<td>32</td>
<td>4.0%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release</td>
<td>29</td>
<td>3.6%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball &amp; Pitch</td>
<td>28</td>
<td>3.5%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Ball</td>
<td>27</td>
<td>3.3%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release</td>
<td>26</td>
<td>3.2%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Upper body</td>
<td>22</td>
<td>2.7%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Pitch</td>
<td>21</td>
<td>2.6%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Lower body</td>
<td>20</td>
<td>2.5%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Other/off-target</td>
<td>19</td>
<td>2.3%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Pitch &amp; Ball</td>
<td>18</td>
<td>2.2%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Arm/ball release</td>
<td>17</td>
<td>2.1%</td>
<td>2</td>
</tr>
<tr>
<td>3 AOI Pattern</td>
<td>n</td>
<td>%</td>
<td>Rank</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>------</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball</td>
<td>72</td>
<td>8.7%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>36</td>
<td>4.3%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Upper body</td>
<td>35</td>
<td>4.2%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release</td>
<td>33</td>
<td>4.0%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Lower body &amp; Upper body</td>
<td>32</td>
<td>3.9%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release</td>
<td>32</td>
<td>3.9%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Pitch</td>
<td>32</td>
<td>3.9%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Ball</td>
<td>26</td>
<td>3.1%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball &amp; Pitch</td>
<td>26</td>
<td>3.1%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Other/off-target</td>
<td>23</td>
<td>2.8%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Pitch</td>
<td>19</td>
<td>2.3%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Arm/ball release</td>
<td>18</td>
<td>2.2%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Arm/ball release &amp; Ball</td>
<td>17</td>
<td>2.1%</td>
<td>2</td>
</tr>
</tbody>
</table>

According to Tables 4.7.9 and 4.7.10, the AOI pattern upper body and arm/ ball release and ball; and arm/ ball release and ball and ball trajectory were ranked similarly for both successful and unsuccessful trials. However, upper body and other/ off-target and arm/ ball release; other/ off-target and upper body and arm/ ball release; upper body and lower body and upper body; lower body and upper body and arm/ ball release; arm ball release and ball and pitch was ranked first during unsuccessful trials but second during successful trials. All other AOI were exactly the same per ranking for stroke outcome.
Tables 4.7.11 and 4.7.12 reflect the descriptive statistics of the number of fixations per three element AOI fixations for in-swing and out-swing trials respectively.

**Table 4.7.11: Frequency distribution per 3 AOI fixation pattern for in-swing trials**

<table>
<thead>
<tr>
<th>3 AOI Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball</td>
<td>78</td>
<td>10.0%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Pitch</td>
<td>39</td>
<td>5.0%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>35</td>
<td>4.5%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Lower body &amp; Upper body</td>
<td>28</td>
<td>3.6%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release</td>
<td>28</td>
<td>3.6%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release</td>
<td>28</td>
<td>3.6%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Upper body</td>
<td>27</td>
<td>3.5%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Ball</td>
<td>21</td>
<td>2.7%</td>
<td>2</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball &amp; Pitch</td>
<td>20</td>
<td>2.6%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Pitch</td>
<td>19</td>
<td>2.4%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Arm/ball release</td>
<td>18</td>
<td>2.3%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Pitch &amp; Ball</td>
<td>18</td>
<td>2.3%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Lower body</td>
<td>17</td>
<td>2.2%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Other/off-target</td>
<td>17</td>
<td>2.2%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Arm/ball release &amp; Ball</td>
<td>17</td>
<td>2.2%</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 4.7.12: Frequency distribution per 3 AOI pattern for out-swing trials

<table>
<thead>
<tr>
<th>3 AOI Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball</td>
<td>77</td>
<td>9.0%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>42</td>
<td>4.9%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Lower body &amp; Upper body</td>
<td>36</td>
<td>4.2%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release</td>
<td>34</td>
<td>4.0%</td>
<td>1</td>
</tr>
<tr>
<td>Ball trajectory &amp; Ball &amp; Pitch</td>
<td>34</td>
<td>4.0%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Ball</td>
<td>32</td>
<td>3.7%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Upper body</td>
<td>30</td>
<td>3.5%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release</td>
<td>30</td>
<td>3.5%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Pitch</td>
<td>25</td>
<td>2.9%</td>
<td>2</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Other/off-target</td>
<td>25</td>
<td>2.9%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Pitch</td>
<td>21</td>
<td>2.5%</td>
<td>2</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Lower body</td>
<td>18</td>
<td>2.1%</td>
<td>2</td>
</tr>
<tr>
<td>Ball &amp; Other/off-target &amp; Ball</td>
<td>18</td>
<td>2.1%</td>
<td>2</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Other/off-target</td>
<td>18</td>
<td>2.1%</td>
<td>2</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Arm/ball release</td>
<td>17</td>
<td>2.0%</td>
<td>2</td>
</tr>
</tbody>
</table>

According to Tables 4.7.11 and 4.7.12, the following AOI fixation pattern was ranked similarly for both in-swing and out-swing trials: upper body and arm/ball release and ball. However, arm/ball release and ball and pitch were ranked first during in-swing trials. In addition arm/ball release and ball and ball trajectory; upper body and lower body and upper body; other/off-target and upper body and arm/ball release; ball trajectory and ball and pitch, were ranked first during out-swing trials. All other AOI were exactly the same per ranking for ball type.
Tables 4.7.13 and 4.7.14 reflect the descriptive statistics of the number of fixations per four element AOI fixations for successful and unsuccessful trials respectively.

**Table 4.7.13: Frequency distribution per 4 AOI fixation pattern for successful trials**

<table>
<thead>
<tr>
<th>4 Element Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>37</td>
<td>5.4%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Pitch</td>
<td>26</td>
<td>3.8%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>25</td>
<td>3.7%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>20</td>
<td>2.9%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory &amp; Ball</td>
<td>19</td>
<td>2.8%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Lower body &amp; Upper body</td>
<td>18</td>
<td>2.6%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Other/off-target</td>
<td>17</td>
<td>2.5%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory &amp; Pitch</td>
<td>16</td>
<td>2.4%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Ball &amp; Pitch</td>
<td>15</td>
<td>2.2%</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 4.7.14: Frequency distribution per 4 AOI fixation pattern for unsuccessful trials**

<table>
<thead>
<tr>
<th>4 Element Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>31</td>
<td>4.4%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Pitch</td>
<td>26</td>
<td>3.7%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>26</td>
<td>3.7%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>22</td>
<td>3.1%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory &amp; Ball</td>
<td>21</td>
<td>3.0%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Upper body &amp; Arm/ball release</td>
<td>20</td>
<td>2.8%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Lower body &amp; Upper body &amp; Arm/ball release</td>
<td>19</td>
<td>2.7%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Ball &amp; Pitch</td>
<td>16</td>
<td>2.3%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Other/off-target &amp; Upper body</td>
<td>16</td>
<td>2.3%</td>
<td>1</td>
</tr>
</tbody>
</table>

According to Tables 4.7.13 and 4.7.14, the first five of the AOI patterns upper body and arm/ball release and ball and ball trajectory; upper body and arm/ ball release and ball and pitch; other/ off-target and upper body and arm/ ball release and ball; lower body and upper body and arm/ ball release and ball and arm/ ball release and
ball and ball trajectory and ball were ranked first during both successful and unsuccessful trials. All other four AOI patterns were exactly the same per ranking for stroke outcome, but three of them had different AOI combinations.

Tables 4.7.15 and 4.7.16 reflect the descriptive statistics of the number of fixations per four element AOI fixations for in-swinger and out-swinger trials respectively.

Table 4.7.15: Frequency distribution per 4 AOI fixation pattern for in-swinger trials

<table>
<thead>
<tr>
<th>4 Element Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Pitch</td>
<td>30</td>
<td>4.6%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>29</td>
<td>4.4%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>25</td>
<td>3.8%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>22</td>
<td>3.3%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Upper body &amp; Arm/ball release</td>
<td>17</td>
<td>2.6%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory &amp; Ball</td>
<td>17</td>
<td>2.6%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Other/off-target &amp; Arm/ball release &amp; Ball</td>
<td>15</td>
<td>2.3%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Other/off-target</td>
<td>14</td>
<td>2.1%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Lower body &amp; Upper body</td>
<td>14</td>
<td>2.1%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Lower body &amp; Upper body &amp; Arm/ball release</td>
<td>13</td>
<td>2.0%</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.7.16: Frequency distribution per 4 AOI fixation pattern for out-swinger trials

<table>
<thead>
<tr>
<th>4 Element Pattern</th>
<th>n</th>
<th>%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Ball trajectory</td>
<td>39</td>
<td>5.4%</td>
<td>1</td>
</tr>
<tr>
<td>Other/off-target &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>26</td>
<td>3.6%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory &amp; Ball</td>
<td>23</td>
<td>3.2%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Arm/ball release &amp; Ball &amp; Pitch</td>
<td>22</td>
<td>3.0%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Arm/ball release &amp; Ball</td>
<td>20</td>
<td>2.8%</td>
<td>1</td>
</tr>
<tr>
<td>Upper body &amp; Lower body &amp; Upper body &amp; Arm/ball release</td>
<td>19</td>
<td>2.6%</td>
<td>1</td>
</tr>
<tr>
<td>Ball &amp; Ball trajectory &amp; Ball &amp; Pitch</td>
<td>19</td>
<td>2.6%</td>
<td>1</td>
</tr>
<tr>
<td>Lower body &amp; Upper body &amp; Lower body &amp; Upper body</td>
<td>15</td>
<td>2.1%</td>
<td>1</td>
</tr>
<tr>
<td>Arm/ball release &amp; Ball &amp; Ball trajectory &amp; Pitch</td>
<td>15</td>
<td>2.1%</td>
<td>1</td>
</tr>
</tbody>
</table>
According to Tables 4.7.15 and 4.7.16, the AOI fixation pattern upper body and arm/ball release and ball and pitch were ranked first for in-swing trials and upper body and arm/ball release and ball and ball trajectory was ranked first for out-swing trials. Six similar four AOI pattern combinations are evident in both ball types and although all were ranked first their percentage fixations differed.

