Visual cue and situational information utilisation in squash and badminton.

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Visual Cue and Situational Information Utilisation in Squash and Badminton

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Abstract

Elite racket sports players have been shown to be able to anticipate strokes in advance of kinematic stroke information, although the use of this ability in match situations is relatively unknown. Previous studies have not considered shot difficulty or the extent to which situational probabilities can influence anticipatory behaviour.

Study 1 compared the anticipatory abilities of different ability squash players when viewing a temporally occluded film task of two elite players with shot difficulty controlled and previous rally information available. Expertise only accounted for the ability to determine where hard shots were to be played and thus the ability to use situational information was thought to define expertise.

Studies 2a and 2b assessed anticipation in National squash and County badminton players by remotely occluding vision whilst playing simulated competitive matches wearing liquid-crystal occlusion spectacles against matched ability opponents. Results suggested that these badminton players tended to use swing sequence visual cues whereas squash players tended to make their decisions based on situational information alone.

Studies 3a and 3b used a high-speed camera analysis to measure the first movement in the correct direction of County badminton and expert squash players. Squash players were more likely to move early for hard shots but less than predicted by the previous studies. Estimates for the squash players suggested anticipation of the hard shots occurred about one third of the time before swing kinematic information was available (two thirds after). Badminton players only anticipated 1 or 2 shots in every 10.

This thesis has provided support for expertise related anticipatory behaviour, which was not always acted upon, possibly due to tactics. Situational information is suggested to be more useful than previously thought. Future research should assess other playing standards and also consider other methods for determining anticipation during actual matches.

Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed. ....(Candidate)

Date....17-6-08...

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references.

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STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

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Aspects of the findings contained within this thesis have been published as follows:

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Caudrelier, T., James, N., Borer, K. & Milton, P. (2005). Anticipatory cues in elite squash. *Journal of Sports Sciences,* **23**, 2, 186-187.

James, N., Caudrelier, T. & Murray, S. (2005). The use of anticipation by elite squash players. *Journal of Sports Sciences*, **23**, 11/12, 1249-1250.

James, N., Borer, K., Caudrelier, T., Cummings, C. and Mellalieu, S. D. (2004). Use of visual cues by elite badminton players. *Journal of Sports Sciences*, **22**, 3, 248-249.

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1.0 Introduction

Successful performance in racquet sports depends, to some extent, on superior anticipation and decision making skills. For example, research has consistently demonstrated expert-novice differences in the ability to recognise and accurately respond to advance visual cues (e.g. Abernethy, 1990a; Abernethy *et al.,* 2001), and/or situational probability information (e.g. Crognier and Féry, 2001) to predict the trajectory of a ball or shuttle. Researchers have typically interpreted these findings to suggest that expert players are able to anticipate better than players with lower levels of expertise by utilising their highly developed knowledge base of their sport, developed through extensive experience in that sport (Williams *et al.,* 1999). The evidence from these studies appears highly consistent, however some ecological concerns are apparent; in particular, the majority of these studies have involved either artificial laboratory conditions (e.g. Abernethy, 1990a) or simulated match situations (e.g. Abernethy *et al.,* 2001), therefore making robust conclusions potentially problematical.

Given the current knowledge of anticipatory behaviour in racket sports a number of issues seem to be worth investigating. It would be sensible to try to determine the extent to which visual cues associated with the kinematic stroke sequence are utilised in comparison to the use of situational information pertaining to known shot distributions, player biases and relative court positions of the players and ball/shuttle. Previous research has not attempted to separate these two potential sources of information although some efforts have been made to control for situational information (e.g. Crognier and Féry, 2001). It might be the case that in some situations these two sources of information are used independently or perhaps together in a sequential manner, furthermore, it may be that it is the situation that determines which type of information source is used or the extent to which they or just one source is used.

In order to gain more specific insight to these questions further methodological advances are necessary. The first methodological issue that will be addressed concerns the difficulty of the shot which participants are required to anticipate. The majority of previous research has not controlled for this, the exception being James and Bradley (2004), who showed that highly skilled players appeared to need some ball flight information to determine where easy shots played by an expert player were directed. This appears to be in contradiction to the majority of previous research that suggests that this level of player should be able to anticipate an opponent's shots. It may be the case however, that easy shots, where no limitations on shot options are placed, cannot be anticipated to the same extent as hard shots, where limitations on shot options are apparent due to the difficulty of the task. This may be true if anticipation is, at least to some extent, a consequence of using situational information e.g. a boast may be the only possible shot when the ball is behind a player. Consequently, whilst the visual cues related to the stroke kinematics maybe very similar between easy and hard shots the situational information may be far more informative in easy shot situations. If previous studies have not considered this potential confounding variable then it may be the case that anticipatory ability has been underestimated in the case of hard shots and overestimated for easy shots. Furthermore, when previous studies have compared elite and novice players playing against opponents of an intermediate level (e.g. Abernethy *et al.*, 2001) the sample of shots is likely to have been skewed with more easy shots needing to be anticipated by the novice players and more hard shots by the expert players.

In real world situations, in comparison to typical film studies, players may use past experience of the opponent to help anticipate likely ball trajectories e.g. opponent tends to play crosscourt in response to a boast. Consequently any findings should consider whether this type of knowledge had any bearing on the anticipatory performance of the study's participants. It may also be the case that in match conditions, players consciously decide not to try to anticipate some or all shots as the chance of an inaccurate decision may outweigh the advantage of anticipating correctly. Experiments that force participants to try to anticipate may therefore over predict the use of anticipation in match conditions. Finally, different shot types e.g. straight and crosscourt shots, may provide different anticipatory cues or are played in predictable patterns. If the sample of shots shown to participants is biased towards any one shot over others or the pattern is incorrect then this may affect results. This would only be the case if players are able to cognitively appraise evolving match situation in terms of shot distributions from different areas of the court. Thus in real world situations this information could theoretically be used to aid anticipation. Similarly, if the shot directions given to participants in experimental settings do not replicate these typical distributions it may be the case that this hinders anticipatory performance as this natural information source has been removed.

Based on the potential limitations of previous studies and the factors discussed above, the principal aim of this thesis is to study anticipation in situations where the task difficulty is better controlled and the shot distributions occur realistically. This will be achieved by addressing three specific objectives. Firstly a laboratory-based temporal film occlusion study of elite squash will be undertaken where shot difficulty is controlled for. The sample of shots to be anticipated will match known shot distributions of expert players (Hughes and Robertson, 1998) and the players in the film clips will be of a higher playing standard than all of the participants. Thus all participants will have very limited or no experience of playing against this standard of player. Consequently participants' performance will be based on their accumulated knowledge of squash, both situational knowledge and visual cue information, but should not contain personal knowledge of the players in the film clips. The second objective is to examine expert and near expert player's anticipatory ability during simulated matches by occluding vision using PLATO liquid crystal occlusion spectacles. Matches will involve equally matched players where occluded shots will be selected based on shots being categorised as either hard or easy. The testing of players on court will enable a comparison with the findings from the first study, players viewing film clips, to assess the validity of using artificial settings to determine anticipatory behaviour. To broaden the applicability of the findings two studies will be used involving squash and badminton. Whilst both are racket sports there are subtle differences in speed and court dimensions that may affect performance. Also different shot options are available in the two sports which may also impact on anticipation. The final objective is to determine the utilisation of anticipatory movements in actual match conditions. To enable comparison with the previous findings both squash and badminton will be assessed using high-speed camera analysis of first movement and split-step timings in relation to racket-ball/shuttle contact. This setting will impose no restrictions on players and will thus enable determination of actual anticipatory behaviour rather than predictions.

The remainder of this thesis consists of five chapters. Chapter 2 provides a review of the conceptual and methodological issues in the existing anticipation literature, with specific focus in the domain of racquet sports, visual cues and situational awareness. The next three chapters then present the studies corresponding to the stated objectives. The final thesis chapter discusses the findings of these three studies in relation to the thesis aims and objectives, practical implications and recommendations for future research.

Chapter 2: Review of Literature

2.1 Overview

Expertise differences in sports performance has been explored intensively over the last few decades, with considerable focus aimed at exploring anticipation in fast externally passed reactive sports (see Chapter 4 in Williams *et al.,* 1999 for a detailed review). Initially, research examined if skill-based differences in anticipation could be accounted for by highly-skilled players possessing refined hardware components (e.g. colour vision, visual acuity and peripheral vision) that were significantly superior to their lesser skilled counterparts. However, research has suggested equivocal findings, suggesting that such a difference is not present (Isaacs, 1981; Blundell, 1985; For a more detailed review see Chapter 3 in Williams *et al.,* 1999).

By the late 1980's the research focus shifted towards exploring expertise differences in 'software' based properties (knowledge structures and processing of visual information; (Abernethy, 1987b; Abernethy, 1990a). Assessing, expertise related differences in the, selection, encoding and retrieval of specific decision forming information. Particularly, research has endeavoured to try and differentiate between the information sources that are utilised in forming anticipatory decisions (e.g. Abernethy *et al,* 2001 Crognier *et al,* 2003; James and Bradley, 2004; James *et al,* 2004).

This thesis focuses on the information sources utilised when making anticipatory decisions in racket sports. The following review of literature will commence with an explanation of how anticipation fits in with other cognitive activities such as general information processing (IP) and decision making (DM). The main body then focuses on racket sports research in advance cue utilisation and the use of situational probabilities both in laboratory and more ecological valid field settings. The chapter will conclude with a critical summary of the present literature highlighting the key conceptual and methodological issues that will be addressed in the present study.

2.1.1 Information processing and decision making

Cognitive psychologists conceptualise human functioning as an information processing unit. This general view-point has been popularised by the development of the information processing model (IP), which proposes various processing stages that can run in serial or parallel (Schmidt and Lee, 1999). Commonly, psychologists utilise a serial 3 stage model of IP (Fig 2.1). Firstly, the S*timulus Identification Stage* is associated with perception (stimulus detection, identification and recognition). Secondly, once the stimulus has been identified the subject needs to decide on an appropriate response taking into account the perceived stimuli. The decision may be to perform a number of actions or not to physically respond at all. This stage is commonly referred to as the *Response-Selection Stage*. Finally, after an appropriate response has been selected the response needs to be initiated; this final stage is referred to as *Response Programming.*

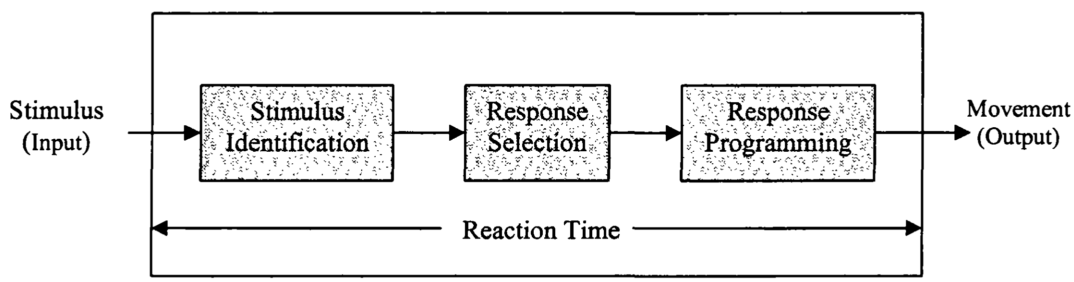

Figure 2.1: Information Processing Model, adapted from Schmidt and Lee (1999)

This IP commonly referred to as RT (reaction time = IP + movement) in empirical research, has been shown to be relatively slow in choice-reaction paradigms. However, RT is usually measured in laboratory-based unrealistic non-sporting environments in which possible sources of information that enable anticipation are not only unavailable but are removed completely from the experiment in order to keep tight control of the experimental process. Experimental procedures that allow anticipation to naturally occur indicate that RT and thus IPM time are drastically reduced (Schmidt and Lee, 1999).

Rosenbaum (1980) employed a choice RT paradigm, in which movement was categorised as either; (a) performed with either the right or left hand, (b) toward or away from the body and (c) towards a target that was either near to or far away from the starting position. The results indicated that providing subjects with advance information concerning any of the 3 movement functions reduced RT by approximately 100 to 150ms, suggesting that when the subjects were provided with appropriate advance information they could engage processing before the stimuli arrived. Furthermore, Schmidt and Lee (1999) suggested that when advance information is available some processing operations can be performed in advance; therefore, these operations can be 'bypassed' when the appropriate stimuli is presented. Moreover, if enough advance information is available the appropriate response can be programmed in advance, indicating that when / if the appropriate stimuli are presented the entire response – selection stage can be by-passed (Fig.2.2).

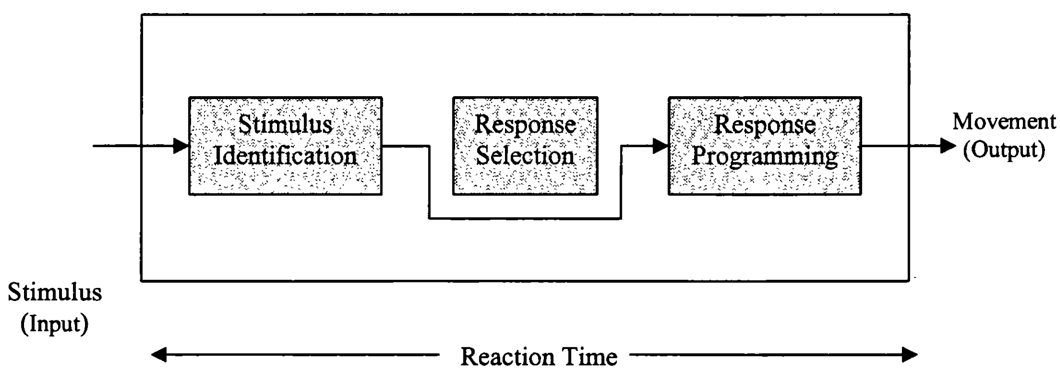

Figure 2.2: Information Processing Model, 'bypassing' functioning of the Response-Selection stage. Adapted from Schmidt and Lee (1999).

The previous section has highlighted the theoretical underpinnings of the process of anticipation and with the severe spatial and temporal constraints imposed on performance by competitive sport; clearly, any reduction in RT has significant competitive benefits.

2.1.2 Research Approaches in Anticipation

The following section gives a brief explanation of the research approaches that typically have been utilised to explore anticipation.