Chapter 5 to follow will discuss the results of this study in order to draw conclusions on hypotheses set.
CHAPTER 5: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This study sought to identify the visual gaze behaviour of sub-elite cricket batsmen when facing fast in-swing and out-swing bowling. This chapter aims to discuss the results obtained for this study and is presented in six sections. The factors controlled for during testing are discussed first. This is followed by the number and duration of fixations. Finally, the starting, last and order of fixations are discussed. Comparisons between variables that were determined to be statically significant are examined and discussed. Explanations are provided for the results obtained and where relevant useful insight into the visual gaze behaviour of sub-elite cricket batsmen is rendered. This chapter is concluded with a summary of the study findings, conclusions as well as limitations experienced during the study and finally provides recommendations for future research.
5.2 FACTORS CONTROLLED FOR DURING TESTING

The following section reflects a discussion of the factors that were controlled throughout the study to ensure that the results obtained are valid.

5.2.1 Eye Dominance

The effect of eye dominance could not be investigated due to the small sample size (nine right eye dominant versus four left eye dominant batsman). Although the eye tracker records data from the right eye only, the calibration of the eye was done with both eyes open while assuming the natural (side on) cricket batting stance. The aforementioned process ensured that the experimental set-up simulated the natural environment in which cricket is played and therefore was assumed not to have had an influence on the visual gaze behaviour data obtained.

5.2.2 Speed of Delivery

The following average speed readings were specifically found for successful: 113.11±5.03 km/h; unsuccessful: 113.07±4.33 km/h; in-swing: 110.16±4.86 km/h and out-swing: 115.22±4.71 km/h trials. According to Bartlett et al. (1996:416) the general speed categories in cricket bowling are classified as follows: slow medium (64.8–97.2 km/h), fast medium (97.2–129.6 km/h) fast (129.6–144 km/h) and express (> 145.8 km/h). The overall average speed for both the stroke outcome and the ball type faced in this study was classified as fast-medium. Although the speed categories for both the stroke outcome and the ball type faced are all classified as fast-medium, it may be possible that the speed of delivery may have potentially influenced the results obtained when comparing in-swing and out-swing trials. The batsmen may have had less time to react when facing out-swing trials subsequently influencing the results obtained. None, the less, caution when interpreting the results when comparing in-swing and out-swing trials should be exercised.
5.2.3 Lighting Conditions During Eye Tracking

The light reading obtained during this study was equivalent to 1400 lux Ca. According to Schlyter (2010), the illuminance equivalent of 1400 lux Ca is full daylight. The present study was conducted in an indoor facility as a direct consequence of the mobile eye tracker not being able to function optimally under the ambient light as the ultraviolet rays from the sun inhibit the recording of visual gaze data. The lighting conditions found in this study replicated the conventional (outdoor) environment in which cricket is played. The lighting conditions were found to be the same for all participants and it could therefore not have had a differentiated influence on the data obtained.

Summary: factors controlled for during testing

The eye dominance of the participants did not influence the results obtained in this study as the calibration of the eye was done with both eyes open while simulating the natural side on cricket batting stance. The overall average speed for both the stroke outcome and the ball type faced in this study was classified as fast-medium however, a significant difference was found when comparing in-swing and out-swing trials. The lighting conditions quantified in this study were the same for all the participants and it replicated the outdoor (natural) environment in which cricket is played. Overall, it seems that the factors that were controlled for during the testing did not influence the results in this study, but caution is exercised when interpreting in-swing versus out-swing.

5.3 NUMBER OF FIXATIONS

The first set of data presented the stroke outcome and ball type faced irrespective of the AOI. The mean number of fixations per AOI for all trials, stroke outcome and ball type faced were illustrated in Table 4.3.1, and subsequent analyses, indicated that there were no significant differences between successful and unsuccessful (F=1.936, p=.172) trials in respect of mean number of fixations. Furthermore, no significant differences were found between in-swing and out-swing (F=.424, p=.519) trials also in respect of mean number of fixations. The following reasons can
possibly account for the lack of significant differences found: the information processing system, the perception and action systems, the influence of situational probability and the effect of anxiety.

The first possible reason alludes to the influence of the information processing system. The batsmen’s perception or (input) component of the information processing system may be the same possibly suggesting that the methodology employed to extract visual information to supplement effective motor programming and execution is similar irrespective of the stroke outcome or the ball type faced. The aforementioned may yield identical visual gaze behaviour in terms of number of fixations which may justify the lack of significant differences obtained for the stroke outcome and the ball type faced. Similar results were found for example by McRobert (2009:480).

The second possible reason pertains to the level of control required to coordinate the neuromuscular and visual system during interceptive timing tasks (Sarpeshkar & Mann, 2011:306). This may suggest that more consistent visual gaze behaviour may be in support of the prospective control strategy to facilitate successful motor planning and execution. This refined pattern may have possibly resulted in smaller discrepancies obtained in the visual gaze behaviour employed by sub-elite batsmen further justifying the lack of significant differences obtained in this study.

Alternatively, the determining factor may potentially exist between the central and peripheral nervous system which is collectively responsible for controlling the effector mechanisms needed to execute the desired response. This particular study only assessed the visual or (input) component and not the sequential and critical link that exists between perception, the central and peripheral nervous system and the action (effector) systems. A possible recommendation for future studies may be to assess the perception component in conjunction with the peripheral nervous system with the inclusion of a visual motion (image) capturing system. The latter system could provide essential kinematic data that can be linked with the visual gaze behaviour data while a performer executes an action. This will provide a deeper understanding of the control processes that contribute to the successful performance of interceptive actions.
The third possible reason may allude to the influence of the situational probability information provided to the batsmen as a result of the highly controlled testing environment. No short pitched deliveries and hazardous strokes were allowed to be executed by the bowlers and the batsmen respectively. The situational probability information may have enhanced the batsman’s anticipatory performance as previous research has indicated that an improvement in performance is expected if the anticipated outcome concurs with the actual outcome (Mann et al., 2014). The aforementioned may have had a potential impact on the lack of significant differences obtained in Table 4.3.1.

On the other hand, the situational probability information may have had an adverse effect on the batsmen’s performance due to the omission of the batting helmet that may have caused anxious batsmen. Anxiety may result in a higher number of fixations which may possibly account for the high number of fixations found in Table 4.3.1. In this instance, one particular batsman accumulated a maximum fixation number of 18 that subsequently resulted in an unsuccessful stroke. Although anxiety was not assessed in this study, a recommendation for future studies is to determine anxiety levels pre and post-test and the effect thereof on the visual gaze behaviour during interceptive timing tasks.

In addition, the high fixation number found may also be attributed to the eye movement and gaze control strategy employed. The prospective control strategy encompasses continuous regulation necessitating regular optical feedback that exists in the form of fixations to warrant information processing (Davids, Renshaw & Glazier, 2005:37; Katsumata & Russell, 2012:499). A higher number of fixations may indicate an increased dependence upon feedback to intensify the quality of information processing that occurs to facilitate successful interception. The unpredictable nature of the flight path of the cricket ball, suggests that saccadic (rapid) eye movements are employed to extract the required visual information during interceptive timing tasks (Vickers, 2007:112 & Piras et al., 2014:1), such as specifically in cricket (Land & McLeod, 2000:1341; Mann et al., 2013:6). The nature of the gaze control strategy in conjunction with the type of eye movements employed may further justify the high fixation number found in this study.
The preceding section discussed research for the stroke outcome and the ball type faced irrespective of the AOI. The succeeding section will still focus on the stroke outcome and the ball type faced, however, the discussion will include the relative contributions of certain AOI to account for some of the significant differences obtained in this particular study.

According to Table 4.3.2, mean number of fixations per AOI for stroke outcome and 4.3.4, mean number of fixations per AOI for ball type, the highest number of fixations was observed for both the stroke outcome and the ball type faced for the AOI upper body. Interestingly, the AOI arm/ ball release was not observed to be statistically significant for stroke outcome (F=3.829, p=.058) but it was fairly close possibly suggesting the potential importance of this AOI in contributing to successful batting performance.

The AOI upper body may be viewed as a task-relevant kinematic cue that forms an integral part of anticipating an opponents’ action which in time-constrained environments is imperative. The AOI upper body may be further utilised to identify the AOI arm/ ball release which was also found to be practically significant for ball type faced (see Table 4.3.5). Extensive research has identified the AOI upper body as an important contributor to the early identification of the ball and overall successful performance during interceptive timing tasks (Singer, 2000:222; Williams, 2000:739; Shim et al., 2005:170; Müller et al., 2006:2164; Shim et al., 2006:334; Jackson & Mogan, 2007:346; McRobert et al., 2009:479; Williams et al., 2009:367; Sarpeshkar & Mann, 2011:308).

In addition, research has also revealed that experts’ initially directed their gaze at the head and face region (upper body) during the initial part of viewing an opponent’s action. This was followed by a shift in the experts’ gaze to the pitching arm and release point significantly more in comparison with non-experts (Takeuchi & Inomata, 2009:977; Ward, Williams & Bennett, 2002:109). It appears that the AOI upper body is considered as a task-relevant kinematic cue to both expert and novice skill groups. The aforementioned, further substantiates the results reflected in Tables 4.3.3 and 4.3.5 highlighting a high frequency of fixations on the AOI upper body for both the stroke outcome and the ball type faced.
The other AOI that were found to be practically significant for the stroke outcome and the ball type faced were lower body and pitch (see Tables 4.3.3 and 4.3.5). A greater frequency of fixations was observed for the successful stroke for the AOI lower body and pitch. The batsmen may fixate upon the AOI lower body to accurately extrapolate the ball landing position from the run-up line of the bowler which has previously been considered as a contributor to successful interception during interceptive timing tasks (Hayhoe et al., 2012:128). Furthermore, the AOI lower body may also be used to control the batsmen’s head position which previous research by Mann et al. (2013:2) has also shown to be linked to successful batting performance.

In addition, research also found that saccadic eye movements are often employed by expert batsmen to predict the ball bounce region and to predict bat-ball contact (Land & McLeod, 2000:1341; Müller et al., 2009:645). The AOI pitch falls within the predicted ball bounce region which may explain the results obtained in this study. On the other hand, the batsmen may fixate on the ball to intercept the ball as late as possible through the use of peripheral vision. The mobile eye tracker can only track foveal and not peripheral vision, subsequently resulting in the batsmen’s gaze directed at the AOI pitch.

Tables 4.3.4, mean number of fixations per AOI for ball type and 4.3.5, frequency distribution of the total number of fixations per AOI for ball type, confirmed no significant differences for the ball type faced except a practical significant difference found for the AOI arm/ ball release subsequently favouring out-swing trials. The results suggest that the information contained in the AOI listed hold advantageous visual information. The degree of deliberate practice (refinement and repetitive action) that accompanies the expert level of performance may suggest that the methodology behind the extraction of visual information may possibly be the same irrespective of the ball type faced. The repetitive execution of similar motor patterns may justify the lack of significant differences obtained between in-swing and out-swing trials (Macnamara et al., 2014:1608; Yarrow et al., 2009:591). These results are accepted due to the moderate degree of similarity that exists with respect to the temporal constraints associated with in-swing and out-swing bowling. The spatial constraints may also be regarded as similar due to the small deviation (swing) that occurs on an indoor synthetic surface.
Table 4.3.2, mean number of fixations per AOI for stroke outcome, confirmed a significant difference between successful and unsuccessful trials for the AOI other/off-target \((F=4.219, \ p=.047, \ d=0.44)\) with the unsuccessful stroke eliciting significantly more fixations than the successful trial. These results suggest that the visual information contained in the AOI other/off-target deters successful batting performance as a direct consequence of inadequate useful optical information contained in this AOI to facilitate effective motor programming and execution in cricket batting. These findings are substantiated by the practical significance found for stroke outcome for the AOI other/off-target (see Table 4.3.3), once again reiterating that higher other/off-target percentages are associated with unsuccessful batting performance. These results concur with McRobert \textit{et al.} (2009:478) who also found that lesser skilled batsmen fixated more upon unclassified AOI in comparison with skilled batsmen who viewed more classified AOI irrespective of the stroke outcome.

In addition, the lowest number of fixations was observed for both the stroke outcome and the ball type faced for the AOI, blink, can also be viewed as a task-irrelevant cue that deters batting performance. Blinking prohibits the perception component of the perception-action relationship (McMorris, 2004:13; Milner & Goodale, 2008:775). This inhibition subsequently prevents the processing of visual information further affecting the actions of the dorsal and ventral stream (see Figures 2.6 and 2.7) to facilitate effective motor planning and execution (Goodale & Westwood, 2004:204; Milner & Goodale, 2008:775). The aforementioned, further substantiate the results contained in Tables 4.3.3 and 4.3.4, indicating the irrelevance of the AOI blink in contributing to successful performance.

**Summary: number of fixations**

The information processing system, the perception and action systems, the influence of situational probability and the effect of anxiety was briefly elaborated on to account for the lack of significant differences found in terms of the mean number of fixations for the stroke outcome and the ball type faced irrespective of AOI. The AOI upper body and arm/ball release were viewed as task-relevant kinematic cues. Furthermore, the AOI that also displayed practical significance for the stroke
outcome were pitch and lower body favouring the successful batting stroke. In contrast, practical significance was also found for stroke outcome for the AOI other/off-target and the AOI blink which were viewed as a task-irrelevant cue that deters successful performance.

5.4 DURATION OF FIXATIONS

The first set of data pertaining to duration of fixations will deal with the stroke outcome and the ball type faced irrespective of the AOI. The results obtained in Table 4.4.1, mean duration of fixations per AOI for all trials, stroke outcome and ball type faced, confirm that there were no significant differences between successful and unsuccessful (F=0.200, p=.660) trials. Furthermore, no significant differences were found between in-swing and out-swing (F=2.000, p=.165) trials. The following factors can account for the lack of significant differences obtained: the information processing system and the participants' level of expertise.

The first possible reason may again allude to the influence of the information processing system which was elucidated upon under section 5.3 (the number of fixations section). It is expected that if the number of fixations generated no significant differences for the stroke outcome and the ball type faced irrespective of the AOI, then the duration of fixations should also reflect similar outcomes namely no significant differences. An earlier study by Savelsbergh (2002:283), found that experts employed significantly longer duration of fixations in comparison with novices when distinguishing between successful and unsuccessful trials. However, a later study by Savelsbergh et al. (2005:1693) found no such difference between successful and unsuccessful trials. The earlier study compared experts and novices, as opposed to the latter group that only included a successful and unsuccessful expert group. The aforementioned reiterates the assumption that greater discrepancies in visual gaze behaviour may be expected when comparing skill groups of different levels.

The second possible reason may be related to the level of expertise of the participants that were investigated in this particular study. The present study did not include novices and it may be more accurate to anticipate greater discrepancies in
visual gaze behaviour when comparing two different skill groups as opposed to and which was the case with participants in the present study where the aim was to conceptualise performance among sub-elite batsmen only. Alternatively, the results suggest that the AOI that were fixated upon may hold advantageous visual information and may not be a key determinant when distinguishing between successful and unsuccessful trials and therefore justify the lack of significant differences found.

The preceding section discussed research for the stroke outcome and the ball type faced irrespective of the AOI. The succeeding section will still focus on the stroke outcome and the ball type faced, but the discussion will now include the relative contributions of certain AOI to account for some of the significant differences obtained in this particular study.

According to Tables 4.4.2, mean duration of fixations per AOI for stroke outcome and 4.4.4, mean duration of fixations per AOI for ball type, the highest mean duration of fixations was observed for both stroke outcome and ball type faced for the AOI upper body. The AOI upper body can be viewed as a task-relevant cue. The bowling phase breakdown, advance cue utilisation and the use of subjective probabilities can possibly account for the results obtained.

The AOI upper body may have accumulated the longest duration of fixations as a result of the run-up phase being the longest phase of all cricket bowling phases (refer to Figure 2.1, Glazier et al., 2000:1015). The significance of the AOI upper body has been previously elucidated upon during discussions in section 5.3 (number of fixations section. See Tables 4.3.2, mean number of fixations per AOI for stroke outcome and 4.3.4, mean number of fixations per AOI for ball type faced, which further substantiate these findings. These results also concur with research conducted in other interceptive timing tasks (Williams et al., 2002:109: McRobert et al., 2009:478).

On the other hand, one does expect that a high number of fixations directed at this AOI, upper body, will result in a lower duration of fixations which this study did not find. A plethora of research has proven that skilled performers acquire and utilise
advance visual information prior to the ball release phase to supplement accurate anticipation during interceptive timing tasks (Abernethy et al., 2001:239; Müller et al., 2006:2171; Weissensteiner, Abernethy, Farrow and Müller, 2008:664; Müller et al., 2009:648; Giblin et al., 2015:6). The batsmen may execute a high duration of fixations at the AOI upper body during the run-up phase to acquire this advance kinematic information which may possibly account for the results obtained. However, it does not suggest that information from the AOI, upper body, is extracted and used in isolation. It appears that elite to sub-elite performers develop relationships among the key kinematic segments of the bowler to conjointly provide the batsmen with additional (advance) information required for the successful prediction of future actions to supplement successful performance specifically in cricket (Müller et al., 2006:2174), as well as tennis (Shim et al., 2006:338; Farrow & Reid, 2012:371). The long duration of fixations found in this study may be due to the batsmen forming those associations between the task-relevant kinematic cues.

The AOI, upper body, appears to be used as a preparatory tool upon which situational probabilities are formed on the basis of the invariable biomechanical nature of the fast bowling action. The invariable nature of the bowling action in conjunction with the situation probability previously discussed means that the performer is able to build a knowledge base regarding the strengths, weaknesses and preferences of their opponents (Farrow & Reid, 2012:368). This situational probability information results in faster response times. In this case, the situational probability information allows sub-elite batsmen to accurately anticipate the AOI arm/ball release to identify the ball earlier and collectively contribute to successful batting performance (Singer, 2000:222 & Williams, et al., 2011:433). The intricate role played by visual search, advance cue identification and the perceived expectations during interceptive timing tasks is depicted in figure 2.11.