2.1.2.1 Encoding / Retrieval

Early research examined the possible function of encoding and the retrieval of task specific information as an explanation of anticipation. Encoding refers to how information is transferred into a storage form in the long-term memory; on the other hand, retrieval refers to the way information, which has previously been stored, is accessed in order to respond to a task specific action (Williams *et al.,* 1999). Typically, recall and recognition paradigms, both of which have been imported directly from the study of expertise in cognitive psychology, have been used to examine skill based differences in encoding and retrieval:

Recall Paradigm:
Within a sporting context, subjects view a static film display of an action sequence for a limited period of time, after which an immediate response is required of the player positions (attack and defence) within the display. Recall performance is then determined by the correlation between the static film displays and subject-recalled schematics.

Recognition Paradigm:
Characteristically, the recognition paradigms require subjects to view a number of static or dynamic film sequences (structured and unstructured), half of which have previously been viewed, whereas the remaining half and never been observed. Recognition performance is determined by the accuracy of subject recognition of the previously presented displays.

Seminal sport-specific research in both the recall and recognition paradigms was conducted by Allard and colleagues (Allard, 1982; Allard and Burnett, 1985; Allard *et al.*, 1980). Recent research has attempted to examine this approach to anticipation in an increased ecologically-valid manner. (see Williams *et al.*, 1999).

2.1.2.2 Signal Detection

The majority of sports require subjects to selectively attend and then to react to ever-changing but 'basic' stimuli (e.g. ball/object flight path). The signal detection approach, involves the examination of any apparent skill-based differences in the detection of a particular object within a visual display. Paradigms used to assess this theory typically involve the subjects' speed and accuracy of response to a subject entering a simulated visual field being assessed. Influential sport specific research into signal detection was conducted by Allard and Starkes (1980). Recently, the signal detection approach has been criticised because of a clear lack of ecological validity, as a plausible way to explain anticipation (Williams *et al.,* 1999).

2.1.2.3 Advance-Cue Utilisation

Advance cue utilisation refers to an athlete's ability to make accurate predictions based on contextual information made available early in an action sequence (Abernethy, 1987a). A significant amount of research has examined the relationship of advance visual cues and anticipation, as it seems a plausible method for counteracting the inherent limitations of the human response time (RT + movement time) when responding in a sporting situation. Research examining advance visual cues can be logically divided as either laboratory-based or field-based. Laboratory approaches typically requires a subject to view a film simulation of a sporting situation. The most popular has been the film occlusion approach (temporal / spatial) and the reaction time paradigm. In the film occlusion approach, the duration and nature of the display are constrained by the experimental process, whereas in the reaction time paradigm, response time or viewing time is inter-connected with response accuracy and is under the control of the subjects. On the other hand, field based approaches, have tried to adopt a more plausible ecologically-valid approach, examining performance from real sporting situations by adopting high-speed film analysis and liquid crystal occlusion glasses.

2.1.2.4 Situational Probabilities

Research has shown that expert performers can utilise their superior knowledge-base to classify many events as being 'extremely unlikely' and therefore can attach a hierarchy of probabilities to the remaining events, reducing the uncertainty regarding 'what' event will occur (i.e. event uncertainty) and when it will happen (i.e. temporal uncertainty; Williams *et al.*, 1999). If a performer is able to undertake this process, laboratory research in choice reaction times (Hick, 1952) suggests that a performer can significantly reduce their reaction time and overcome the previously-discussed inherent limitations of human information processing. Early research in this field was conducted by Alain and colleagues (Alain and Girardin., 1978; Alain and Proteau, 1978, 1977, 1980; Alain and Sarrazin., 1990; Alain, Lalonde and Sarrazin., 1983; Alain, Sarrazin and Lancombe., 1986) examining the decision making behaviours of subjects when viewing simulated sporting conditions.

Abernethy *et al.* (1993) suggested that, with the exception advance cue utilisation and situational probabilities these approaches lacked ecological validity. During dynamic competitive play, a player can view the action developing and use the contextual information (e.g. the movements of opponents when kicking a ball) and situational probabilities to anticipate future ball movements. Thus, contemporary studies have focused on exploring anticipation by looking at performers' abilities to utilise advance kinematic (visual) cues (Abernethy *et al.,* 2001), and the potential usefulness of situational (event) probabilities in anticipation (Crognier and Féry, 2002). As such the remainder of the review will focus on these two latter approaches.

2.2 Terminology

2.2.1 Anticipation

Anticipation is defined as "the ability to look forward and judge correctly what is going to happen next" (Kent, 1994). Poulton (1957) goes further, than this basic definition and defines anticipation in three forms. Firstly, *receptor anticipation,* this refers to when a performer detects an upcoming event with various sensory receptors. Secondly, *effector anticipation,* this occurs when the performer estimates the period of time needed to achieve their own movement to the desired location. Finally, *perceptual anticipation* this occurs when the performer doesn't view an upcoming event, but the upcoming event is still predictable because of the performer's considerable knowledge base. Schmidt and Lee (1999) recognise Poulton's definition but conceive that anticipation should also be separated into *spatial / event anticipation* and *temporal anticipation.* Spatial / event anticipation occurs when a performer predicts what kinds of stimuli occur and thus predicts the necessary responses. In contrast, temporal anticipation refers to the ability of a performer to predict when the stimuli will occur. The rest of this review will refer to the encompassing term anticipation, but it is taken that receptor, perceptual and spatial / event anticipation are the most significant forms in anticipation in racket sports.

2.2.2 Advance cue utilisation

Advance cue utilisation refers to an athlete's ability to make accurate predictions based on contextual information made available early in an action sequence (Abernethy, 1987a). Typically, this contextual information is of a visual nature.

However, it is plausible that performers are able to gain less pertinent contextual information of an audible or sensation nature.

2.2.3 Situational Probability / Awareness

Situational probabilities/awareness refers to the ability of skilled performers to utilise their superior knowledge-base to classify many events as being 'extremely unlikely' and therefore can attach a hierarchy of probabilities to the remaining events, reducing the uncertainty regarding 'what' event will occur (i.e. event uncertainty) and when it will happen (i.e. temporal uncertainty) (Williams *et al,* 1999). More specifically, when two highly skilled squash players are competing, research suggest a number of factors will influence shot selection:

- players' ability
- physical fitness
- tactical ability
- experience
- knowledge of opponent
- tactical initiative (increasing tactical and time-based pressures on an opponent).

For example, if a player has just played a deep groundstroke, increasing tactical initiative over their opponent, the player will naturally assess their opponent's likely responses, thus, decreasing the number of stroke choices to react to.

2.2.4 Expertise

Expertise in sport is typically thought of as when a player possesses a very high level of skill, where skill is defined as *"the ability to bring about some end result with maximum certainty and minimum outlay of energy, or of time and energy"* (Guthrie, 1952; p. 136). Hence an expert squash player is one who hits the ball with levels of precision and speed as would be expected from an expert performer of any domain where a large number of hours of deliberate, purposeful practice have been undertaken (Ericsson, Krampe and Tesch-Römer, 1993; Ericsson, 1996). Of course higher order cognitive functions are also required of the expert rackets player. Attentional demands can be considered high in racket sports as this processing of information requires the ability to shift focus as required, the ability to recognize pertinent information from the visual display to allow anticipatory behaviour, and rapid decision-making to elicit the best course of action. Consequently, the expert performer, within many sports, has been defined by the ability to be aware of certain aspects of play and make more appropriate decisions when faced with a number of options usually under severe time constraints (Ward and Williams, 2003). These requirements have been well researched in sports psychology.

Historically, a great deal of the research in sports psychology that concerns perceptual expertise can be traced back to the pioneering work of de Groot, (1946/1978). His research methodology, which was later refined by Chase and Simon (1973), assessed chess expertise by requiring players of different standards to reproduce from memory the chess pieces of a typical mid-game scenario viewed for a few seconds. Sports researchers have utilized this methodology using static slides and film clips of various sports situations and have found that, as with the chess experiments, experts have superior recall and recognition of sport-specific patterns of play (e.g. Allard, Graham and Paarsalu, 1980; Starkes, 1987; Williams, Davids, Burwitz and Williams, 1993). Typically experts' advantage over novices has been restricted to structured representations of their sport (e.g. offensive patterns of play ending in a shot at goal) depicted via video clip (Williams *et al.* 1993). Unstructured representations (e.g. players walking off the pitch) have not discriminated differences between experts and novices (for a review of these studies see Starkes and Allard, 1991). These researchers have thus come to the same conclusions as Chase and Simon (1973), namely that experts have more accomplished knowledge resources, stored as complex patterns (chunks), accumulated through many years of experience within the domain from which they are able to pattern match. This observation is well established in the sports domain although the pattern recognition model clearly does not comprehensively explain expert performance. Indeed Ericsson (2003), a leading researcher into the nature of expertise, suggests that these laboratory tasks fail to capture the experts' superior performance and its mediating mechanisms because of their artificiality. He also points out that even the most fundamental conclusions should be treated with caution, as recent studies have shown that after only fifty hours of practice novices can match the recall performance of chess masters with thousands of hours of chess-playing experience (Ericsson and Harris, 1990). Also with a limited amount of practice, chess experts could display consistently superior performance on 'random' chess configurations (Ericsson, Patel and Kintsch, 2000). Awareness, through recall of prior sporting events is, however, undoubtedly useful for determining the appropriate response. For example a badminton player may recall previous encounters with an opponent who favours a disguised smash and thus can select the optimal manner for defence. However the recall/recognition paradigm does not shed light on the nature of the psychological processes involved.

2.2.5 Perceptual action coupling

The validity of the findings from film occlusion studies have been questioned mainly due to the artificiality of the task as the technical and temporal demands of each response made by participants are always unrealistic. It has been argued that perception and action are inseparable and artificially breaking this natural coupling is bound to disrupt perceptual processes (Gibson, 1979). In the natural setting the responses, in the form of unrestrained whole body movements to intercept the ball are coupled with the visual information such that responses can take place at a time point solely under the control of the participant. Film studies, on the other hand, require a constrained, uncoupled response, such as indicating on a schematic (e.g. Abernethy 1990a) or verbalising (e.g. Abernethy 1990b) after a pre-determined time interval specified by the experimenter. Williams *et al.* (1999) have suggested that the unrealistic timing of the response, e.g. Tenenbaum *et al.* (2000) allowed an inter-trial interval of 5 seconds to allow participants to respond, may allow extra processing of information stored in memory subsequent to the natural response (termed 'iconic persistence'; Sperling 1963). Thus, the degree to which anticipatory performance during film studies is related to the visual information presented is unclear given the potential contamination of experimental effects and perception-action decoupling. Consequently, the findings from film occlusion studies have been compared with experimental findings from studies involving alternative methodologies. For example, Abernethy *et al.* (2001) compared participant's anticipatory ability across a two-dimensional film display (stereotypical occlusion study), a three-dimensional point-light display (as previous but image altered) and a real world setting (vision occluded during on-court simulated matches via liquid crystal occlusion spectacles, Milgram, 1987). Since the participants were required to continue to move and attempt to play the next shot in the on-court matches the perception-action coupling was deemed to have remained intact. The results revealed close similarities between film-based and in situ performance suggesting that film studies require participants to use similar perceptual processes as used in natural settings. This is not a unique finding as, for example, Starkes *et al.* (1995) also found similar differences between expert and novice volleyball players' predictions of landing location when tested in situ wearing liquid occlusion spectacles compared to previous film studies (e.g. Wright *et al.* 1990) although the perception-action coupling in the Starkes *et al.* study was not preserved. Nevertheless, the only apparent significant difference appears to be a poorer performance on the film studies compared to the real world task, presumably due to the reasons outlined above, and an apparent inferior ability to make depth judgements compared to lateral ones of the balls/shuttle's trajectory on film tasks, although this is thought to be simply related to the two dimensionality of the film display (Williams *et al.*, 1999; James *et al.*, 2004; Abernethy 1990a, 1990b).

More recently Farrow and Abernethy (2003) found that expert tennis players, tested in a natural setting, when ball flight information had been withheld, were able to predict tennis serve direction better than expected by chance alone, when both a coupled natural movement response and an uncoupled verbal response was required. Novices in these situations were unable to anticipate above chance levels. A single significant difference occurred between the coupled and uncoupled conditions; for both experts and novices, performance significantly decreased when participant's vision was occluded at 300 ms prior to racket-ball contact compared with 600ms. This was surprising given that a performance gain would have been predicted as more information was available. Since this was a repeated measures design i.e. the same participants watched the same intermediate level tennis players' serving for both coupled and uncoupled conditions it is unlikely that this difference was as a result of idiosyncratic behaviour but rather an experimental anomaly. The authors repeated the experiment with intermediately skilled juniors and found no differences between the coupled and uncoupled tasks for any prior to racket-ball contact condition although these participants were unable to perform above chance levels. It would therefore seem that de-coupling the natural response and replacing it with an experimentally prescribed one does not necessarily affect the nature of the anticipatory performance, although some performance decrement is likely to be present, this seeming to be true for different experimental methodologies. Furthermore, this performance decrement is likely to have the effect of reducing the expertise related advantage e.g. Farrow and

Abernethy (2003) found that experts' performance decreased significantly in a de-coupled prediction task where ball flight information was available compared to the natural response condition.

2.2.6 Ecological validity

Ecological validity refers to the extent to which an experiment i.e. the methods, materials and setting of the experiment, approximate the real-life situation that is being investigated. Ecological validity can be confused with external validity (which is the extent to which a study's results generalise) but whilst closely related, they are independent; a study may possess external validity but not ecological validity and vice-versa (Shadish *et al.*, 2002). To put this into perspective for a study to have ecological validity, participants must undertake the same procedures as they would in the real world setting. Thus a squash player needs to see the same viewing perspective, be under the same physical and psychological pressures and make the same response as would occur in the natural squash setting. Any divergance from this reduces the ecological validity of the study. When a study lacks ecological validity to some degree e.g. film studies do not replicate the real world situation and are therefore not ecologically valid, it does not follow that the external validity of the study is fatally compromised, although it is likely that the extent to which the findings can be generalised is at least made with caution.

2.3 Laboratory Research in Anticipation and Racket Sports

2.3.1 Visual Occlusion Approach

Typically, laboratory research in anticipation and racket sports has utilised the film occlusion approach. This approach involves the production of a test film simulating the visual display available to players in the natural game, which is generated from the on-court perspective of defending player. The film displays are then edited to manipulate the temporal and / or spatial information displayed to the viewer.

The empirical work of Jones and Miles (1978) is seen as a pioneering study in implementing temporal occlusion, in order to determine the critical advance cues needed for anticipation/decision making in tennis. Subjects were categorised as professional tennis coaches with top level playing experience (n = 11), professional coaches (n = 21) and undergraduates with no tennis experience (n = 60). Film occlusion occurred at 336 ms post racket-ball contact, 126 ms post racket-ball contact, and 42 ms prior to racket ball contact. Subjects reported their perceptual predictions by indicating where they thought the ball would land on a schematic representation of the service court, which was laterally divided in to 3 sections (down the line, court centre or wide service directions). Across all skill levels anticipatory performance was impaired when occlusion occurred prior to racket ball contact, whereas post racket-ball contact, the anticipatory performance remained stable. Significant between-group differences emerged in the 42 ms prior to and 126 ms post racket-ball contact, with the tennis coaches having an increased anticipatory skill in comparison with the undergraduates. In a related study Isaacs and Finch (1983) returned very similar results after adhering to the same methodology (see, Table 2.1) as Jones and Miles (1978). However, the authors assessed the anticipatory ability of beginners (n = 34) and intermediate (n = 16) players, and the film occlusions occurred at 10 ms prior to racket-ball contact, at contact and 15 ms post racket-ball contact. Anticipatory response was evaluated in serve placement latitude (width), longitude (depth) and radial (vector) error.

Jones and Miles (1978) and Isaacs and Finch (1983) produced consistent results, confirming that differences existed in the awareness of experts and novices to advance information. However, the authors made no attempt to assess if spatial differences occurred in the pick-up of information. Buckolz, Prapavesis and Fairs (1988) attempted this with a more qualitative approach towards advanced cue utilisation. Subjects consisted of intermediate and advanced tennis performers who were asked to predict the type of opponent's passing shot (down the line passing shot, cross court passing shot or a lob) and how they predicted that shot type. Results revealed that the advanced performers were superior at predicting the type of passing shot and these performers utilised different, more pertinent cues (central body areas, particularity the waist-hip region, as well as racket and ball) to the intermediate performers. These results were attributed to the notion that experts were more aware of what telegraphic cues were for given shots, and they were more capable of using these cues for decision making, even when both subject groups were aware of them.

Abernethy and Russell (1987a) compared the temporal and spatial characteristics of anticipatory cues utilised by expert (20 international level competitors) and novice (35 untrained undergraduates) badminton players. The simulated film task utilised an expert performer as a model, which was temporally occluded at (1) 167 ms prior to contact, (2) 83 ms prior to contact, (3) at contact, (4) 83 ms post contact and (5) no occlusion occurred. The second experiment involved elements of the display being occluded, once again 5 occlusions were utilised (1) the racket and racket arm, (2) the racket, (3) the head, (4) lower body and (5) an irrelevant background object. Prediction accuracy was based on radial, lateral and depth errors returned by the subjects in a schematic form. Results indicted that an expert-novice difference in prediction accuracy was apparent, the authors' identified the critical period for extraction of visual information was between 83 ms prior to and 83 ms post racket-shuttle impact. Furthermore, advance visual cues available prior to racket-shuttle contact appear to be utilised in the prediction of stroke direction, while information required to predict stroke depth occurs post racket-shuttle contact. Subjects' registering fewer errors when predicting horizontal compared with vertical flight direction has been demonstrated in a number of other sports (Salmela and Fiorito, 1979; Williams and Burwitz, 1993). Experiment 2 revealed that expert's prediction accuracy was based on advance visual cues, arising from the racket arm and the racket itself. On the other hand novices were dependent on purely the racket for advance visual cues. The authors' highlighted that the experts utilisation of earlier-arising, more proximal advance visual cues, demonstrates an essential link between perceptual skill and the kinematic evolution of the action being observed and provides a feasible explanation of the apparent paradox between the time constraints imposed by fast ball/shuttle sports like badminton and the known human information processing limitations with respect to RT.

Abernethy (1990a) established similar results in squash, as he had previously in badminton. The aim of the experiment was to compare the temporal and spatial characteristics of advance visual cues utilised by expert and novice squash players utilising the same methodology as in the author's 1987a study. The results revealed a high correlation between perceptual skill, subject's state/world ranking and temporal occlusion task. Furthermore, the crucial time for extracting both direction and depth information was very similar to the authors' previous work appearing to be between, 160 – 80 ms prior racket-ball contact to and the first 80 ms of ball flight respectively. The increased crucial time period from 80ms prior to racket-shuttle contact in badminton and 160 ms prior to racket-ball contact in squash may be a function of the weight of the racket and thus the need for increased momentum producing an early occurring and/or longer racket swing. Spatial occlusion data produced equivocal results; no particular masked cue source caused a significant increase in prediction error, for either subject skill level.

Tenenbaum *et al.,* (2000) examined the interaction of experience (age/years of participation) and skill level (high/low) in anticipation. Subjects (n = 80, split into 4 age categories and two skill level sub-categories with each age group) predicted the landing position of eight different tennis strokes from a temporally occluded film (temporal occlusions ranged from -480 ms prior to racket-ball contact to 320 ms post contact). Predication accuracy was based on radial, lateral and depth errors (for definitions see Abernethy and Russell, 1987a). The results indicated that the highly skilled players were able to draw from their playing experience and exhibited more developed anticipatory skills. However, this anticipatory advantage was only apparent under the greatest temporal constraints. Furthermore, analyses of on-court stroke initiations suggest that differences in perceptual and cognitive skill attribute to skill level are apparent only under conditions of strict temporal demand or high complexity (Tenebaum and Bar-Eli, 1993). This suggests that the highly skilled player's prediction advantage may not purely be based from their ability to perceive and utilise advance visual cues, but their decisions may well be based on earlier situational information occurring prior to their opponent's stroke kinematics.

2.3.2 Visual Search Approach

Differences in visual search strategies have been suggested as a possible explanation of skill-based differences in anticipation (Williams *et al.,* 1999). However, equivocal findings have been produced throughout the research body. Abernethy and Russell (1987b) examined this plausible relationship between skill level and visual search strategy, utilising eye movement registration and temporal/spatial film occlusion in badminton. Again expert (n = 15) superior prediction performance was apparent between 83 ms prior to racket-shuttle contact and the no occlusion condition. Furthermore, experts were again shown to utilise advance visual cues from the racket arm and racket, whereas novices just utilised the racket as a source of visual cues. However, the authors noted minimal skill-based differences in visual search behaviour.

Ward, Williams and Bennett (2002) examined the effect of manipulating the perceptual display on visual search during anticipation of ground strokes, utilising experienced and inexperienced tennis players. Experienced participants were defined as club level players, whereas the inexperienced participants were recreational play with no competitive match play or coaching. Two skilled male tennis players of club level or above were used as models. The models were filmed from the front playing forehand and backhand ground strokes during match play. Normal film and 21-point-light displays were the two viewing conditions. Test films were viewed on a life-like screen (3m x 3.5m, at a distance of 5m), which allowed a viewing perspective that was similar to experiences in a live situation. Participants stood on two pressure pads, and were asked to respond, quickly and accurately, to the virtual tennis ground strokes, by stepping on to one of four pressure sensitive pads located 0.4m directly in front, behind, left, and right of the participant and by swinging the racket in an interceptive manner. Participants' responses were measured using choice response time. Eye movements were recorded using an eye-head integration system. Three components of visual search were recorded; percentage viewing time, search rate, and search order, anticipatory response variables included decision time and response accuracy.

Irrespective of viewing condition, experienced tennis players spent significantly more time fixating on the head and shoulder and trunk-hip regions in comparison to arm hand, leg-foot, ball, and unclassified areas of the display. In contrast, inexperienced players spent more time fixating on the racket than any other area. Experienced players concentrated successive fixations around central body areas more than their inexperienced counterparts. Both groups demonstrated a decrease in the pattern of fixations from and to these areas when viewing point-light compared to normal displays. Experienced tennis players did not significantly change their pattern of fixations around racket, ball, and racket ball contact areas between viewing conditions. Differences in the percentage of viewing time indicated that the two skill groups based their anticipatory responses on different information sources.
Irrespective of viewing condition, inexperienced players tended to focus on later occurring, more visible, distal movements of the racket during the opponent's ground stroke. Experienced tennis players were able to use information from earlier, proximal

cues, consistently extracting subtle, relative motions from the central body area. Greater use of fine-constantly-changing cues by this group in both normal film and point light conditions indicates a greater awareness of biomechanical information.

When viewing point light displays both groups used fewer fixations of longer duration directed at the intersection of cues deemed to pertinent. However, a lack of support as evident for the hypothesis that experienced players would utilise a more consistent visual search strategy across viewing conditions, and no significant differences in search rate emerged between skill groups. The authors' concluded that the nature of information selected during a tennis ground stroke might, therefore, lie in movement transition, not merely position. Conversely, Singer *et al.,* (1996) (see Table 2.1) and Goulet, Bard and Fleury (1989) argue that performers eye movement characteristics are the most salient variables for classifying expert performance.

Table 2.1: Summary of studies using the film occlusion approach to examine advance cue usage and/or visual search strategies in racket sports.

Study	Sports Task Examined	Participants	Methodology	Conclusions
Jones and Miles (1978).	Assessed the usefulness of advanced visual cues to anticipation.	n= 92 (32 experienced tennis coaches, 60 inexperienced undergraduates).	Film occlusion occurred (1) 336 ms after racket-ball impact, (2) 126 ms post racket-ball contact, and (3) 42 ms prior to racket-ball contact. Anticipatory response was assessed by the frequency of correct responses from 3 possible service locations.	• Expert-novice difference seen at conditions (2) and (3). • The participants scored significantly better than chance (i.e. 33.33% success rate) in these situations and so indicative of advance cue utilisation.
Isaacs and Finch (1983).	Evaluated expertise differences in the ability to anticipate tennis serve placement.	n = 50 (34 Beginner and 16 Intermediate players).	Film occlusion occurred (1) 10 ms prior to racket-ball contact, (2) at contact, (3) 15 ms after contact, and finally (4) 30 ms after contact. Anticipatory response was evaluated in serve placement latitude and longitude dimensions, and exact placement.	• An expert-novice difference was observed. • Superior anticipatory responses were yielded for the greater viewing times.
Abernethy and Russell (1987a).	Compared the temporal and spatial characteristics of anticipatory cues used by expert and novice badminton players.	n = 60 (25 Experts and 35 Novices).	Participants predicted the final landing position of eight different strokes from temporally and spatially occluded films. Prediction accuracy was based on radial error, lateral and depth errors.	• Expert-novice difference in prediction accuracy. • The critical period for extraction of visual information appeared to be between -83ms and 83ms following shuttle contact. • The arm holding the racket as well as the racket itself provides crucial sources of information.
Abernethy and Russell (1987b).	Explored the relationship between expertise and visual search strategies through the use of eye movement registration and temporal and spatial film	N = 31 (15 Experts and 16 Novices).	Participants had to predict the landing position of the shuttle from various strokes. Prediction accuracy was based on radial error, lateral and depth errors. Eye movement characteristics such as fixation	• An expert-novice difference was observed. • Little difference was observed in the visual search behaviours between the two groups.

Study	Sports Task Examined	Participants	Methodology	Conclusions
	occlusions.		duration and location were recorded.	• Visual search data suggested (and supported) a reliance upon arm and racket cues.
Buckolz *et al.*, (1988).	Identified the specific advance visual cues that are used in predicting passing strokes in tennis.	N = 44 (21 Advanced and 23 Intermediate).	Participants predicted the type of passing shot and the cues that they used to come to the decision from occluded film. Prediction accuracy was based on correct prediction percentages and also the accuracy of the cues being utilised.	• Both skill groups were able to utilise advance cues to predict strokes. • The difference was due to the intermediate players being less efficient at extracting information from the specific cue they cited.
Abernethy (1990a).	Examined the temporal and spatial characteristics of anticipatory cues used by expert and novice squash players.	N = 36 (16 Experts and 20 Novices).	Predict the outcome (direction and depth) of the stroke from temporally and spatially occluded film clips. Prediction accuracy was based on radial error, lateral and depth errors. Additionally, subjects rated their relative importance of cues.	• Experts were superior at predicting the outcome of the stroke. • The crucial time for extracting both direction and depth information appeared to be between 160-80 ms prior to the stroke until 80 ms of ball flight. • Spatial occlusion data produced equivocal findings.
Singer *et al.* (1996).	Assessed visual search characteristics while viewing tennis serves and ground strokes. Furthermore, compared physical attributes to the attainment of expertise.	n = 60 (30 highly rated university players & 30 beginner players).	Subjects watched a film of opponents performing serves and ground strokes. Visual search patterns (number of, and duration of fixations) were recorded. Anticipatory response accuracy and characteristics (speed, location and placement) of the serves and ground strokes were recorded.	• Prior to impact fixations were clustered around the racket arm and the racket area, and after impact the experts tracked the ball. • Experts tended to use proximal-to-distal visual scanning. • Novices were less consistent in their visual search patterns.
Tenenbaum *et al.* (2000).	Compared how visual anticipatory capabilities developed in high and low skilled tennis players and the role that experience played.	n = 80 (male tennis players- split into four age categories and two skill level sub-categories within each age group).	Participants predicted the final landing position of eight different tennis strokes from a temporally occluded film. Prediction accuracy was based on radial error, lateral and depth errors that were averaged for each of the strokes.	• The highly skilled players gained more from experience and so exhibited more developed visual anticipatory skills. • This advantage was most apparent under the greatest temporal constraints.

Study	Sports Task Examined	Participants	Methodology	Conclusions
Ward *et al.* (2002).	Investigated the effect of manipulating the perceptual display on visual search during the anticipation of ground strokes.	n = 16 (8 experienced and 8 inexperienced tennis players).	Normal film and point-light displays of forehand and backhand strokes. Participants stood on two pressure pads and responded with ground strokes by stepping on to one of four pressure pads located around them. Choice response times were measured and eye movements were recorded using an eye-head integration system.	• Both groups demonstrated a decrease in the pattern of fixations when viewing point-light compared to normal displays. • Experienced tennis players fixated around racket, ball, and racket-ball contact areas in both viewing conditions. • Differences in the percentage viewing time indicated that the two groups based their responses on different information sources.

2.3.3 Empirical Limitations Inherent to the Laboratory Research

Research reviewed thus far has demonstrated that skill-based differences in anticipation in racket sports are apparent. Experts are able to utilise advance visual cues early in the kinematic stroke sequence and perceive these cues from a wider variety sources (not racket specific) than their novice counterparts. However, laboratory research has a number of limitations, all of which are linked with the inherent lack of ecological validity laboratory research permits.

Firstly, the majority of research has presented subjects with action clips from only one 'model' performer (Jones and Miles, 1978; Salmela and Fiorito, 1979; Abernethy and Russell, 1987a). Therefore, any idiosyncrasies in this model's technique may have an effect on the subject's task of anticipation, by either making the anticipation task easier or harder, depending on the subject's skill level. This has the effect of making comparison and conclusive conclusions across the research base tentative.