Table 4.4.4, depicting mean duration of fixations (sec) per trial by AOI for ball type faced, highlighted significant differences for ball type faced for the AOI, ball (F=7.606, p=.009, d=0.29) and arm/ball release (F=4.795, p=.035, d=0.33). Furthermore, Table 4.4.5, reflecting the percentage of time per trial by AOI for ball type faced also illustrated significant differences for ball type faced for the AOI, ball (F=5.426, p=.025, d=0.26) and arm/ball release (F=4.121, p=.050, d=0.31).
Interesting to note, was the almost significant difference for the number of fixations for the stroke outcome for the AOI arm/ ball release section (see Table 4.3.2). These results merely reiterate the significance of these AOI in contributing to successful batting performance. The information concerned with the target of interest in conjunction with the speed of delivery may possibly account for the results obtained. Previous research have suggested that information acquired from the ball through the employment of efficient eye movements provides confirmatory cues that are used to regulate and refine the batsmen’s motor pattern to the point of interception (Croft et al., 2010:761; Müller & Abernethy, 2012:179). The specific sequential eye movement strategy employed by sub-elite batsmen in this study will be explored in more detail in a subsequent section focusing on the order of fixations.

In addition, it needs to be noted that in this particular study, the batsmen only faced relatively full pitched deliveries as a direct consequence of the omission of the batting helmet. The longer ball flight duration accompanying full pitched deliveries, possibly allowed the batsmen to pursuit track the ball for a longer duration which may account for and justify why the occurrence of the AOI, ball, was found among the longest AOI fixated upon (Land & McLeod, 2000:1342; Spering & Gegenfurtner, 2008:77 & Croft et al., 2010:761). Furthermore, the greater average speed that was found for out-swinger trials (see Table 4.1.1) may suggest that a shorter duration of fixations is expected which further justify the results found in Tables 4.4.4, mean duration of fixations per AOI for ball type faced and 4.4.5, the percentage of time per trial by AOI for ball type faced.

Skilled performers often employ predictive saccades to the AOI, arm/ ball release point, to detect the ball earlier and subsequently providing the performer with additional time to execute the desired response (Land & McLeod, 2000:1341; Müller & Abernethy, 2012:179; Mann et al., 2013:1; Pybus, 2016). The AOI, arm/ ball release, has previously been identified as crucial to successful performance in other sports codes (Shim et al., 2006:334; Jackson & Mogan, 2007:346; Takeuchi & Inomata, 2009:977; Williams et al., 2009:367) as well as specifically in cricket (Land & McLeod, 2000:1341; McRobert et al., 2009:479).
The lowest duration of fixations were observed for the stroke outcome and the ball type faced for the AOI blink (see Tables 4.4.2 and 4.4.4) and will be classified as a task-irrelevant cue that appears to deter batting performance. The detrimental effect of this AOI has been previously elucidated upon in section 5.3 (number of fixations).

**Summary: duration of fixations**

Overall, no significant differences were found for the stroke outcome and the ball type faced in respect of fixation duration. However, the information processing system and the participants' level of expertise was briefly elaborated upon to account for the possible lack of significant differences found for the stroke outcome and the ball type faced irrespective of AOI. The AOI, upper body, arm/ ball release and ball were identified as task-relevant cues for the ball type faced and overall the AOI, blink, was classified as a task-irrelevant cue that deters batting performance.

**5.5 STARTING FIXATIONS**

The first set of results will deal with AOI irrespective of the stroke outcome and the ball type faced. According to Table 4.5.1, ranking 1 was found to be practically significant for the AOI upper body (55.9%) at the start of trials. Similar results were also found in other interceptive timing tasks where experienced goalkeepers in soccer directed their gaze at the head or torso area during the initial 500 ms of viewing an opponents' approach (Savelsbergh et al., 2002: 283; Dicks et al., 2010:712). The use of the AOI upper body as a preparatory cue has been previously elucidated upon in 5.3, the number of fixations section for the stroke outcome and the ball type faced.

The preceding section discussed the AOI irrespective of the stroke outcome and the ball type faced at the start of trials. The succeeding section will still focus on the AOI however, the discussion will also consider the stroke outcome and the ball type faced to account for some of the significant differences obtained in this particular study.
According to Tables 4.5.2, the mean number of fixations per AOI at the start of trials for stroke outcome and 4.5.5, mean number of fixations per AOI at the start of trials for ball type faced, no significant differences were found for the stroke outcome and the ball type faced. Furthermore, a greater number of fixations were observed at the start of trials for the stroke outcome and the ball type faced for the AOI upper body. The AOI, upper body, can be viewed as a task-relevant cue. The availability of advantageous visual information, the sequential confirmatory contribution of each individual AOI to facilitate successful performance and the use of movement preparatory cues can possibly account for the lack of significant differences obtained.

The first possible reason may suggest that the information contained in the AOI upper body appears to hold advantageous visual information that may facilitate visual information processing. A prerequisite to successful batting performance may be to extract information from each of the AOI listed in the tables to evoke appropriate response programming. This assumption is substantiated by the practical significant difference found for the stroke outcome and the ball type faced for the AOI upper body (see Table 4.5.3 and 4.5.6) and lower body (see Table 4.5.3). These results suggest that higher percentages of fixations directed at the aforementioned AOI may subsequently contribute to successful batting performance. The practical significance found for stroke outcome (see Table 4.5.3) may further classify the AOI pitch as a task-relevant cue. The aforementioned AOI were also elucidated upon in section 5.3 (number of fixations section).

The second reason may be related to the possibility that information is acquired sequentially but in a descending order decreasing in the number of fixations each time. As previously mentioned, the AOI upper body is fixated upon to extract the required kinematic information from the bowler and to predict the anticipated arm/ball release point. The proposed descending order may suggest that a smaller magnitude of subtle yet imperative visual cues are required to regulate the batsman’s movement to the point of interception.

According to Table 4.5.4, statistics for the number of the most common AOI and two, three and four element fixations at the start of each trial according to the outcome of
the trial, significant differences were found for the two element AOI fixation pattern (upper body and arm/ ball release) as well as the three element AOI fixation pattern (upper body and arm/ ball release and ball) for the stroke outcome. A greater number of fixations in both patterns were observed in successful trials. A sequential relationship can be seen in Table 4.5.4 and 4.5.7, statistics for the number of the most common AOI and two, three and four element fixations at the start of each trial according to the ball type faced, between the AOI upper body, arm/ ball release and ball as identical patterns were found at the start of trials for the stroke outcome and the ball type faced.

The aforementioned patterns reiterate the assumption that information is acquired in a sequential manner and this sequence is dictated by the completion of the bowling phases (Glazier et al., 2000:1015). Each segment of the sequence conjointly facilitates the accurate and future prediction of the succeeding informatory cue to finally culminate in the development of an efficient motor pattern which is continuously regulated to the point of interception. In addition, the results may also suggest that the AOI upper body and arm/ ball release are used as movement preparatory cues to initiate the batsman’s movement, as opposed to the AOI ball that provides critical information that is used to regulate the batsmen’s movement to facilitate the successful completion of a batting stroke (Katsumata & Russell, 2012:499).

In this particular study, the researcher was unable to control the amount of swing that took place, due to testing taking place in an indoor facility. It must be noted that the degree of swing (pre-ball bounce) and seam movement (post-bounce) that takes place on an indoor synthetic surface is seemingly less when compared to the natural (outdoor) pitch. However, whether playing on an indoor synthetic or outdoor surface the temporal constraints to batting remain the same. A recommendation for future research is to include ball tracking technology that serves to quantify the amount of swing that takes place, for a delivery to be classified to have swung.

In contrast, the lowest number of fixations was observed at the start of trials for both stroke outcome and the ball type faced for the AOI, blink (see Tables 4.5.2 and 4.5.5). The AOI, blink, can therefore be viewed as a task-irrelevant cue due to a
lower number and frequency of fixations directed at this AOI resulting in a possible decrement in batting performance. The AOI, blink, was previously elucidated upon during the discussion of the number and duration of fixations (see Tables 4.3.2 and 4.4.2).

The AOI that were found to be practically significant for the ball type faced listed in Table 4.5.6 have been previously elucidated upon. However, an alternative explanation alluding to the use of predictive saccades may be used to explain the occurrence of the AOI, pitch. As previously stated, the AOI, pitch, may be used to get in line with the anticipated ball trajectory and ball landing position earlier (Müller & Abernethy, 2006:446; McRobert et al., 2009:482; Müller et al., 2009:649). On the contrary, this batting strategy can potentially be viewed as a weakness when facing swing bowlers, as incorrect body positioning due to the occurrence of late swing may subsequently result in dismissal. The aforementioned may suggest that the AOI pitch can also be viewed as a task-irrelevant cue for the stroke outcome which may further justify the practical significance found for stroke outcome for the AOI pitch (see Table 4.5.3), illustrating that higher percentages were observed for the unsuccessful stroke.

Summary: starting fixations

No significant differences were found for the individual AOI at the start of trials for the stroke outcome and the ball type faced, although the AOI, upper body, accumulated the highest number of fixations at the start of trials. The two element AOI fixation upper body and arm/ ball release and the three element AOI fixation upper body, arm/ ball release and ball were not only found to be significant for the stroke outcome (with the successful trials exhibiting more fixations) but the pattern was also identical for the ball type faced.