Secondly, in the production of a test film a three dimensional display is converted by projection to a two dimensional presentation. Which causes a loss of stereoscopic depth information and as such visual field, object/image size and display resolution are degraded. This degradation has been suggested as a plausible explanation for the apparent increased ability of expert performers to predict stroke direction as opposed to depth (Williams *et al.,* 1999). Furthermore, a few visual occlusion paradigms have altered the speed of displays, further removing the subject from their natural performance and response (Buckolz *et al.,* 1988).

Thirdly, within the confines of laboratory research, it is extremely difficult to simulate the stressors and specific time constraints that exist when performance occurs in its natural setting; this is especially significant when considering an appropriate response selection. The majority of laboratory research has consistently simplified the response processes, requiring subjects to respond verbally, mark a schematic or perform a physical response that has no direct link with the stimulus (Isaacs and Finch, 1983; Buckolz *et al.,* 1988; Abernethy and Russell, 1987a; Abernethy, 1990a), thus negating the requirement for the subject movement to be organised in time to permit interception with the approaching object (Singer *et al.*, 1996; Goulet, Bard and Fleury, 1989; Abernethy, 1989). Linked to the response action is the response time allocated by the experiment procedure (inter-trial time/iconic persistence). Visual occlusion research has tended to introduce an inconsistent temporally-blank period between trials on the simulated film display. Sperling (1963) suggested that visual information is retained in the short-term memory for some time after the occlusion of the stimuli. Therefore, a direct relationship between subject performance and film occlusion time utilised cannot be examined, instead the relationship may well link the occlusion period plus the duration of the iconic persistence and subject performance. This suggests that research that has utilised a larger iconic persistence may lead to increased subject performance compared with performance in its natural setting. However, Farrow and Abernethy (2003) refuted the need for such consideration to be given to iconic persistence and coupled movement-based responses, indicating that there was not a significant difference in response accuracy when a coupled response (a movement-based action) was used as opposed to a verbal response protocol when viewing tennis serves. It would seem therefore that de-coupling the natural response and replacing it with an experimentally prescribed one does not necessarily affect anticipatory performance regardless of the experimental methodology. However this may be due to the fact that the experimental intervention itself has disrupted the natural response.

Farrow and Abernethy (2003) also assessed prediction performance in a condition where ball flight information was available and found a significant effect of de-coupling the natural response such that the experts' performance decreased significantly. This may indicate that the natural response had taken place in the coupled condition, resulting in a clear improvement in performance. The conclusion therefore is that some of the expertise related advantage may be removed when experimental interventions disrupt the natural response.

Fourthly, research has consistently only utilised a single stroke per trial, on which the subject has to make a predication. Therefore, no situational probabilities (e.g. previous shot type, opponents location on the court, time pressure), a potentially potent source of anticipatory information exists.

Fifthly, subject classification is inconsistent (classifications are not defined e.g. what makes an expert?) in the majority of research (Abernethy and Russell, 1987a; Singer *et al.,* 1990; 1 *et al.,* 2000).

Furthermore, temporal periods elected by the experimenters, may direct subjects to specific cues that provide abnormal sources of information. This links well with the general question as to whether a process, assumed to be autonomous such as anticipation is affected by conscious processing these empirical paradigms demand. Furthermore, specific to spatial occlusion approaches, ineffective occlusion techniques have been adopted that only mask the outline of objects (Abernethy and Russell, 1987a); obviously this makes the results of such studies tentative. Visual search studies have not accounted for the 2D visual display or for the possibility of peripheral vision having a role in stimulus identification as well as retina fixation (Williams *et al.,* 1999). Finally, Abernethy *et al.*, (1993) argues that simplistic or contrived laboratory tasks may negate expert advantage by (1) removing from the task the experimental basis for their advantage. (2) Introducing potential floor or ceiling effects in the measurement process. (3) Causing experts to function differently either by denying them access to information they would normally use, or by causing them to utilise different information to solve a particular problem.

Notwithstanding the above criticisms, laboratory based approaches have successfully provided the experimenter with rigorous control over the test environment. However, there is a need for replication and verification of the laboratory findings within the actual performance setting (Williams *et al.,* 1999).

2.4 Field Based Research

This section examines field based research from a methodological perspective. It begins with a brief scope of examinations of visual search strategies conducted in a more natural setting, and then will move on to research conducted utilising research approaches from an ecologically valid background (High speed camera analysis and Visual occlusion technique).

2.4.1 Visual Search Strategy

Abernethy (1990b) utilised an expert / novice temporal occlusion paradigm in squash, under laboratory and field conditions (experiment 1) and made a further comparison with the visual search behaviours (experiment 2) of expert and novice participants. In the first experiment the subjects were required to judge and then verbally respond to the direction and depth of the viewed player's stroke from a temporally occluded film display (comparable to the temporal occlusion manipulation reported in Abernethy and Russell, 1987a) and in the second experiment during the 'live' viewing of an on-court display. Eye movement characteristics such as fixation duration, location and order of fixations were recorded in both experiments.

The authors reported that in the temporal occlusion task systematic expert – novice differences were identified in the predicative task, and only minor differences were apparent between the visual search characteristics of the two groups, with experts spending significantly more time per trial fixated on the arm and head of the opponent and less time fixating on the contact zone, when compared to novices. In keeping with the observations of other examinations of skilled based differences in a laboratory paradigm (Abernethy and Russell, 1987b) the authors' concluded that the visual search patterns of both expert and novice squash players are characterised more by global similarities than by differences. Furthermore, under the 'natural' on-court settings, the same superior ability in picking up advance information was revealed, while no evidence of fundamental expert-novice differences in visual search was apparent. The visual search characteristics of the subjects were essentially similar under the two conditions with the same basic features (racket, racket-arm, contact zone and the ball) being the sources of the fixations. Such results were reported by Cohen (1978) in comparison of subjects viewing, a natural driving stimulus, on a film displays or in reality. Although, consistent results were produce in the latter study, there is concerning methodological limitations. The field test only marginally increased the ecological validity as the subjects viewed simulated strokes being played in a Perspex cage from behind the court.

Singer *et al.,* (1998) and Williams *et al.,* (1998) tried to overcome the latter limitation by assessing whether visual search could be collected 'on-line' in tennis and examine intra-expert differences in visual search strategies (see Table 2.2). Visual search data was gained from highly ranked university tennis players (n = 5). Visual search strategy was divided into measurable components (pursuit tracking, saccades and fixation location and duration). Furthermore, analysis of general visual search patterns and the physical movement (during the ritual, backswing, fore swing and follow through phases) were analysed.

The results revealed minor variation in the tracking technique and fixation source. The highest ranked players utilise pursuit tracking, during the ball toss phase and fixated on the racket and racket-arm region during the ritual phase of the serve, conversely, lower ranked players either focused on the expected ball toss area or followed the ball from toss to apex using visual saccades. The greatest variation occurred post racket-ball contact, higher ranked players had a more consistent smooth-pursuit pattern, from service to ball return, implying their use of an eye-head movement system to extract ball flight information (Williams *et al.,* 1998). In comparison, lower ranked players scanning patterns were considerably more scattered and variable, indicating they tended to utilise anticipatory saccades to place their focus in front of the flight path of the ball, then letting the ball image move across their retina, suggesting the use of image-retina scanning (Williams *et al.,* 1998; Singer *et al.,* 1998). However, research has not demonstrated that either system is more appropriate; as the effectiveness of either system is dependent on ball velocity and the player's dynamic visual acuity (Cauraugh and Janelle, 2002).

A number of methodological limitations are apparent across the field based visual search. In comparative studies with laboratory findings (Abernethy, 1990b), limitations inherent with the laboratory based research have not been overcome. Generally, only one model has been utilised to produce the strokes for the task, and thus idiosyncrasies within this models' strokes may attribute to differentiation in anticipatory task difficulty for each of the subject skill groups. Research has consistently utilised limited numbers of subjects (Williams *et al.,* 1998; n = 5) and the consistency of the participant skill level is questionable (Williams *et al.,* 1998; utilised University Players). Furthermore, the steps that have been made to increase the ecological validity have not always progressed to a 'natural' test condition with partial floodlight conditions utilised in many tennis methodologies. Finally, definitions of the phases of stroke progression have not been available and as such comparisons with laboratory research are somewhat tentative.

In summary, the research examining visual search strategies has shown that visual search data could be collected online in an ecologically valid method. However, the equivocal findings have failed to explain the differences between experts and novice prediction accuracy in both simulated and natural settings.

Table 2.2: Summary of field-based studies examining visual search strategies in racket sports.

Study	Sports Task Examined	Participants	Methodology	Conclusions
Abernethy (1990b).	Examined the visual search behaviours of expert and novice squash players under laboratory and field conditions through the use of eye movement registration system.	n = 32 (15 Experts and 17 Novices).	Participants were required to verbally report the outcome (direction and depth) of the stroke from temporally occluded film and during on-court conditions. Eye movement characteristics such as fixation duration and location and the order of fixations were recorded.	• Expert-novice difference was identified. • Only relatively minor visual search differences were observed between the two groups with fixations being directed towards the arm and racket of the player. • No visual search behaviour differences were observed in the natural settings • It was not simply inappropriate searches used by novices but an inability to extract information from the display.
Singer *et al.* (1998).	Assessed whether visual search patterns could be collected 'on-line' in tennis.	n = 5 (Highly ranked university players).	Visual search data was gained from participant's viewing serves from an opponent *in situ*.	• Players fixated on the arm/racket region during the ritual phase of the serve. • Top-ranked players utilised pursuit tracking during initial and final ball flight. • The lesser skilled players used a variety of search approaches.
Williams *et al.* (1998).	Assess visual search patterns in dynamic tennis situations.	n = 5 (Highly ranked university players).	Visual search data was gained from participant's viewing on-court serves from opponent.	• Higher ranked players initially focused on the arm-racket-shoulder and then tracked the ball as it was tossed to the point of racket-ball contact. • The greatest variation in visual search behaviour was observed after racket-ball contact. The higher ranked players used smooth-pursuit pattern from service to ball return. • Lower ranked player's scanning patterns were considerable more scattered and variable.

Study	Sports Task Examined	Participants	Methodology	Conclusions
Farrow and Abernethy (2003)	Assessed the extent to which the natural coupling of perception and action influences tennis player's ability to utilise kinematic movement patterns to anticipate service direction, and whether the type of information (pre/post contact) affects this ability.	$n = 16$ (8 experienced and 8 novice tennis players).	Two experiments using temporal occlusion assessed the anticipatory ability of elite and novice tennis players (exp. 1) and intermediate tennis players (exp. 2) in a coupled (natural movement based) and uncoupled (verbal) response condition.	• Superior prediction accuracy for coupled condition, when ball flight information was available. • Expert superiority more apparent under natural coupled response (non-sig.)

2.4.2 High Speed Camera Analysis

High speed camera analysis seems to be methodological-sound approach to examine anticipatory movements, in which the ecological validity of the experiment is not in question. This methodology is characterised by short clips of specific events being recorded (at approximately. 250 frames per second), for example two strokes in a rally can be filmed and later examined to analyse movements and identify anticipatory actions.

Howarth *et al.,* (1984) used high speed film analyses to examine skill-based differences in the anticipatory movements of squash players within an ecologically valid experimental condition. Participants (n = 4; 2 Grade A, 2 Grade D) undertook matches against an opponent of a similar standard. Rally sequences were filmed at 100 frames per second from a position above the court during matches. Trials were analysed to identify (1) the offensive players' racket-contact with the ball, (2) the contact of the ball with the wall, (3) the contact of the ball with the floor, (4) the first anticipatory movement of the defensive player, and (5) the defensive players' racket-contact with the ball. The authors defined the first anticipatory movement as 'the first displacement of the receiver's body (prior to the ball making contact with the floor) in the direction necessary to intercept the oncoming stroke'. Viewing time was estimated to end at a time ~200ms prior to the initiation of the first anticipatory movement; this was taken to be the inherent RT visual latency time over which visual-based corrections could be executed (Mcleod, 1987).

Results showed that although the overall game speed was similar for both skill levels, the highly skilled players (Grade A) made their anticipatory movements significantly earlier than their lesser skilled counterparts, 112.5 ms compared with 280 ms after the offensive player struck the ball. Subtraction of the suggested visual latency period (~200 ms) revealed that the viewing time of the expert players was negative, suggesting that they based their decisions upon advance information. However, no differentiation could be made as to whether subject's based their decisions on advance visual cues or situational probabilities, or a mixture of both sources of information.

Although the authors took a leap forward in the examination of anticipation in a 'natural' competitive match, inherently the methodology is not as controlled as the authors would have liked and has limitations. Firstly, only two games were analysed, so any idiosyncrasies in player's performances could not be accounted for, nor did the experiment produce enough data for the production of statistically significant results. Secondly, stroke difficulty was not controlled, therefore, the effect of situational probability and the effect it has on subject's anticipation ability cannot be accounted for (Alain and Sarrazin, 1988).

James and Bradley (2004) assessed expert's utilisation of advance visual cues, while situational probabilities were allowed to naturally occur but controlling for shot difficulty. A world ranked squash player was filmed playing competitive matches against three different opponents of differing standards (ranked 4, 6 and 76 in the world, during the previous 2 years). The main subject was also filmed in a training situation. High speed camera analysis of the training scenarios occurred at 250 frames / second. Trials were analysed to identify (1) ball bounce, (2) racket swing, (3) point of ball contact, and (4) foot movement timings of the opponent. Furthermore, synchronised images (to ball contact and ball bounce on floor) of the player hitting the different strokes were recorded. The results revealed that disguise was utilised by the highest ranked player to such an extent that differences in stroke types were only apparent between 70ms seconds and 30ms before racket-ball impact. Furthermore, when playing easy shots experts were able to disguise their intent sufficiently to prevent the opponent utilising advance visual cues. Additionally, spatial adaptation occurred around the 'T' area when recovering from differing shot types, in keeping with results found by Wells (2001).

James and Bradley (2004) proposed that their results may disagree with previous laboratory research, by suggesting that, at an elite level, and with certain shot difficulty, anticipation cannot be purely based on advance visual cues. The results developed specific knowledge of expert's anticipation abilities, and managed to control a number of factors that have previously limited research (e.g. shot difficulty; Howarth *et al.,* 1984; for more detail see Table 2.3). However, two limitations exist that plague the reviewed high speed camera analysis research. Firstly, although defined, the measurement of the initial anticipatory movement of a subject is a concern, as inter trial accuracy cannot be precisely controlled. Mcleod's (1987) RT visual latency period was utilised as a general timing for all subjects; however, laboratory research has shown that between subjects RT differentiates around this figure, and RT can be drastically reduced with experience of a task (Bakker, Whitley and van der Brug, 1990). Secondly, to aid analysis the performer was seen as an essentially linear and serial processor of information. Decision-making is seen as a discrete process, whereas, it is in fact, likely to be more of a continuous cumulative process with early differentiated aspects of the movement response being frequently commenced before the final response selection, and usage of all available cues is completed (Miller, 1982). Therefore, the DM process may seem shorter and the RT longer than it actually is.

Table 2.3: Summary of high-speed camera analysis studies examining visual cue usage in racket sports.

Study	Sports Task Examined	Participants	Methodology	Conclusions
Howarth *et al.* (1984).	Compare the anticipatory movements of squash players during real matches.	n = 4 (2 Grade A and 2 Grade D players).	A high-speed camera was used to record segments of rallies during matches. Trials were broken down to analyse the movements of the players in relation to their opponent and the ball. An anticipatory movement was defined as '*the first displacement of the receiver's body (prior to the ball making contact with the floor) in the direction necessary to intercept the oncoming stroke*'.	• Grade A players made their initial anticipatory movements significantly earlier than their lesser-skilled counterparts. • Subtraction of the reaction time latency (0.2 s) showed that the viewing time of the expert players was negative and so suggested that they based their decisions upon advance cue information.
James and Bradley (2004).	Assessed expert squash players' utilisation of visual cues whilst controlling for shot difficulty.	n = 4 (World ranked squash players).	High-speed film analysis of real matches and training scenarios at 250 fps. Foot movement timings in relation to racket-ball contact were made.	• Disguise was utilised, with clear differences in stroke type only becoming apparent between 0.07 s and 0.03 s before racket-ball contact. • During easy shots expert players are able to disguise their intent sufficiently to prevent the opponent utilising advance cues to anticipate. • Spatial adaptation occurred around the T area when receiving differing shot types signifying that situational probabilities were used.

2.4.3 Visual Occlusion Techniques

Experimenters wishing to explore anticipatory processes in the real world have utilised methodologies in which technological devices occlude the vision of participants' whilst trying to maintain a state of natural performance and strict experimental control.

Day (1980) replicated Jones and Miles (1978) research, utilising a visual occlusion helmet to mask vision at the point of racket-ball contact in tennis. Subjects were positioned on the baseline facing forehand ground strokes from an opponent who was able to play strokes to any position in the singles court. Visual occlusion took the form of an electric shutter, which was triggered by a pressure switch located on the racket of the ball striking player. In keeping with laboratory research, the results indicated that skilled tennis players were able to make accurate predictions based on pre-contact cues. Furthermore, the results suggested that subjects were able to predict directional information far better than depth. Thus the increased difficulty experienced by subjects when attempting to estimate depth might not necessarily be an artefact of the use of a two dimensional display (e.g. Salmela and Fiorito, 1979; Williams and Burwitz, 1993).

Contemporary research has utilised a liquid crystal occlusion technique (Milgram, 1987) in examination of the kinematic information available to a player during stroke formation (Abernethy, 2001; see Table 2.4), and to assess skill-based differences in the utilisation of visual cues (kinematic information) in as 'natural' as setting as possible (realistic situational probability information was available) (James *et al.*, 2004).

Abernethy *et al., (*2001) conducted two experiments on the nature of expert perception in squash. The first experiment was laboratory based, participants 10 expert (from the Australian Institute of Sport unit) and 15 novice (university undergraduate students) where presented with a film task and a point light task. The film task was the same as the one utilised by Abernethy (1990a, 1990b) and consisted of a number of shots executed by two expert male squash players (World Ranked Players) and filmed from a head high position on the court, in order to replicate the viewing perspective typically experienced in squash. The participants attempted to predict the direction and force of squash strokes from either a film display, which was occluded at variable time periods before and after the opposing player had struck the ball, and matched point-light display occluded at the same time periods. Experts were shown to outperform novices at all time periods and under both display conditions (similar results were found by; Abernethy and Packer; 1989; Ward, Williams and Bennett, 2002) and lateral error was significantly greater in the point light display for both experts and novices. Furthermore, the time periods where both expert and novice performers were able to pick-up information in the film display, were maintained in the point-light display. The author's concluded that the expert's perceptual advantage is directly related to their superior pick-up of essential kinematic information (see *Section 2.3.1*)

Six expert (current or past members of the Australian Institute of Sport squash unit, or were number 1 players within the highest level of district competition) and 6 novice participants (playing in the lowest level (division D3) of a local squash competition) participated in the second experiment. All participants played simulated matches on-court against the same opponent (a player of intermediate ability between the two groups). Each participant completed a 5-minute warm up, and was then fitted with a pair of PLATO liquid crystal occlusion goggles (Milgram, 1987). The participants were then required to play a competitive squash match against the opponent. At various, quasi-random times during the match (but not every point) temporal occlusion trials were presented by activating the PLATO liquid crystal occlusion goggles. Participants were then instructed (when the view was occluded) to make an attempt to play their return stroke, but for safety play was to immediately stop after the completion of the return stroke. A minimum of 64 occlusion trials were presented to each participant, the authors attempted to ensure that the occlusions were at a range of points before and after the opposing performer's striking of the ball and with occlusion trials distributed evenly across different court positions and different stroke types executed by the opponent. Occlusions were presented most often on drive strokes hit down the wall; these strokes have been shown to be the most frequently utilised squash stroke (Hong *et al.*, 1996) as a consequence of the general strategy utilised by squash performers over the range of skill levels. The precise temporal-occlusion time, presented to each participant were determined through a trial-by-trail examination of the video record. On each trial a judgement was made whether the participant had moved to the correct side of the court (left or right) most appropriate for the direction of the opponent's stroke, and to the half of the court (front or back) most appropriate for the depth of the opponent's stroke. Mean percentage errors were collated across skill groups for each of the eleven adjacent 80ms time period. The authors concluded that simple examination of the 'descriptive data provided by the mean error rates for each skill group across the occlusion times should be used, rather than to apply inferential statistical procedures.' This was because the approach utilised by the authors, as with the laboratory setting (see also Abernethy, 1987a, 1990), meant the number of observations upon which the percentage error estimates at each total occlusion period were based, varied from participant to participant. The results indicated that when perception and action are naturally linked, and the perceptual information provided is real rather than a simulation, expert performers continue to demonstrate a superior pick-up of early information from an opponent's movement pattern (see Fig. 2.3 / Fig. 2.4).

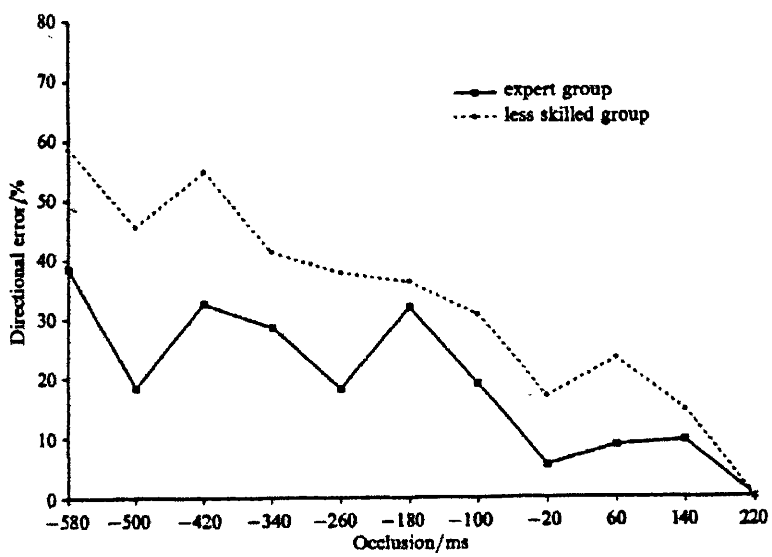

Fig. 2.3: Percentage errors in judging stroke direction as a function of time and skill groups. Occlusion times shown are the mid-points of each of the eleven 80 ms time windows used in analysis. (Abernethy *et al.*, 2001)

This pattern is consistent, regardless of occlusion condition or the specific component of stroke prediction (direction or depth) that was examined. The author's concluded 'this evidence indicates that the expertise related differences observed in early laboratory occlusion procedures are genuine ones and not simple epiphenomena arising from specific laboratory task manipulations used'.

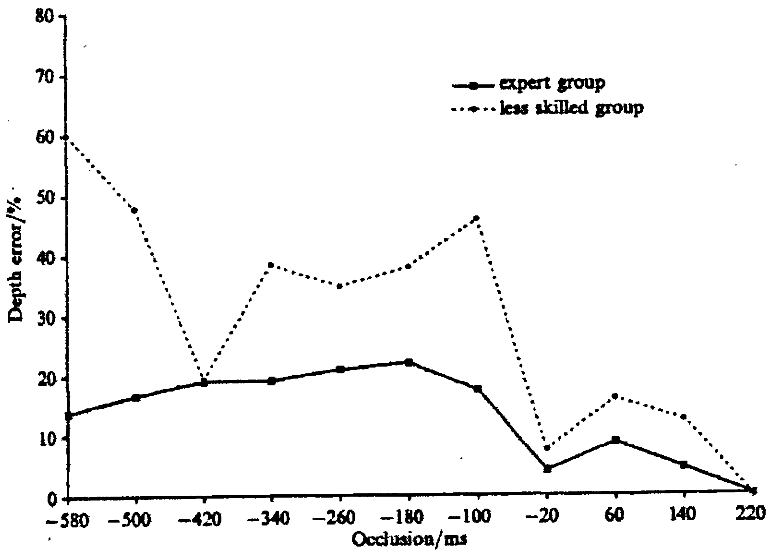

Fig. 2.4: Percentage errors in judging stroke depth as a function of time and skill groups. Occlusion times shown are the mid-points of each of the eleven 80 ms time windows used in analysis. (Abernethy *et al.,* 2001)

However, the results develop understanding by demonstrating that expert advantage in direction and depth predication is consistent well in advance (as early as 620 ms prior to racket-ball impact) of the earliest occlusion conditions investigated in laboratory occlusion studies to date. This expert advantage in predicting the direction and depth of the opponent's stroke during these advanced periods cannot purely be attributed to superior pick-up of information available within kinematics of the opponent's hitting action, because many of the temporal occlusions occur before the opponent's has commenced his/her movement pattern in order to execute the stroke. In a natural task, not all stroke options executed by the opposing player can occur with equal frequency or probability (Abernethy *et al.*, 2001).

In racket sports, the maximisation of uncertainty about a stroke, by utilisation of a range of shots with equal frequency, is countered by other strategic demands, such as maintaining a dominant position on court, or moving an opponent to create holes in their defence. Therefore accurate knowledge of stroke/event probabilities may be a potentially powerful source of information for the skilled player (Girardin and Alan, 1978). The authors concluded that the expert advantage present prior to the pick-up of kinematic information from the opposing performer's stroke is due to their superior knowledge and use of the subjective probabilities associated with each stroke option at the opposing performer's disposal. The authors' conclusions in the latter study are limited by three main factors. Firstly, all participants played simulated matches on-court against the same opponent; a player of intermediate ability between the two groups, this suggests that the participant's categorised as expert, would have been expected to outperform novices at all time periods because they were viewing a less skill performer, as such a expert-novice difference was inherent within the task construction. Secondly, shot difficulty was not controlled, suggesting that expert players were able to exert more pressure on their opponent (an intermediate player) so reducing their stroke options and increasing the likelihood of certain strokes being played; indicating, that experts may be co-utilising situational probabilities and visual cues as a base to their prediction, even when kinematic information is apparent. Finally, laboratory research has previously been criticised for subject responses not being ecologically valid by removing the subject from their natural autonomous processing and breaking the perception-action link. The present study attempts to close this link by asking the subjects to make directional movements to intercept their opponents shot. However, a squash court is relatively small and as such simple front / back, left / right directional analysis could be seen as fairly simplistic. However, it is worth noting that this would reduce the chance of participant's guessing to 25%, and as such may be an appropriate measure of anticipatory performance.

James *et al.* (2004) assessed this analysis technique by measuring directional errors (lateral / depth). The authors utilised the liquid crystal occlusion technique to evaluate expert and near-expert performer's utilisation of visual cues when realistic situational probabilities existed in simulated competitive match play. Seven national badminton players (aged 19 – 38) of matched ability, each undertook 30 recorded trials of simulated match conditions. During play one of the subjects wore a pair of adapted PLATO liquid crystal occlusion spectacles. At various quais-random intervals, the spectacles were remotely triggered to occlude participant's vision. The time period between occlusion and racket-shuttle contact was calculated using video analysis. Occluded shots were selected when the participant's opponent received high shots to the back of the court (high lifts or clears), providing three possible stroke options (clear, smash and the drop). Trials were disregarded if an unidentifiable or inconsistent stroke was made. Measurements were then taken of the participant's predicted shuttle landing position (x and y co-ordinates) to examine error discrepancies in comparison with the actual landing position. In keeping with Abernethy *et al.,* (2001) suggested temporal windows the mean direction and depth errors were calculated into 80 ms intervals (-620 to +100 ms in relation to racket-shuttle contact). The results revealed non-significant differences in participant's errors across the nine temporal periods, as a function of direction and depth (Fig. 2.5).

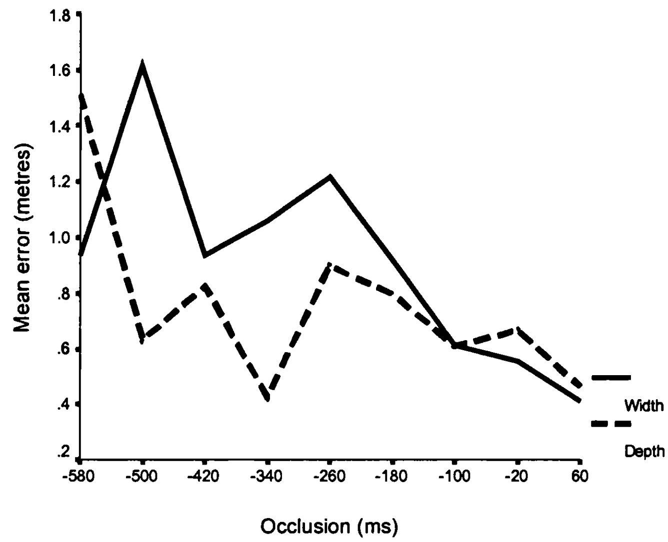

Figure 2.5: Anticipatory performances in terms of lateral and depth error as a function of occlusion time (James *et al,* 2004).