5.6 LAST FIXATIONS

The first set of results will deal with the AOI irrespective of the stroke outcome and the ball type faced. According to Table 4.6.1, frequency distribution of the number of fixations per AOI at the end of trials, ranking 1 was found to be practically significant
for the AOI, pitch (66%). The following reasons may account for the lack of significant differences obtained: the bowling phase breakdown, the instruction contained in cricket batting coaching manuals and lastly the possible effect of the quiet eye period.

The first possible reason may allude to the bowling phase breakdown (Glazier et al., 2000:1015). The AOI, pitch, is the primary dominant ending fixation for the extraction of visual information the moment after ball release, the follow through and ball bounce. The second reason pertains to the instruction contained in cricket batting coaching manuals, emphasising the importance of a batsman attempting to play the ball under their nose (Mann et al., 2013:7). This proposed batting strategy may possibly contribute to the AOI pitch as the primary dominant last fixation.

The final reason is concerned with the influence of the final fixation or quiet eye period. This study did not assess the starting and end times per AOI to determine the length of the final eye period which is to be 100ms or longer (Vickers, 2007:77; Wilson et al., 2015:23). It, therefore, can only be assumed that the AOI, pitch, is the final fixation that contributes to information processing ensuring that the batsmen’s action is regulated and refined to the point of interception (Lim, 2015:2 & Wilson et al., 2015:22). The influence of the quiet eye period can be seen in Figures 2.2 and 2.3, which substantiate the importance of this period during successful batting performance.

The preceding section discussed the AOI irrespective of the stroke outcome and the ball type faced at the end of trials. The succeeding section will still focus on the AOI however, the discussion will also include a focus on the stroke outcome and the ball type faced to account for some of the significant differences obtained in this particular study.

According to Tables 4.6.2, mean number of fixations per AOI at the end of trials for stroke outcome and 4.6.5, mean number of fixations per AOI at the end of trials for ball type, the highest mean number of fixations was observed for the stroke outcome and the ball type faced for the AOI pitch. The AOI, pitch, can be viewed as a task-relevant cue. These results are further substantiated by the practical significance
found for stroke outcome for the AOI, pitch (see Table 4.6.3), highlighting that higher percentages were observed for the successful stroke outcome.

Table 4.6.2, mean number of fixations per AOI at the end of trials for stroke outcome highlights a significant difference ($F=0.012$, $p=.047$, $d=0.51$) for the AOI, blink, with a higher fixation value registered for the unsuccessful trials. These results are further substantiated by the practical significance found for stroke outcome for the AOI, blink (see Table 4.6.3), highlighting that a lesser percentage was observed for the successful stroke. Furthermore, the lowest number of fixations at the end of trials were observed for stroke outcome and the ball type faced for the AOI ball trajectory (see Tables 4.6.2 and 4.6.5). These results are further substantiated by the practical significance found for the stroke outcome, highlighting that an increased frequency of fixations on the AOI ball trajectory was observed for the unsuccessful stroke outcome (see Tables 4.6.3 and 4.6.6). The AOI blink and ball trajectory can be viewed as task-irrelevant cues.

The unfavourable effect of the AOI, blink, on successful batting performance has previously been discussed under the number and duration of fixations which again substantiate the results obtained (see Tables 4.3.2, 4.3.4, 4.4.2, 4.4.4). As previously mentioned under the starting fixation section, the AOI ball trajectory may be anticipated from the AOI, pitch. It is assumed that a performer may not have to direct a high number of fixations at the AOI, ball trajectory, at the end of trials as the delivery line would have been identified early in the bowler's approach or the start of trial data. The aforementioned would result in a lower number of fixations directed at the AOI, ball trajectory, at the end of trials which is supported by the results obtained. On the other hand, the batsmen may potentially fixate on the ball through employing predictive saccadic eye movements which resulted in the gaze being located ahead of the ball and therefore viewed as ball trajectory. The detrimental effect of the AOI, other/ off-target, has been previously elucidated upon under the number of fixations section.

Tables 4.6.4, the mean number of fixations for the most common AOI and two, three and four element AOI fixation at the end of each trial reflected no significant differences for the stroke outcome. These results suggest that similar visual gaze
behaviour is employed irrespective of the stroke outcome. Furthermore, these results also suggest that the visual information is acquired sequentially as identical patterns are also listed in Table 4.6.7, mean number of the most common AOI and two, three and four element fixations at the end of each trial for the ball type faced. However, a significant difference was found for the three element fixation pattern, ball trajectory, ball and pitch, for the ball type faced favouring the out-swinger ball type. This combination pattern reiterates the sequential manner through which information is acquired. The batsman anticipates the line of delivery which facilitates accurate body positioning. Furthermore, information from the ball provides confirmatory cues that assist in regulating the batsman’s movement and finally the AOI, pitch, is used to identify the anticipated ball bounce region. A greater understanding can be gained into the methodology behind information extraction when viewing the AOI in combination as opposed to in isolation.

Overall, it appears that the starting fixations serve as preparatory cues for object recognition and tracking in an effort to accurately predict and identify the location of the ball earlier. In contrast, the ending fixations serve to control and contribute to the successful interception of the object (Vickers, 2016:3). This can be seen in Table 4.5.4, as the AOI (upper body and arm/ ball release and ball) facilitates ball recognition and the AOI ball trajectory, ball and pitch serve to regulate the action to the point of completion (see Table 4.6.7).

**Summary: last fixations**

Ranking 1, AOI pitch was found to be practically significant at the end of trials for the stroke outcome and the ball type faced. The lack of significant differences obtained was attributed to the bowling phase breakdown, the instruction contained in cricket batting coaching manuals and lastly the possible effect of the quiet eye period. The AOI, blink, was found to be significant for unsuccessful trials. Furthermore, a significant difference was found for the three element fixation pattern, ball trajectory, ball and pitch, for the ball type faced suggesting that information is extracted sequentially.


5.7 ORDER OF FIXATIONS

For the purpose of this section only, the one, two and three element fixation patterns will not be discussed in isolation. The explanation for the one, two and three element fixations patterns will be similar. Therefore, to avoid redundancy, the results will be discussed collectively for the four element fixation pattern to facilitate a better understanding of the visual gaze behaviour patterns that were found in the study.

The results from this study revealed the following most common four element fixation pattern; Upper body and Arm/ball release and Ball and Ball trajectory. This pattern occurred most frequently across all trials as can be seen in Tables 4.7.13, 4.7.14, 4.7.15 and 4.7.16 when distinguishing between the stroke outcome and the ball type faced. Interesting to note, the first five element fixation patterns listed in Table 4.7.13 and 4.7.14 are identical for the stroke outcome. The following reasons can possibly account for the results obtained; the degree of similarity concerned with the manner through which visual information is acquired, the effect of the prospective control strategy and saccadic eye movements and finally the contribution of anticipation.

The aforementioned results indicate that there are great similarities in relation to the manner in which visual information is acquired during both successful and unsuccessful trials which may possibly indicate that the distinguishing trait for the stroke outcome may be a peripheral nervous system discrepancy. Furthermore, the final four fixation elements may provide a more concrete reason to account for a difference found in the stroke outcome. Successful trials have a more sequential element fixation order pattern compared to unsuccessful trials which seem to be incoherent. These findings further reiterate the assumption that more refined visual gaze behaviour patterns are to be associated with successful performance (Sarpeshkar & Mann, 2011:306). A more concentrated or sequential element fixation pattern can be seen for ranking 1 during in-swing trials (see Tables 4.7.3, 4.7.7, 4.7.11 and 4.7.15). The irregular element fixation patterns found between in-swing and out-swing trials may also justify the significant differences obtained for the ball type faced (see Table 4.4.4).
The results suggest that information is acquired in a sequential manner synonymous to the bowling phases as previously mentioned during the starting and last fixations section (Glazier et al., 2000:1015). The use of predictive saccades in conjunction with the prospective control strategy not only ensures that one’s gaze is consistently located ahead of the target or in this case the succeeding AOI governed by the bowling phase, but also regulates the batsmen’s movement pattern to facilitate the successful execution of a batting stroke execution (Land & McLeod, 2000:1341; Davids, Renshaw & Glazier, 2005:37; De Xivry & Lefévre, 2007:11; Vickers, 2007:112; Katsumata & Russell, 2012:499). The aforementioned is a possible explanation for the sequential order of fixation patterns found during successful trials and the irregular patterns found during unsuccessful trials.

Alternatively, the most common four AOI fixation pattern highlights the significant contribution of anticipating the succeeding AOI as a result of the movement latency and temporal constraints inherent to the game in order to attain the sequential search of visual information to contribute to a successful stroke (Müller & Abernethy, 2006:248). The intricate role anticipation plays is depicted by the occurrence of the anticipated AOI arm/ ball release (see Tables 4.7.13, 4.7.14, 4.7.15 and 4.7.16) which is possibly predicted from the kinematics or biomechanical properties of the bowler (Müller et al., 2006:2163; Sarpeshkar & Mann, 2011:311). The aforementioned could further justify the occurrence of the fixation order pattern generated from this study.