In keeping with Abernethy et al. (2001) experts and near-experts were found to be extremely accurate in prediction of shuttle landing position when presented with very limited visual information. Additionally, the results show that these elite performers were able to anticipate exact shot location (depth = 1.5 m; direction 0.95 m) when no kinematic information was present, these results are comparable to the conclusions drawn by James and Bradley (2004) and Girardin and Alan (1978) who concluded that in racquet sports the maximisation of uncertainty about a stroke, by utilisation of a range of shots with equal frequency, is countered by other strategic demands, such as maintaining a dominant position on court, or moving an opponent to create holes in their defence. Therefore accurate knowledge of stroke/event probabilities may be a potentially powerful source of information for the skilled player.

Table 2.4: Summary of field-based studies using the visual occlusion approach to examine advance cue usage in racket sports.

Study	Sports Task Examined	Participants	Methodology	Conclusions
Abernethy *et al.* (2001).	Explored the nature of expert perception and anticipation from film displays and in real-world situations.	n = 37 (16 Experts and 21 Novices).	Participants were required to judge the outcome (direction and depth) of the player's stroke from occluded film and point-light displays. In the second experiment, participants had to move in response to the stroke played by their opponent *in situ*. Prediction accuracy was based on whether the participant moved in the correct direction (left or right) and depth (front or back) of the court.	• Expert-novice difference observed. • Experts were able to significantly reduce their prediction uncertainty prior to the ball contact. • The expert advantage is directly related to their superior extraction of kinematic information leading to the stroke. • *In* situ expert prediction performance was high even where no kinematic stroke information was available. This was attributed to the experts being attuned to situational information.
James *et al.* (2004).	Evaluated the utilisation of visual cues by expert and near-expert performers when realistic event probabilities were available in badminton.	n = 7 Near-experts	During rallies, players' vision was occluded using visual occlusion spectacles. Participants had to predict the landing position of the shuttle. Anticipatory response was evaluated on the error associated with participants' prediction of the shuttles' landing position (x and y co-ordinates).	• Performers were superior at anticipating shuttle direction compared with depth. • Superior performance was linked to shot type, with anticipation being significantly poorer for the 'clear' than the shots sampled. • Response accuracy was high even when no stroke kinematics were viewed suggesting anticipatory response was based on situational probabilities.

2.5 Situational Probability / Awareness

Contemporary research in anticipation, has suggested that anticipation may not purely be based on the visual cue utilisation (Abernethy *et al.,* 2001; James and Bradley, 2004; as proposed by laboratory research). This section will discuss situational probability research, highlighting the redundancy of early research, due to the results gained from laboratory-based advance visual cue research. Then it will focus on situational probabilities as a significant component in anticipation highlighted by contemporary ecologically valid field-based research.

2.5.1 Situational Probability/Awareness in Anticipation Research

Seminal work examining the importance of situational probabilities in racket sports has been conducted by Alain and colleagues (Alain and Guardin, 1978; Alain and Proteau, 1977, 1978, 1980; Alain and Sarrazin, 1990; Alain, Lalonde and Sarrazin, 1983; Alain, Sarrazin and Lacombe, 1986). Alain and Guardin (1978) examined situational probabilities' utilisation from a reversed perspective by examining how the 'on-court' positions of players affected how subjects assigned shot probabilities. Specifically, the authors examined how racket-ball players of varying abilities, manipulated the amount of uncertainty conveyed by their shots. Subjects (A-, B-, and C-level (National French Ranking System)) were required to play in normal match conditions, which were filmed and then analysed. The amount of uncertainty conveyed by the player's shots was computed from a frequency count of the number of times that each type of shot was used when the two players were in the same positions on the court. The results indicated that the amount of uncertainty associated with each shot did not increase as a function of the skill of the player (Williams *et al.,* 1999).

Whiting (1979) suggested that this was a surprising result as experience and knowledge base increased as a function of expertise, and as such experts would be expected to adopt tactics to minimise the ability of their opponent to anticipate the forthcoming shot. Alain and Proteau (1978) suggested that this unforeseen result could be explained by the nature of Racketball; a sport in which power and speed may have the affect of making an uncertainty based attack strategy redundant. Perhaps the more common approach is to adopt a strategy of striking the ball as hard as possible in order to reduce the time available to an opponent (Williams *et al.,* 1999). However, although the research may suggest that an uncertainty approach may not be extensively utilised in Racketball, not all of the shot types carried the same probabilities; back-court shots conveyed a greater uncertainty than forecourt shots. This suggests that situational probabilities inherently play a role in Racketball, but the nature of the game is such that, during a rally the majority of players have the strategy to purely reduce opponent's interception time.

Alain and Proteau (1977) utilised a laboratory-based choice-reaction time task to examine the importance of subjective probabilities. Subjects moved in response to two stimulus lights arranged on a subjects forehand and backhand sides, a movement to either one of these sides and the action of playing a stroke in order to strike a ball suspended from the ceiling was required. The subject's reaction time and movement times were measured under varying conditions of stimulus probability ranging from 10% to 90%. The results revealed that reaction time performance was only different from when probability of events was equal was when the probability of the stimuli reached 90%. This suggests that if the attacking players have the option of presenting their opponents with one or two possible strokes, they can utilise their preferred stroke 80% of the time and the opponent would not react faster than if both shots probability was equal. These results are in keeping with Alain and Guardin's (1978) results, suggest that situational probabilities are rarely utilised in anticipation. However, the authors did recognise the inherent limitations with a laboratory choice reaction time paradigm, with the removal of the subject's natural performance settings, a response selection and time restraints.

Alain and Proteau (1978) tried to overcome these ecological validity limitations by examining the extent to which different players in racket sports utilise situational probabilities to anticipate the shots performed by their opponents in a natural situation. Squash, tennis, badminton and racket ball player's decision-making behaviours were assessed; rallies during the games were selectively filmed. After play, the subjects viewed the filmed sequences and were asked specific questions regarding shot selection during the rally. Subjects were asked to comment on the situational probabilities they had assigned to perceived stroke probabilities (each possible shot was assigned with either 10. 30, 50, 70, 90 % confidence levels).

Furthermore, the subjects were asked whether their movements while playing were guided by their anticipations based on these subjective probabilities, these reports were compared with the filmed sequences and subject's initial movement in the direction required to intercept the opponent's stroke. The results revealed that the higher the probability that a defensive player subjectively attributed to an event, the higher the portion of anticipatory movements they made. The authors concluded that these initial movements were guided by the performer's expectations with subsequent corrective or confirmatory movements being made with ever increasing amounts of contextual information. Furthermore, the authors highlighted that a threshold existed at the 70 % confidence level. Indicating that as a subject expects a certain stroke type with > 70 % certainty they begin anticipatory actions (Williams *et al*, 1999). The probability threshold presented by Alain and Proteau (1978) (70 %) is significantly lower than that presented by the laboratory work of Alain and Proteau (1977). Abernethy (1987b) provided the explanation for this as the difference between providing the subjects with objective probabilities and having subjects formulate their own based on knowledge and previous experience. Furthermore, Singer (1980) suggests that subjects see self acquired information as more significant, as opposed to external laboratory information. However, the authors themselves accounted for the discrepancy by suggesting that subjects in the laboratory task formed conservative strategies as there where no restrictions in response time (ecological validity limitation, as seen with the majority of laboratory research in advance visual cues). Consequently, it may be that subjects decided not to react quickly to the stimuli presented as an incorrect response would equal failure, as such they may well have abnormally held back their decision until more confirmatory information was present (Williams *et al.,* 1999).

The later findings of Alain and colleagues (Alain and Sarrazin, 1990; Alain *et al.,* 1986; Proteau, Levesque, Laurencelle and Girouard, 1989) supported this interpretation by demonstrating that a performer's reaction time is based on the interaction between subjective probability and the time available to complete the response. Therefore, performers are more likely to adopt a strategy of relying on situational probabilities in situations where the speed of response is paramount (Williams *et al.,* 1999).

The research conducted by Alain and colleagues, provides base evidence that players utilise situational probabilities to guide their perceptions. However, these initial experiments were inevitably methodologically floored. Dillion, Crossini and Abernethy (1989) highlighted that the conservative strategy utilised by the subjects in Alain and Proteau (1977) work was 'clearly' an artefact of using a fully between-subject design. They used a methodology to identify between group differences in reaction time. The results showed a significant increase in reaction time difference values when the probability differences reached 0.7 / 0.3.

With the advancement of research into the relationship between advanced visual cues and anticipation providing seemingly conclusive results (e.g. Abernethy and colleagues; Williams and colleagues) a redundancy of situational probability research in racket sports occurred. However, speculation towards the utilisation of situational probabilities by expert performers again grew, after the step towards ecologically valid advance visual cue research (see 2.4.2).

Table 2.5: Summary of field-based studies examining situational probability usage in racket sports.

Study	Sports Task Examined	Participants	Methodology	Conclusions
Féry and Crognier (2001).	Observed whether the tactical significance of a rally situation allowed enhanced anticipation of a stroke.	n = 7 Experts.	Participants predicted the depth of passing shots from a film display or *in situ* which was either of: High, moderate or low tactical significance. The participant's vision was occluded 100 ms following ball contact using a pair of visual occlusion spectacles. Prediction accuracy was based on correct judgement of the depth of the stroke and also the timing of the decisions (RT).	• Varying the significance of a situation did not affect the prediction accuracy of the subjects. • Consistent with other video–based studies, subjects found it hard to predict the depth of strokes.
Crognier and Féry (2002).	Observed the effect that tactical initiative (playing intention) has on the capability to anticipate the outcome of a passing shot.	N = 16 Experts.	Subjects had to try to intercept a passing stroke as normal during a rally, however, at a certain point leading up to the stroke their vision was occluded using a pair of visual occlusion spectacles. The level of tactical initiative was manipulated to three conditions: high, moderate and low tactical initiative. Prediction accuracy was based on a correct movement to the side of the court the ball was travelling to.	• It was found that as the amount of tactical initiative increased the better the predictions of the subjects became. • Players were 'expecting solutions' as they reduced their opponents playing possibilities. • It was concluded that kinematic information complemented by tactical information is advantageous in anticipation.
Crognier *et al.* (2003).	Observed whether task-specific knowledge is related to the ability to anticipate tennis shots.	n = 20 Regional level.	Participants tried to intercept a stroke from an opponent during rallies of varying tactical initiative. Additionally, during breaks in play of normal competitive matches the subjects were asked '*what were you thinking about whilst playing that point?*'	• The players that were more accurate in their anticipations were also better to verbalise their reasons for playing strokes. • The correlations between anticipation and knowledge structure only appeared in situations of high tactical initiative.

2.5.2 Contemporary Speculation on Situational Probability /Awareness

A more contemporary approach in the study of anticipatory information sources has been to explore the potential usefulness of situational probability information. It is suggested that skilled performers are able to use expectations (probabilities) of certain events occurring to aid anticipation in sport (Williams *et al.,* 1999; see Table 2.5).

Féry and Crognier (2001) observed whether the tactical significance (tactical and time-based pressures on an opponent) of a rally situation allows enhanced anticipation of the prediction of a stroke, from a film display and 'in-situ'. Expert tennis players watched a tennis situation of high, moderate and low tactical significance. High tactical significance was defined as a rally that was viewed when the defensive player moved into the net and the opponent played a passing stroke. Medium tactical significance occurred when players viewed a passing stroke played with the defensive player standing on the baseline and a low tactical significance situation was defined as when no rally occurred and the offensive player just played a passing stroke. In the 'in-situ' situations the subjects wore liquid crystal glasses. Subjects had to press a button that corresponded to a zone on which the ball was thought to have rebounded. This device was designed to establish a complete spatial correspondence between the alignment of the buttons and the alignment of the four zones the ball could rebound into. When the defensive player struck the ball, a signal was transmitted (from a pressure receptor on the racket) to the visual occlusion glasses, which enabled them to close 100 ms after the stroke. The ball then bounced on one of the four zones marked on the court, and the participants had to press on of the four buttons, that represented the on-court positions when they estimated that the ball bounced. The participants also wore a light helmet which emitted a masking noise preventing the participants from locating the balls by the sound emitted from their rebounds. The actual and estimated rebound zones, as well as the actual and estimated shot durations were recorded.

The results revealed that varying significance of a situation did not affect the spatial and temporal estimations of the subjects. Consistent with the idea that the essential anticipation information is contained in viewing the opponent's stroke movements and in the initial part of the trajectories that play a predictive role in several racket sports, such as badminton (Abernethy and Russell 1987) and squash (Abernethy, 1990a). The authors also reveal that experts seem to be able to construct a full peripheral representation of a display on the basis of very limited perceptual cues (Abernethy, 1993). However, there are several important limitations with regard to the difficulty of reproducing realistic situations in an ecologically-valid methodology.

Firstly, the contrived rally situations may not have produced the kind of temporal or spatial pressure situations that would become apparent in a normal competitive game situation. Secondly, unnatural responses were made in response to natural stimuli by the participants, and these participants viewed the field test as opposed to participating, indication of the lack of ecological validity that was inherent within the experiment and the fact that the subjects were removed from their natural sporting environment and as such decreased their perceptual abilities, and negated the comparisons made between the laboratory and 'in-situ' tasks (Abernethy, 2001).

In order to overcome the previous limitations, the same authors examined the effect that tactical initiative has on the capability of a tennis player to anticipate the outcome of a passing shot. Seventeen expert male participants played simulated on-court matches in which the level of tactical initiatives was experimentally manipulated. In the highest level of tactical initiative the defensive participant played an approach shot and ran towards the net with the intent of an offensive stroke. The participant's opponent performed a natural passing stroke. In the moderate level of tactical initiative, the participant was directly in the volley position, dropped the ball and addressed it towards their opponent, the opponent then performed a natural passing stroke. The weakest level of tactical initiative only differed from the moderate level, in the fact that the opponent just dropped a ball and addressed it as a passing shot to the defensive player in location at the net. The participants wore a pair of liquid occlusion spectacles, which were occluded at the point when the stroke preparatory movement had finished (backswing). The displacement movement (which was considered correct when the participant selected the appropriate half a court) and the target movement (radial error between the ball and the racket) were recorded, for each tactical situation eighteen trials per participant were recorded.

The results revealed that experts were able to anticipate the ball flight to a significantly higher degree in the high tactical initiative (22% incorrect displacements) compared with the moderate and weakest level of tactical initiative (45% incorrect displacements). This suggests the players utilise a situational probability strategy that minimises their opponent's stroke options.

In the most recent research to directly examine situational probabilities, Crognier *et al* (2003) continued the assessment of situation probabilities by comparing a regional level tennis player's ability to anticipate passing shots in real situations, in which the level of tactical initiative was once again manipulated, and comparing these results with the subject's task specific knowledge. The temporal occlusion paradigm followed the same protocol outlined by (Crognier and Féry, 2002), however; all participants played against the same experienced (+5/6 – French ranking system) opponent.