**Summary: order of fixations**

The most common four element fixation pattern was upper body and arm/ball release and ball and ball trajectory. The visual gaze behaviour pattern found highlights the sequential manner through which visual information is extracted. More importantly, it highlights the critical contribution of accurate anticipation in successful visual information extraction and motor programming. The invariable nature of the bowling action does seem to allow batsmen to exploit the probability information available to them in predicting the likely outcome of the opponents’ action.
5.8 SUMMARY OF RESULTS

All the factors that were controlled for during the testing did not influence the results obtained in this study. The information processing system, the perception and action systems, the influence of situational probability and the effect of anxiety were briefly elaborated on to offer possible explanations for the lack of significant differences found for the number of fixations for the stroke outcome and the ball type faced irrespective of AOI. The AOI upper body, arm/ ball release, pitch and lower body were viewed as task-relevant kinematic cues that appeared to contribute to successful performance. In contrast, the AOI other/ off-target which was also found to be significant, in conjunction with the AOI blink was viewed as task-irrelevant cues that deter successful performance.

No significant differences were found for the duration of fixations for the stroke outcome and the ball type faced irrespective of AOI. However, the information processing system and the participants’ level of expertise was briefly elaborated upon to provide possible reasons for the lack of significant differences obtained. The AOI upper body, arm/ ball release and ball were identified as task-relevant cues for the stroke outcome and the ball type faced. Overall, the AOI blink was again classified as a task-irrelevant cue that deters batting performance.

No significant differences were found for individual AOI at the start of trials irrespective of the stroke outcome and the ball type faced. However, the AOI, upper body, accumulated the highest number of fixations at the start of trials. The two AOI element fixation pattern (upper body and arm/ ball release) and the three AOI element fixation pattern (upper body, arm/ ball release and ball) were not only significant for the stroke outcome but the pattern was also identical for the ball type faced.

The AOI, pitch, was most common AOI at the end of trials for the stroke outcome and the ball type faced. The lack of significant differences obtained was attributed to the bowling phase breakdown, the instruction contained in cricket batting coaching manuals and lastly the possible effect of the quiet eye period. The AOI, blink, was found to be significant for unsuccessful trials. Furthermore, a significant difference
was found for the three AOI element fixation pattern ball trajectory, ball and pitch for the ball type faced possibly suggesting that information is extracted sequentially.

The most common four AOI element fixation pattern was upper body and arm/ball release and ball and ball trajectory. The visual gaze behaviour pattern found highlights the sequential manner through which visual information is extracted. More importantly, it highlights the critical contribution of accurate visual information extraction for successful anticipation and motor programming during interceptive timing tasks.
5.9 FINDINGS OF THE STUDY

Following is a summary of the study findings:

- Although unsuccessful trials overall produced a higher mean number of fixations (8.71±2.80) than successful trials (8.23±2.96), the difference was found to be not significant (F= 1.936, df=1;51, p=.172).

- Although out-swing trials overall reflected a higher mean number of fixations (8.58±2.97) than in-swing trials (8.36±2.80), the difference was found to be not significant (F=0.424, df=1;51, p=.519).

- The AOI, other/ off-target, was found to be significant (F=4.219, p= .047, d=0.44) in terms of the mean number of fixations for the stroke outcome with the unsuccessful strokes eliciting more mean fixations than the successful strokes (1.45±0.78 versus 1.15±0.62).

- The AOI that were found to be significantly different when comparing the ball type faced in terms of mean duration of fixations were ball (F=7.606, p=.009, d=0.29) and arm/ ball release (F=4.795, p=.035, d=0.33). In both cases the in-swing ball presented with the higher mean fixations (ball: 0.37±0.11 versus 0.34±0.09; and arm/ ball release: 0.25±0.14 versus 0.21±0.10).

- Although unsuccessful strokes reflected a slightly higher mean duration of fixations than successful trials (2.30±0.21sec versus 2.29±0.13sec), the difference was found to be not significant (F=0.200, df=1;51, p=.660).

- Although In-swing (2.31±0.21sec) balls produced higher mean duration of fixations than out-swing (2.28±0.13sec) trials, the difference was found to be not significant (F=2.000, df=1;51, p=.165).

- Significant differences were found in respect of the percentage of time spent fixating on the AOI, ball (F=5.426, p=.025, d=0.26) and arm/ ball release
(F=4.121, p=.050, d=0.31), for the ball type faced, with the in-swinging ball producing more mean percentage time per trial fixating on the two AOIs than the out-swinging ball (ball: 16.12% versus 15.04%; and arm/ ball release: 10.88% versus 9.18%).

- The AOI that was fixated upon the most during the start of trials irrespective of stroke outcome and ball type faced, was the AOI upper body (55.9%), followed by other/ off-target (18.9%), lower body (15.7%), pitch (5.9%) and the least was blink (3.5%).

- A significant difference (F=6.401, p=.016, d=0.48) was found for the two element fixation AOI, upper body and arm/ ball release, at the start of trials for the stroke outcome. The successful stroke produced significantly more mean fixations than the unsuccessful stroke (0.31 versus 0.19) for the relevant two element fixation AOI.

- The three element fixation AOI, upper body and arm/ ball release and ball, was found to be significant (F=7.299, p=.010, d=0.51) at the start of trials for the stroke outcome with the successful stroke producing the larger mean fixations than the unsuccessful stroke (0.23 versus 0.12) for the relevant three element fixation AOI.

- The AOI that was fixated upon the most at the end of trials irrespective of stroke outcome and ball type faced, was pitch (66%), followed by blink (12%), other/ off target (11%), ball (8%) and the least was ball trajectory (4%).

- The AOI, blink, was found to be significant (F=0.012, p=.047, d=0.51) at the end of trials for the stroke outcome with the unsuccessful stroke reflecting more mean fixations (occurrence) than the successful stroke (0.17 versus 0.07).

- The three element fixation AOI, ball trajectory and ball and pitch, was found to be significant (F=4.119, p=.050, d=0.41) at the end of trials for the ball type
faced with the out-swinging ball indicating more mean fixations than the in-swinging ball (0.20 versus 0.12).

- The most common order of fixations for both the stroke outcome and the ball type faced was; upper body, arm/ ball release, ball, ball trajectory and pitch.

- Overall, the results suggest that successful trials had fewer rank 1 fixation pattern combinations in comparison with unsuccessful trials suggesting that successful strokes elicited more consistent AOI sequencing than unsuccessful strokes.

5.10 CONCLUSION

In terms of mean number of fixations and mean duration of fixations there were no significant differences found in the visual gaze behaviour for stroke outcome and ball type faced of sub-elite batsmen. However, when considering fixation on selected AOI (area of interest) significant differences for the stroke outcome and the ball type faced were observed. When considering the sequencing of AOI and its distinguishing power, results do suggest that the AOI, upper body, arm/ ball release, ball and pitch are sequentially used to extract the required visual information that necessitates successful batting performance. The sequencing of the AOI appears to be dictated by the bowling phases and batsmen should isolate individual AOI on the basis of the bowling phase’s breakdown to extract the required information. Furthermore, the results suggest that batsmen should attempt to control or diminish the number of blinks that are executed at critical time periods and in particular at the end of trials.

In respect of the original research hypotheses formulated both the following hypotheses are partially accepted:

- Visual gaze behaviour is different for successful and unsuccessful trials for sub-elite cricket batsmen.
- Visual gaze behaviour is similar for in-swinging and out-swinging trials for sub-elite cricket batsmen.
5.11 LIMITATIONS

Despite the positive results shown by this study, there were a few limiting factors that could have affected the outcome of the study.

➤ The indoor synthetic pitch that was used possibly contributed to a more predictable post-bounce. This does not simulate the natural post-bounce characteristics of an outdoor pitch.

➤ The inability to quantify the amount of swing that took place. The degree of swing (lateral deviation) will increase the difficulty of the batting task.

➤ The limitation of the ASL mobile eye tracking system to function optimally in ambient light to allow for the assessment of visual gaze behaviour in the natural setting.

➤ The synthetic surface, the omission of fielders or induced pressure created a very stable batting environment. The game of cricket is played under immense pressure stemming from the bowler, the fielders and the spectators. It is imperative to attempt to reproduce this environment in order to attain a true reflection of visual gaze behaviour.

➤ The use of only two right-handed fast bowlers bowling over the wicket. Different bowlers present different constraints and in any typical batting innings, a batsman faces a variety of bowling styles that collectively contribute in their dismissal.

➤ Anxiety levels pre and post as well as the effect thereof on the visual gaze behaviour of cricket batsmen pre and post testing. Research has shown that anxiety can disrupt a performer's visual gaze behaviour. A true test of the batting performance may, in fact, be the batsmen's ability to control their visual gaze behaviour during these stressful conditions.
The possible effect of eye dominance could not be investigated due to the small sample size. Eye dominance reflects a performer's ability to acquire visual information from their dominant eye and whether or not it is significant may question the validity in retrieving information from the non-dominant eye.

The inability to accurately quantify the live speed at which the balls were bowled.

5.12 RECOMMENDATIONS FOR FURTHER RESEARCH

It is recommended that the following recommendations are made for future studies:

- The current research is repeated to confirm the findings of this study, and the following be considered:
  
  - Conduct testing on an outdoor cricket wicket.
  
  - Include ball tracking technology that serves to quantify the amount of swing that takes place, for a delivery to be classified to have swung. One can then only include deliveries that have swung for statistical measures.
  
  - Utilise an ASL mobile eye tracking system that can operate in ambient light, which will allow for testing on an outdoor cricket surface.
  
  - Generate a testing environment that simulates natural match conditions with the possible inclusion of fielders applying pressure and scoreboard or situational pressure.
  
  - Attempt to incorporate left versus right-hand bowling options including both fast and spin bowling to further challenge the batsmen.
  