In the second experiment, the participants were interviewed between points during friendly tennis matches, the McPherson and Thomas (1979) verbal report paradigm. The question that was proposed to the participant's was 'what were you thinking about whilst playing that point?' The participant's knowledge was coded into units of information (concepts) and classified according to concept categories (goal, action, condition and emotion). The total number of concepts, the total number of different concepts and quality of the concepts were measured. The authors reported a significant effect for tactical initiative, the percentage of incorrect displacements was 25% in the high tactical initiative situations, whereas percentage incorrect displacements were close to 45% (a percentage indicating a randomly selected response) in the other two tactical initiative situations. However, no significant correlation was found between anticipation and knowledge score. Nonetheless, it is noteworthy that in the high level tactical initiative situation, the participant's who were better able to anticipate also generated more total concepts ($r = 0.43$) and made more links between concepts ($r = 0.53$).

The previous two studies have moved away from the laboratory settings of previous work in situational probability (Alain and Proteau, 1977; Crognier and Féry, 2001) and have tried to match subject responses to those performed in the natural game situation (an explanation proposed for the surprising results of Crognier and Féry, 2001). However, a few methodological limitations cause concern. The number of trials under taken by participants in each tactical initiative was surprisingly low (Crognier and Féry, 2002; Crognier *et al.,* 2002) and the occlusion point was subjective, thus not controlling the amount of contextual information that may have been available in each trial. However, the manipulation of the natural game to account for the three forms of tactical initiative is the most concerning factor with the research, asking the question, as to whether these contrived situations produce the same temporal and spatial pressures that are inherent in a natural competitive game. Notwithstanding the above criticisms, the field-based work of Crognier and colleagues has highlighted something referred to by the majority of authors performing contemporary research in anticipation (William *et al.,* 1999; Abernethy, 2001; James and Bradley, 2004; James *et al.,* 2004), the possible occurrence of performer utilisation of situational probabilities in anticipation in racket sports.

2.6 Chapter Summary

This review has considered the plethora of work which has examined anticipation research in racket sports. Seminal research generally employed laboratory based temporal occlusion paradigms (Abernethy and Russell, 1987a) that provided significant experimental controls. This laboratory base consistently revealed expert-novice temporal and spatial differences in the ability to utilise contextual advance visual cues (Jones and Miles, 1978; Buckolz, *et al.,* 1988; Abernethy and Russell, 1987a). However, laboratory research was plagued by ecological validity issues (Abernethy, 2001), and with the advance of new experimental techniques (e.g. Visual Occlusion Spectacles, High Speed Camera Analysis) research migrated form the laboratory to the field.

The majority of field-based research (with the exception of James and Bradley, 2004) supports and validates the previous laboratory findings. However, contemporary field based research has suggested that there may be other components to anticipation, other than contextual advance cues. Specifically, contextual advance cues, from the kinematic information from an opponent's stroke may be utilised in association with situational probabilities (McPherson, 1999; Abernethy, 2001; James and Bradley, 2004). In keeping with the research conducted directly into expert / novice differences in situational probability utilisation (Crognier and Féry, 2002) and skill-base differences in knowledge base (Crognier *et al.,* 2003) concluding that in high tactical initiative situations (when a performer is under high temporal and spatial pressures) performers utilise situational probabilities. However, field based research is not without ecological validity concerns. With the exceptions of James and Bradley (2004), who controlled for shot difficulty, and Crognier and colleagues, whose major concern was situational probabilistic information, few studies have controlled for situational probabilistic information, and as such the previous belief that subjects were merely utilising advance visual cues may be inadequate. There is a need therefore to validate previous laboratory findings by controlling for shot difficulty and situational probability information, and to assess the extent of expert / novice differences in anticipatory ability and utilisation when the latter two controls are maintained.

Chapter 3: Study 1

3.1 Introduction

3.1.1 Anticipatory Behaviour

A widely adopted methodology for exploring the anticipatory behaviour of racket-sports players, particularly the utilisation of advance cues, has been to ask them to predict the outcome of film clips of match sequences (e.g. Abernethy and Russell, 1987a). These studies have attempted to determine either the time periods at which players are able to extract relevant information to enable a prediction of shot outcome (temporal occlusion) or establish which kinematic cues are useful (spatial occlusion). Usually researchers have assessed expertise-related differences hypothesising that experts are superior to novices at using kinematic visual cues (Abernethy, 1987). Findings from an array of racket sports consistently suggest that expert performers are better at anticipating the shot direction irrespective of when the film is occluded with this superiority tending to increase the earlier the occlusion takes place (see Table 2.1 in chapter 2 for specific findings). Less agreement is evident as to specifying what visual information is useful for anticipation purposes with the racket-arm and racket orientation suggested for highly skilled players in badminton (Abernethy and Russell 1987a; Abernethy and Russell 1987b) although a similar study in squash failed to support this contention (Abernethy 1990a).

3.1.2 Participant Viewing Perspective

Although attempts have been made, previous film occlusion studies have failed to closely replicate the viewing perspective of an on-court player (e.g. Abernethy and Russell 1987a; Abernethy 1990a). However, without having a head-mounted camera recording the perspective of a player it is impossible to accurately replicate this real world view. Consequently, the question arises as to the extent to which a change of perspective affects a person's ability to utilise the visual cues in terms of anticipatory performance. Removing performers from their normal perspective potentially uncouples the hypothesised natural bond between visual cues and cognitive response and may force participants in film studies to utilise a different analytical perspective from the playing one (e.g. that of a spectator or coach watching from behind the court). If this were true, then the findings from studies using the behind the court perspective, which indicate that elite players are significantly better able to anticipate strokes on a film task than their lesser-skilled counterparts, may simply be signifying that elite players have more domain knowledge, gained from extensive playing and watching squash. However, Farrow *et al.,* (2005) recently showed that players tested using the on-court perspective, a coupled interceptive movement, produced similar responses to a behind-the-court film perspective, a simple un-coupled response. This finding suggests that previous film studies do provide evidence of the expertise-related advantage, but it is not known to what extent the game-specific expertise, shown in the actual match condition, is responsible for the advantage shown in the film studies.

3.1.3 Player selection for experimental studies

Several studies have used film clips portraying player(s) of an intermediate standard somewhere between the playing standard of the experimental participants who were experts and novices (e.g. Abernethy and Russell 1987a; 1987b; Abernethy 1990a; 1990b). The reason for selecting this intermediate standard of player may be related to maximising the chance of finding significant differences between the experimental participants. This would be due to the experts being used to playing at a higher standard than the standard portrayed on the film and thus the relatively slow speed of play would make assessing visual cues relatively easy. In comparison, the opposite would be true for the novices, who would be viewing, to them, a relatively fast paced game making visual cue recognition relatively difficult. Also the expert participants would be much more likely to have played against this level of player previously, thus potentially enabling the experts to recognise the limited abilities of the players' shot selections. If this was the case, then it is plausible that the experts recognised limited shot possibilities and were therefore able to better select the likely shot to be played without necessarily resorting to visual cue recognition. However, even if this explanation is not completely accurate it is feasible that experts can utilise probabilistic information i.e. in any particular situation one shot is more likely than another, to aid their shot selection better than novices. This difference alone could explain the novice expert differences found in previous studies meaning that in terms of visual cue usage there may be no significant difference between experts and novices at all. This would be more likely to happen if the novices in a study had no, or limited, experience of playing against the standard of player depicted in the video clip (see Renshaw and Fairweather, 2000; for a similar conclusion in cricket).

In studies where participants are assessed on court playing opponents of a different playing ability, similar problems exist for determining why experts exhibit superior anticipatory performance. In the Abernethy *et al.* (2001) study, expert (at least highest level of district) and less skilled (lowest league) squash players played matches against the same opponent who was of an intermediate standard. This scenario makes it likely that the shots played by the intermediate player were much more difficult when playing against the expert compared with when playing against the novice. Hence when the experts and novices were asked to predict where shots were going to be played to (PLATO spectacles were used to prevent vision; Milgram, 1987) the task was not of the same difficulty. For the expert player it is likely that the lower ability opponent was under pressure when playing the shot and hence may have had as few as one shot option available. Thus, even when very limited visual information was provided, the expert could have predicted where the shot was to be played simply by using his squash knowledge based on experience of similar situations. Thus, the experts may have been able to anticipate shot selections on the basis of probabilities alone and not needed to assess visual cues. The situation for the novice however, was likely to have been very different. The intermediate player in this situation may well have been playing fairly simple shots and as such would have had a relatively large array of shots to select from. Clearly then, the novice would have had a far more difficult task compared to the expert in terms of probabilistic information. This discrepancy alone may have been the reason for the expertise related difference.

The final issue regarding player selection is the number of players used in a particular study. Players may have idiosyncrasies which help or hinder visual cue usage and if small numbers of players are used then the chance of this skewing the results increases. This effect is more likely when players of less than expert level are used as experts tend to have very well refined swings and appear far more similar than lesser players do. Consequently, the findings from studies using small numbers of less than expert players in their film clips may under or over-estimate the true anticipatory ability of the subjects.

3.1.4 Situational Information

Players are likely to use situational information to select likely shot directions in conjunction with, or instead of, visual cues emanating from an opponent's swing and body position. Situational information pertains to event probabilities based on previous knowledge. For example a player may utilise knowledge of an opponent's tactical preference such as tending to play a cross court drive in response to a boast to anticipate the shot direction. This rule-based decision making i.e. IF boast THEN cross court drive, is a typical by-product of experience and is likely to account for some of the expertise related differences found in previous studies. However the extent to which these differences may be attributed to this type of decision making behaviour is impossible unless some control over the information sources is present.

Situational information may be more prevalent when players are familiar with each other as knowledge of individual player tendencies is likely to be present. However even when players are not known to each other probabilistic information may be present due to the location of the shot being played, the shot difficulty and the time into the rally or match. These factors have largely been ignored in the experimental setting although Alain and Girardin (1978) assessed the relationship between the intention to make an opponent uncertain of the intended shot and the skill level of the player. They used the frequency of shot types from eight different court positions in racketball to assess whether more skilful players exhibited a more varied shot selection. When no such relationship was found the authors concluded that experts were more concerned in playing the optimal shot for the situation as opposed to playing a wide selection of shots to increase the opponent's uncertainty. This conclusion seems sensible and would thus suggest that expert players have knowledge of the typical shots that are played in certain situations, presumably the optimal one, and this may also assist them to anticipate the intended shot direction. Indeed, previous research has shown that decision-making was significantly enhanced when situational information was made available to the participants in baseball (Paull and Glencross, 1997). However, in light of this observation, it is surprising that many previous studies have not adequately allowed for participant's utilisation of these situational probabilities. For example, Abernethy (1990a) showed participants a selection of four different shots from different areas of the court to increase the ecological validity of the study. However since the frequency of each shot from each position was not in a similar proportion to that normally exhibited in a real match between players of this standard it may be argued that this non-realistic distribution of shots prevented the participants from utilising the situational probability information they normally would have used. This is because players are likely to recognise specific shot distribution patterns as well as slightly unusual emerging patterns of shots as they develop during matches. For example, when an inferior player plays against a superior opponent the expectation is that the superior player would play certain shots in particular situations based on previous experience regarding the optimal shot to be played. However, the superior player may play other shots in these situations due to the higher skill level allowing some variation in strategy, which would probably surprise the inferior player as the shot wouldn't conform to previous experiences and expectations. However, it is then likely that this experience of playing against this new shot selection would diminish the unfamiliarity maybe to the extent that the pattern would become familiar. It is thus argued here that utilising a realistic and perhaps familiar pattern of shots to experimental participants with knowledge of the racket sport would increase the likelihood of the utilisation of situational probabilities to anticipate shot directions. Hence the shot distributions used in this study will follow shot distribution patterns found through notational analysis studies of elite squash (Hughes and Robertson, 1998).

This experiment attempts to validate previous laboratory based visual occlusion studies by controlling for player selection and situational information as it is felt that these were potentially confounding variables in most previous studies. This will enable an assessment of whether a film occlusion approach can effectively discriminate anticipation ability in squash. The temporally occluded film footage was compiled from a television recording of the final of the 2004 Swedish Open involving two highly ranked players (both top 20 in the world). These players were of superior ability to all of the participants in this study meaning that the task would have been difficult for all participants although the senior elite players would have had limited experience of playing against this standard of player, although none had actually played either player in the film. The task was also designed to control for situational information. This was achieved by including all previous strokes in the rally as well as ensuring that both players' positions on the court were viewable. This meant that all situational information from the rally situation was available to the participants. There was a possibility that some of the participants had more knowledge of the players in the film than the others, due to them having watched or heard about the players, but this was thought unlikely to have been of material benefit to them as the players in the film were of such a high standard and did not have idiosyncratic techniques. The rallies shown to the participants were carefully selected to present a selection of both 'hard' and 'easy' occluded shots, for which they had to predict the outcome.

It was hypothesised that in hard shot situations, where the shot options available to the player were restricted due to the shot difficulty, the participants would be able to anticipate the shot outcome using the situational information related to court position and the player's proximity to the ball as well as visual cue information related to the player's swing characteristics. In the easy shot situations, however, the player would have more shot options available, thus making shot prediction more difficult for the participants as situational information would be reduced. In this situation it was hypothesised that if participants were able to discriminate shot outcomes it was more likely to be as a result of utilising visual cue information. However if participants were unable to discriminate any visual information regarding the player's swing and proximity to the ball then situational information related to court positions would be relied upon.

3.2 Method

3.2.1 Pilot testing

Pilot testing was undertaken to ascertain the correct procedures used in the study. The methods and results of this testing is shown in Appendix 3.1.

3.2.2 Participants

Eight senior elite squash players (males n = 8) aged 18 – 40 years (M ± SD: 26.13 ± 7.49), eight junior elite players (males n = 7, females n = 1) aged 12 – 18 years (M ± SD: 15.25 ± 2.05) and ten senior club players (all males) aged 25 – 60 (M ± SD: 38.20 ± 14.86) participated in the study. The senior elite players were internationally ranked, although outside the top 100 in the world, the junior elite players were nationally ranked with respect to their age group. Members of both groups were primarily recruited from the Welsh Institute of Sport, Squash unit. The senior club players were drawn from a gallery of players at a national squash tournament and had mean playing experience of 21.4 years (SD = 8.3). These skilled based groupings were carefully considered to ensure a similar task difficulty for all participant groups, with the players in the film clips of a much higher standard than any of the participants. Renshaw and Fairweather (2000) indicated that experience of seeing and playing against a particular type of shot was necessary to enable sufficient visual discrimination of early cues to make anticipatory performance possible. It was thus hypothesised that the participants would be unlikely to be able to discriminate the early visual cues, likely to emanate from the movement taking place at the time of the racket swing. Informed consent was gained from the participants prior to the experiment taking place

3.2.2 Task Construction

The film task consisted of a collection of strokes recorded from Sky Sports television coverage of the final of the Swedish Open 2004. The viewing perspective was taken from an elevated position behind-the-court (a common TV and viewing perspective). The strokes were executed by two male squash players (ranked ninth and eleventh in the world at the time of filming).