  - Conduct anxiety assessment measures pre and post testing and induce anxiety through collaborating with a sports psychologist whom may be an expert in that particular field.
➢ Use an ASL mobile eye tracker that can calibrate both eyes and that is cordless posing less of a distraction to the participant and increasing their level of comfort.

➢ To employ ball speed tracking technology that allows you to use trials that have a smaller variability in speed subsequently strengthening the degree of control and validity of the data obtained.
LIST OF REFERENCES


73. Sarpeshkar, V. & Mann, D.L. 2011. Biomechanics and visual-motor control: how it has, is, and will be used to reveal the secrets of hitting a cricket ball. *Sports Biomechanics*, 10(4):306-323.


## LIST OF APPENDICES

### APPENDIX

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<td>EMPIRICAL STUDIES</td>
<td>157</td>
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## APPENDIX A: MICROSOFT EXCEL SPEED CONVERSION TABLE

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APPENDIX B: INFORMED CONSENT FORM

NELSON MANDELA METROPOLITAN UNIVERSITY
INFORMATION AND INFORMED CONSENT FORM

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<td><strong>Principal investigator</strong></td>
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<td><strong>Postal Code</strong></td>
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A. **DECLARATION BY OR ON BEHALF OF PARTICIPANT**

| I, the participant and the undersigned | (full names) |
| ID number |  |
| OR |  |
| I, in my capacity as | (parent or guardian) |
| of the participant | (full names) |
| ID number |  |
| Address (of participant) |  |

A.1 **HEREBY CONFIRM AS FOLLOWS:**

| I, the participant, was invited to participate in the above-mentioned research project |
| that is being undertaken by | Wayde Percival Douglas |
| From | Faculty of Health Sciences, Human Movement Science Department |
| of the Nelson Mandela Metropolitan University. |  |
THE FOLLOWING ASPECTS HAVE BEEN EXPLAINED TO ME, THE PARTICIPANT:

| 2.1 Aim: | The investigators are studying the Visual Gaze Behaviour of Sub-Elite Cricket Batsmen When Facing Fast In-Swing And Out-Swing Bowling  
 | | The information will be used to inform coaches and cricketers |
| 2.2 Procedures: | I understand that I will be required to bat |
| 2.3 Risks: | No more risk than what is usually relevant during practice or match conditions |
| 2.4 Possible benefits: | Insight into the visual gaze behaviour that can be used in training |
| 2.5 Confidentiality: | My identity will not be revealed in any discussion, description or scientific publications by the investigators unless specific permission is given in writing |
| 2.6 Access to findings: | Any new information or benefit that develops during the course of the study will be shared with participants |
| 2.6 Voluntary participation / refusal / discontinuation: | My participation is voluntary  
 | | YES | NO  
 | My decision whether or not to participate will in no way affect my present or future care / employment / lifestyle | TRUE | FALSE |

3. THE INFORMATION ABOVE WAS EXPLAINED TO ME/THE PARTICIPANT BY:

Mr Wayde Douglas

<table>
<thead>
<tr>
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<th>English</th>
<th>Xhosa</th>
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and I am in command of this language, or it was satisfactorily translated to me by

(name of translator)

I was given the opportunity to ask questions and all these questions were answered satisfactorily.

4. No pressure was exerted on me to consent to participation and I understand that I may withdraw at any stage without penalisation.

5. Participation in this study will not result in any additional cost to myself.
A.2  I HEREBY VOLUNTARILY CONSENT TO PARTICIPATE IN THE ABOVE-MENTIONED PROJECT:

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</thead>
<tbody>
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<table>
<thead>
<tr>
<th>Signature of witness:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full name of witness:</td>
</tr>
</tbody>
</table>

| Signature or right thumb print of participant |

B.  STATEMENT BY OR ON BEHALF OF INVESTIGATOR(S)

1. Mr Wayde Percival Douglas declare that:
   
   1. I have explained the information given in this document to (name of patient/participant) and / or his representative (name of representative)
   
   2. He was encouraged and given ample time to ask me any questions;

<table>
<thead>
<tr>
<th>This conversation was conducted in</th>
<th>Afrikaans</th>
<th>English</th>
<th>Xhosa</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>(language)</td>
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</tr>
</tbody>
</table>

   3. And no translator was used OR this conversation was translated into (language) by (name of translator)

<table>
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<tr>
<th>I have detached Section D and handed it to the participant</th>
<th>YES</th>
<th>NO</th>
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<table>
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<tr>
<th>Signed/confirmed at</th>
<th>on 20</th>
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<th>Signature of interviewer</th>
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<tbody>
<tr>
<td>Signature of witness:</td>
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<tr>
<td>Full name of witness:</td>
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## APPENDIX C: DATA CAPTURING TEMPLATE

<table>
<thead>
<tr>
<th>Fast Bowling Sample</th>
<th>ID</th>
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<table>
<thead>
<tr>
<th>BOWLER</th>
<th>DELIVERY</th>
<th>BATSMAN'S SHOT</th>
<th>Successful</th>
<th>Unsuccessful</th>
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</thead>
<tbody>
<tr>
<td>Options</td>
<td>1=In swinger</td>
<td>1=Yes</td>
<td>In Swinger</td>
<td>Out Swinger</td>
</tr>
<tr>
<td></td>
<td>2=Out swinger</td>
<td>2=No</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Bowler ID</th>
<th>Type</th>
<th>Shot Played</th>
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<th>2</th>
<th>4</th>
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APPENDIX D: EMPIRICAL STUDIES:

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Croft, J.L., Button, C. &amp; Dicks, M.</th>
</tr>
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<tbody>
<tr>
<td>Year</td>
<td>2010</td>
</tr>
<tr>
<td>Article Name</td>
<td>Visual strategies of sub-elite cricket batsmen in response to different ball velocities.</td>
</tr>
<tr>
<td>Methods</td>
<td>9 sub-elite batsmen batted against a bowling machine. Testing took place in an indoor facility with the use of a standard cricket wicket. Participants received 12 familiarization practice trials after which they faced 36 experimental trials in a six block of trial block. A 20-30 s inter-trial break was allocated to alter the bowling machine. Speed increments were comprised of the following (40, 44, 48, 52, 56 miles h⁻¹).</td>
</tr>
<tr>
<td>Results</td>
<td>The ball is initially tracked by the participants but then the gaze drops below the ball trajectory 250 ms after ball release where it then remains under the ball trajectory until approximately 250 ms before ball bounce. The ball is tracked again until the ball bounce point. Researchers also found that no clear pattern existed for pursuit tracking duration. Several participants fixated their gaze below the ball for a significant portion of ball flight. This strategy may be indicative of anticipatory knowledge of the downward trajectory of the ball.</td>
</tr>
<tr>
<td>Discussion &amp; Conclusion</td>
<td>There is no clear evidence between ball projection speed and the initial period of pursuit tracking. Moreover, the results suggest that a combination of smooth pursuit and saccadic eye movements are employed to track the ball. Skilled cricket batsmen display a number of perceptual strategies to guide their actions which are not necessarily related to the speed of ball delivery. Some batsmen were highly consistent whereas others barely fixated on the ball.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Takeuchi, T. &amp; Inomata, K.</td>
</tr>
<tr>
<td>------------------------</td>
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<tr>
<td>Year</td>
<td>2009</td>
</tr>
<tr>
<td>Article Name</td>
<td>Visual search strategies and decision making in baseball batting</td>
</tr>
<tr>
<td>Methods</td>
<td>Seven experts and seven novices batted with a custom plastic while viewing film of a pitcher and were recorded to press a button when they made a decision to swing the bat. A total of 10 pitches were thrown by a right-handed pitcher and participants were only to prepare the swing phase of the hitting action. Participants wore the eye mark recorder model EMR-8 to record eye movement data.</td>
</tr>
<tr>
<td>Results</td>
<td>There was no significant difference for the duration of the pitcher's motion. However, the number of fixations were significantly different between the two groups, experts’ fixating on two areas compared to the non-expert group who fixated on one. During the initial and middle phases of the pitcher’s action, the gaze was directed towards the head and face. In contrast, during the final phase, experts’ fixated upon the pitching arm and arm/ ball release point significantly more in comparison with non-experts. Experts’ gaze shifted from proximal to and finally the ball. In contrast, the non-expert group only fixated on the head and face region.</td>
</tr>
<tr>
<td>Discussion &amp; Conclusion</td>
<td>The non-expert group did not display the capability of extracting information from the pitcher's arm. The results further suggest that the expert group had superior cognitive skills that allowed them to extract information from the arm/ ball release region.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>McRobert, A.P., Ward, P., Eccles, D.W. &amp; Williams, A.M.</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------------------------------------------------</td>
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<tr>
<td>Year</td>
<td>2011</td>
</tr>
<tr>
<td>Article Name</td>
<td>The effect of manipulating context–specific information on perceptual-cognitive processes during a simulated anticipation task</td>
</tr>
<tr>
<td>Methods</td>
<td>10 skilled and 10 less skilled cricket batters responded to video simulations. Participants assumed their standard batting stance while wearing the ASL mobile eye tracker. Participants responded to 24 test stimuli. Six male skilled cricket bowlers were recruited to create the video test stimuli. Each bowler was instructed to bowl a block of six deliveries. The participants responded to 24 test stimuli. In the first condition (low condition) batsmen viewed (two balls from four fast bowlers) and eight balls from two fast bowlers presented in random order. In the second condition (high context) participants responded to four fast bowlers whom each delivered six deliveries. Two of these deliveries were previously bowled in the first condition.</td>
</tr>
<tr>
<td>Results</td>
<td>The less skilled batters spent more time fixating on distal cues and unclassified locations compared to skilled batters. Contrastingly, skilled batters spent more time fixating on more proximal predictive cues (bowling arm/predicted ball release). Skilled batters reduced their fixation durations in the high context conditions when compared to low context conditions. Skilled batters also viewed more fixation locations compared to their less skilled counterparts.</td>
</tr>
<tr>
<td>Discussion &amp; Conclusion</td>
<td>Skilled batters recorded higher accuracy scores on the simulated cricket batting test when compared to less skilled individuals. Skilled batters also employed a more refined and effective visual search strategy and more elaborate domain specific representations.</td>
</tr>
<tr>
<td><strong>Author(s)</strong></td>
<td>Renshaw, I. &amp; Fairweather, M.M.</td>
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<tr>
<td><strong>Year</strong></td>
<td>2000</td>
</tr>
<tr>
<td><strong>Article Name</strong></td>
<td>Cricket bowling deliveries and the discrimination ability of professional and amateur batters</td>
</tr>
<tr>
<td><strong>Methods</strong></td>
<td>18 (six national, regional and club) experienced cricket batters batted against video stimuli where the test film included either the bowler’s entire run-up through to ball bounce or the run up along with the first 0.08 s. six familiarization trials were given to the batsmen. The deliveries comprised of a leg-spinner, top-spinner, googly, flipper and the back-spinner.</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td>National and regional players discriminated googly deliveries better than club players. Furthermore, only national level players could identify the flipper deliveries. Batsmen of all standards could identify the googly the easiest and the top-spinner was the most difficult.</td>
</tr>
<tr>
<td><strong>Discussion &amp; Conclusion</strong></td>
<td>Expert batters displayed greater perceptual discrimination ability, which appeared to be linked to the type of delivery and previous exposure. Additional ball flight information added no greater advantage to the discrimination ability subsequently substantiating the importance of advance visual information.</td>
</tr>
<tr>
<td><strong>Author(s)</strong></td>
<td>Land, M.F. &amp; McLeod, P.</td>
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</tr>
<tr>
<td><strong>Year</strong></td>
<td>2000</td>
</tr>
<tr>
<td><strong>Article Name</strong></td>
<td>From eye movements to actions: how batsmen hit the ball</td>
</tr>
<tr>
<td><strong>Methods</strong></td>
<td>Three batsmen of different skill levels (professional, amateur, low club level) batted against a bowling machine delivering balls at 25 m/s while wearing a mobile eye tracker. Batsmen faced delivery sequences of 36 to 48 with the ball bounce region varied from ball to ball.</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td>The participants gaze maintained a stationary position initially focusing on the point of delivery. A saccadic eye movement was then made to anticipated ball bounce region. The eyes along with the participants head moved down to track the ball. The professional batsman exhibited more pursuit tracking in contrast to other batsmen who relied on a combination of saccadic and pursuit tracking to identify the anticipated ball bounce region. The difference between the professional batsman and the club batsman was the professional batsman’s ability to efficiently use of pursuit tracking and saccadic eye movements to accurately identify the ball bounce region</td>
</tr>
<tr>
<td><strong>Discussion &amp; Conclusion</strong></td>
<td>When batsmen face fast bowling, they do not fixate on the ball throughout the entire duration of its flight. They fixate on it as it is delivered and for a period of 200 ms after ball bounce. Top batsmen emphasize the need for early information about the trajectory of the ball. Information extraction from early ball flight was deemed crucial when batting against fast bowlers. A batsman can pick up information during the first 100-150 ms of the ball’s flight.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Müller, S., Abernethy, B., Reece, J., Rose, M., Eid, M., McBean, R., Hart, T. &amp; Abreu, C.</td>
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<tr>
<td>--------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
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<tr>
<td>Year</td>
<td>2009</td>
</tr>
<tr>
<td>Article Name</td>
<td>An in-situ examination of the timing of information pick up for interception by cricket batsmen of different skill levels</td>
</tr>
<tr>
<td>Methods</td>
<td>Six highly skilled (three left and three right-handed) batsmen were required to strike balls while wearing vision occlusion goggles. Testing took place in an indoor facility. Three right-hand fast swing bowlers were recruited for the study. Batsmen were provided with 12 familiarization trials and then faced a total of 45 trials in rotating blocks of six trials per bowler. The bowlers delivered three different balls in random order (full length in swinger, full-length out-swing and a ball short of a length). Balls were delivered at a speed range of 110 km/h-120 km/h. A modified cricket ball was used (plastic) to reduce the risk of injury as a result of occlusion trials.</td>
</tr>
<tr>
<td>Results</td>
<td>Foot movement accuracy revealed that highly skilled players significantly improved their judgments from pre-release to pre-release but not from pre-release to no occlusion. Less skilled players were unable to improve their judgments across either condition. The aforementioned revealed that early ball flight information was critical for judgment of full ball length. Overall, the results indicate that highly skilled players were better able than low skilled players to utilise information from early ball flight to attain any form of contact. Highly skilled players were also better able to use ball bounce and late ball flight to significantly increase the percentage of good contacts.</td>
</tr>
<tr>
<td>Discussion &amp; Conclusion</td>
<td>Early ball flight information is critical for accurate ball landing position. Highly skilled players are better able than lesser skilled players to utilise advance ball flight information to guide accurate foot movements and bat ball interception.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Panchuk, D. &amp; Vickers</td>
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<tr>
<td>Year</td>
<td>2006</td>
</tr>
<tr>
<td>Article Name</td>
<td>Gaze behaviours of goaltenders under spatial-temporal constraints</td>
</tr>
<tr>
<td>Methods</td>
<td>Eight elite goaltenders wore the ASL 501 mobile eye tracker while attempting to stop shots. The goaltenders faced shots taken from five and 10 m. Trials were presented in random order until 10 saves and 10 misses were obtained. The goaltenders were permitted a 10 min window period to warm up and get accustomed to wearing the eye tracker.</td>
</tr>
<tr>
<td>Results</td>
<td>The fixation duration was significantly longer on saves as opposed to goals. A lower fixation frequency occurred at the five-meter distance compared to the 10m distance. Quiet eye duration was significantly longer during saves compared to goals scored. The greatest concentration of fixations was located around the puck.</td>
</tr>
<tr>
<td>Discussion &amp; Conclusion</td>
<td>A greater percentage of saves occurred at the 10m distance compared to the 5m distance. Fixation frequency and duration were significantly longer during the saves compared to goals. The primary fixation was the puck.</td>
</tr>
</tbody>
</table>
Author(s) | Mann, D.L., Spratford, W. & Abernethy, B.  
---|---  
Year | 2013  
Article Name | The head tracks and gaze predicts: how the world’s best batters hit a ball.  
Methods | Two elite and two club level cricket batters batted against a (Pro batter) bowling machine. In addition, the batsmen watched video stimuli of the bowlers run up providing advance kinematic information after which the ball was projected through a hole in the screen. Testing took place on an artificial cricket surface. The location of ball bounce varied between the following: full, good and short. The ball delivery line was also varied. Participants received 15 trials for familiarisation purposes and a further 18 trials (3 trials for each of the six types of deliveries).  
Results | Elite batters kept their gaze in alignment with or ahead of the ball irrespective of where the ball bounced. Elite batters directed their gaze further behind the ball. Club level batters tended to lag behind the ball. Elite batters made a greater number of saccadic eye movements ensuring their gaze was consistently located ahead of the ball. The first to predict ball bounce location and the second to predict bat-ball contact.  
Discussion & Conclusion | Batsmen are coached to play the ball under their nose. Predictive saccades play an important role in successful batting. Elite batters displayed a tight and efficient coupling between head and eye movements.
<table>
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<tr>
<th>Author(s)</th>
<th>Weissensteiner, J.R., Abernethy, B. &amp; Farrow, D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
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<tr>
<td>Article Name</td>
<td>Hitting a cricket ball: what components of the interceptive action are most linked to expertise?</td>
</tr>
<tr>
<td>Methods</td>
<td>11 highly skilled and ten lesser skilled male cricket batsmen completed a batting task with the inclusion of a bowling machine that required them to play front foot drives to demarcated areas. Full protective clothing was worn by the participants. A standard cricket bat, as well as a custom made half and third-width bat, was made. The front foot drive was chosen as it is a fundamental stroke to execute in cricket batting. The measured outcomes were: shot accuracy, quality of bat-ball interception, timing and sequencing and movement duration measures.</td>
</tr>
<tr>
<td>Results</td>
<td>The highly skilled group displayed superior accuracy in the full and half bat width conditions but not in the third bat width condition. Interestingly, the higher skilled group systematically scored lower with each reduction in bat width. In contrast, the lesser skilled group were consistent in their scoring across all bat width conditions. The highly skilled group completed their front foot stride significantly earlier to the time of contact than their lesser skilled counterparts.</td>
</tr>
<tr>
<td>Discussion &amp; Conclusion</td>
<td>The superior shot accuracy displayed by highly skilled batsmen has been linked to their ability to initiate and organise their movements (front foot landing) earlier in comparison with lesser skilled players. They were also more consistent than lesser skilled batsmen with regards to coincidence timing of bat downswing and ball bounce. The ability to couple the front foot stride with the bat swing was shown to be an indicator of technical performance.</td>
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