Forty unique clips were shown to the participants with each being occluded at either the point of racket-ball contact (n = 20) or at four frames (-160ms) prior to this contact (which approximately coincides with the top to the backswing of the player). Additionally, clips were categorised by three level 5 squash coaches as portraying occluded shots that were either easy (n = 20) or hard (n = 20). Easy shots were defined as situations where all shot options were potentially available. These shots involved the racket ball contact taking place away from the wall and the player not being under undue time pressure to make the shot i.e. not overly stretching. Hard shots, on the other hand, involved situations where not all shot options were available. This was due to increased shot difficulty due to either the proximity of the ball or time pressure. Hence the shot was hard if the racket ball contact occurred on or very close to the wall such that the wall influenced the shot options, the ball was behind the player or the player had been forced to over stretch. The clips were collated using Adobe™ Premiere 6.0 computer software. Each clip was presented with all the strokes in the rally sequence up to the point of occlusion being seen. The selection of clips was carefully arranged so that the frequency of shot outcomes from each quadrant of the court closely matched the frequency of shot outcomes found via a notation analysis of elite squash (Hughes and Robertson, 1998). The final task was projected on to a 1.00 x 1.50m screen using an Epson PowerLite 820p Projector operating at standard projection speed.

3.2.3 Procedure

Participants viewed each clip twice with a two second gap dividing them. This was done so that they could familiarise themselves with where the point of occlusion was made in the first viewing. The second viewing would then allow them to focus on the occluded stroke and pick out the useful information to predict the stroke. Following the second viewing the film was paused to allow the participants to respond in two ways. First, participants indicated the region of the court (choice of four quadrants) that they perceived that the ball would have landed following the occluded shot (quadrant shot response). Quadrants were chosen because squash shots are typically played towards the corners of the court, as this maximises the distance an opponent needs to run. Secondly, participants indicated the quadrant of the court where they thought the most tactically sound shot (given the rally situation) would have been played to. This was described to the participants as the stroke that a coach would typically recommend to a player in this situation i.e. the "ideal" shot. It was thus suggested to the participants that these tactically sound responses would be based upon the location of the opponent and the ball rather than other factors such as the player not getting into position correctly and thus limiting the shot possibility. Each of the responses were indicated on a schematic of a squash court and participants were free to answer with the same quadrant as their initial response.

3.2.4 Analysis of data

Normality of the data was assessed using Kolmogorov-Smirnov and Shapiro-Wilks tests. Further, descriptive measures of skewness and kurtosis were also inspected. To find whether the data was spherical, Mauchly's Test of Sphericity was inspected and where necessary a Greenhouse-Geisser correction used. An *a priori* alpha level was set at 0.05. Responses were deemed correct when the quadrant that the participant perceived the ball would land was the actual quadrant where the shot had been played to. Responses were sub-divided according to the occlusion period and the difficulty of the stroke for each skill level. Differences were assessed by mixed model analyses of variance (participant skill level was the between subjects factor and occlusion type and shot type the within subjects factors). When significant interactions were found simple main effects (SME) analyses were conducted. Also when interactions narrowly failed to reach significance exploratory SME's were also carried out. To assess the extent to which the participants were guided by situational probability information (as opposed to visual cues emanating from the player) both shot responses and tactically sound responses were collated according to the quadrants that the occluded shots had been played from. This enabled the frequencies of all responses to be compared with known distributions of shot outcomes (based on notational analysis findings).

3.3 Results

The quadrant selection task used in this study meant that if participants were unable to select what they thought was the correct quadrant they were able to guess. This is a feature of this type of task and hence some uncertainty always exists in regard to participants' accuracy. Whilst the true extent of chance cannot be ascertained with any certainty some calculations can offer an imprecise guide to participant accuracy (Table 3.1). It can by hypothesised that if a participant did not know any of the correct quadrants he could have guessed on each of the tasks and with a 1 in 4 chance of success he was likely to have had 2.5 correct responses out of 10. As Table 3.1 shows the element of chance is likely to increase the total score of a participant but as more correct responses are made this chance element diminishes. For example, a participant who knew 2 correct quadrants would have guessed on 8 shots, had a chance likelihood of getting 2 out of the 8 and thus achieved a total score of 4.

Table 3.1: Analysis of quadrant responses factoring in a chance element for 1 to 10 tasks.

Correct	Guess	Number correct by chance alone	***Total score***
0	10	2.5	2.5
1	9	2.25	3.25
2	8	2	4
3	7	1.75	4.75
4	6	1.5	5.5
5	5	1.25	6.25
6	4	1	7
7	3	0.75	7.75
8	2	0.5	8.5
9	1	0.25	**9.25**

The Senior Elite (SE) participants had a mean correct quadrant response of 55.31% (SD = 6.7%) suggesting that they made on average at least 4 correct responses. Similarly the Junior Elite (JE) made on average 49.38% (SD = 6.8%) and the Senior Club (SC) an average of 38.50% (SD = 7.6%) correct quadrant responses which equated to an average of at least 3.5 and 2 correct responses respectively.

3.3.1 Occlusion period and shot difficulty effects

The three different standards of squash player differed significantly in their shot quadrant responses with the degree of correctness (SE mean = 55.31% (SD = 6.7%), JE mean = 49.38% (SD = 6.8%), SC mean = 38.50% (SD = 7.6%) mirroring their level of expertise ($F_{2,\,23}$ = 13.01, $p < .001$, Appendix 3.2). There was also a main effect for shot difficulty ($F_{1,\,23}$ = 11.23, $p < .01$) with less success found for easy shots (mean = 4.34) compared to hard shots (mean = 5.21). However, non-significant interactions were also apparent for the standard of player with shot difficulty ($F_{2,\,23}$ = 2.599, $p = .096$) and with the period of occlusion ($F_{2,\,23}$ = 3.212, $p = .059$).

To investigate the non-significant interactions simple main effects analyses were carried out. The first analysis revealed that a highly significant difference existed between the three standards of squash player for hard shots ($F_{2,23}$ = 12.71, $p < .001$, Appendix 3.3) where the elite players (SE and JE) performed at similar levels, which was significantly better than the SC players (Figure 3.1).

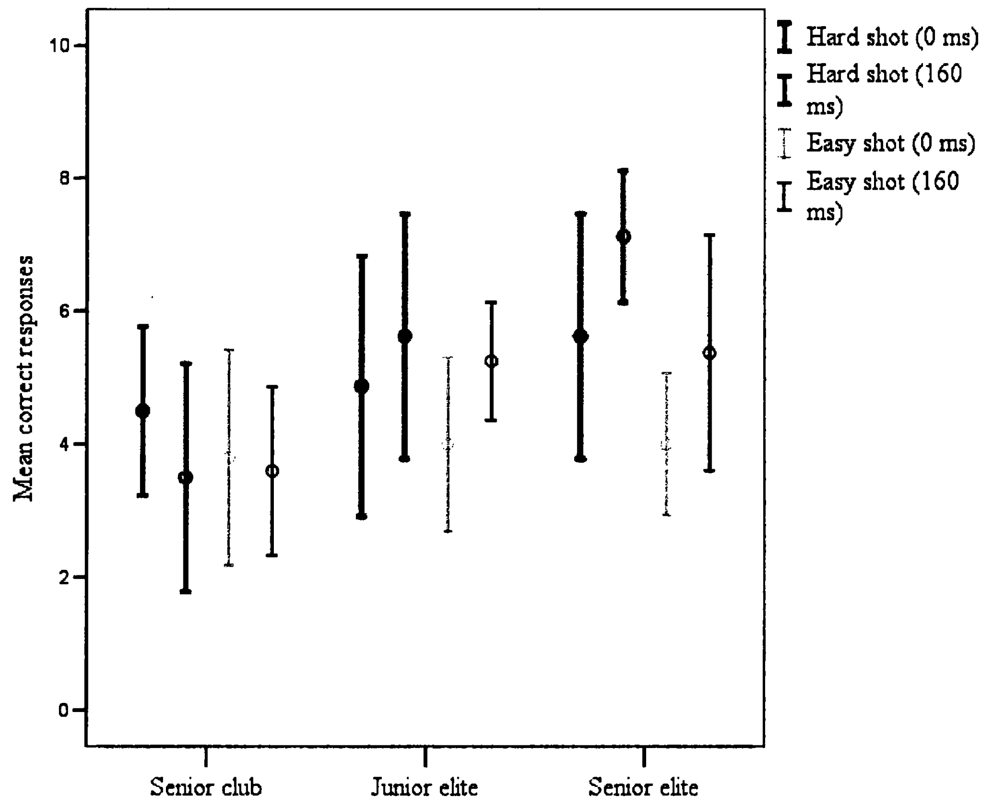

Figure 3.1: Mean correct responses (error bar represents one standard deviation) for the three standards of squash player.

There was no significant difference between the three standards of squash player for easy shots ($F_{2,23} = 3.17$, $p = .061$). When comparing the difference between successful response between easy and hard shots it was found that no significant differences were evident except for SE players who performed significantly better on those that were categorised as hard ($F_{1,23} = 13.12$, $p < .001$, Appendix 3.4).

Simple main effects analyses also revealed that the elite players (SE and JE) performed at similar levels, which was significantly better than the SC players for clips occluded at 160ms only ($F_{2,23} = 16.82$, $p < .001$, Appendix 3.4). Furthermore, only the SE players performed differently on clips occluded at 160ms compared to 0ms having significantly better performance on those occluded at 160ms ($F_{1,23} = 5.03$, $p < .05$).

3.3.2 Situational Probabilities and Expertise.

When participants correctly identified the shot quadrant it cannot be ascertained whether this response was as a result of using visual cues, situational probabilities or a combination of both. They may also have simply used guessing or guessing to some degree. However when participants were incorrect whatever technique they applied had clearly not worked. It was therefore decided to analyse incorrect responses to see if any pattern emerged that may shed light on the processes used to make a shot response. Figures 3.2 – 3.5 displays the percentage frequency of participants' incorrect shot quadrant responses, according to the quadrant where the shot was to have been played from (shaded quadrant on each Figure).

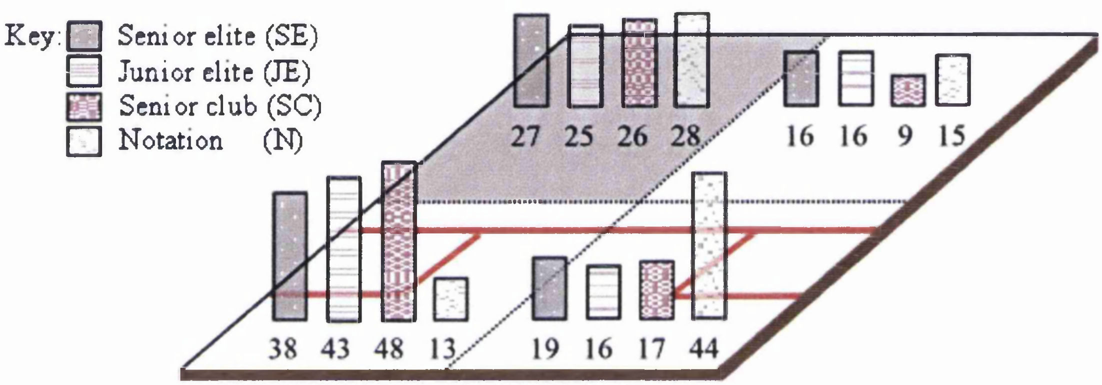

Fig 3.2: Percentage frequency of shot placements from the front left quadrant

Alongside participant responses the expected frequency of shot quadrant outcomes are displayed (labelled notation) based on a notational analysis of elite matches (Hughes and Robertson, 1998). These values were also used when selecting the clips for the task and hence the total of correct quadrant responses closely mirrored the proportions displayed as notation. It was hypothesised that if participant quadrant responses matched the frequencies obtained from the notational analysis then participants were using their knowledge of situational probabilities to assist their response selection to some extent.

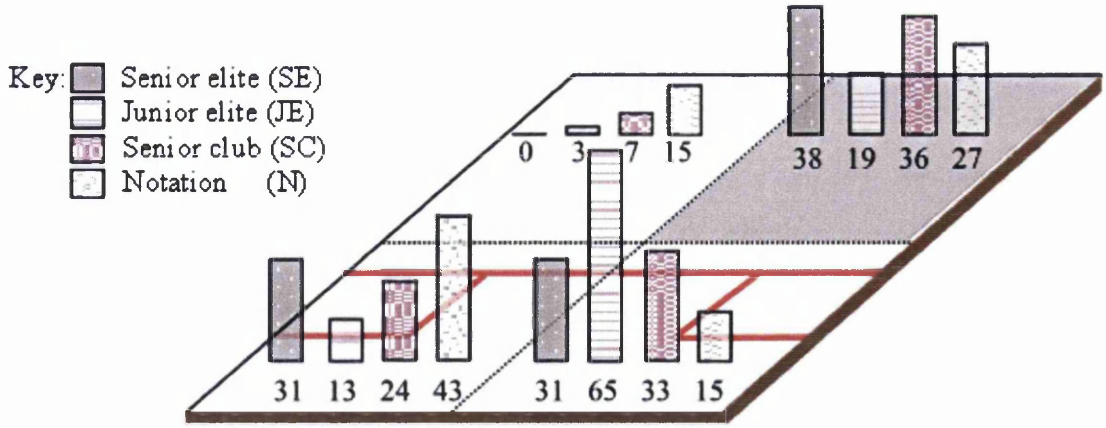

Fig 3.3: Percentage frequency of shot placements from the front right quadrant

The notation analysis for shots played from the front two quadrants (Figs 3.2 and 3.3) suggest that elite players tend to play a similar pattern of shots from the two quadrants i.e. about 70% of shots are straight drop shots (finishing in the same quadrant) or crosscourt to the back of the court (lobs or drives). Apparently elite players seldom play the straight drive (13% and 15% according to Hughes and Robertson, Figs 3.2 and 3.3) or the cross court drop from these positions. The pattern of participant responses when incorrect however did not mirror the notation frequencies but rather showed a tendency for participants to predict 70% of shots to be straight from the front (Figs 3.2 and 3.3).

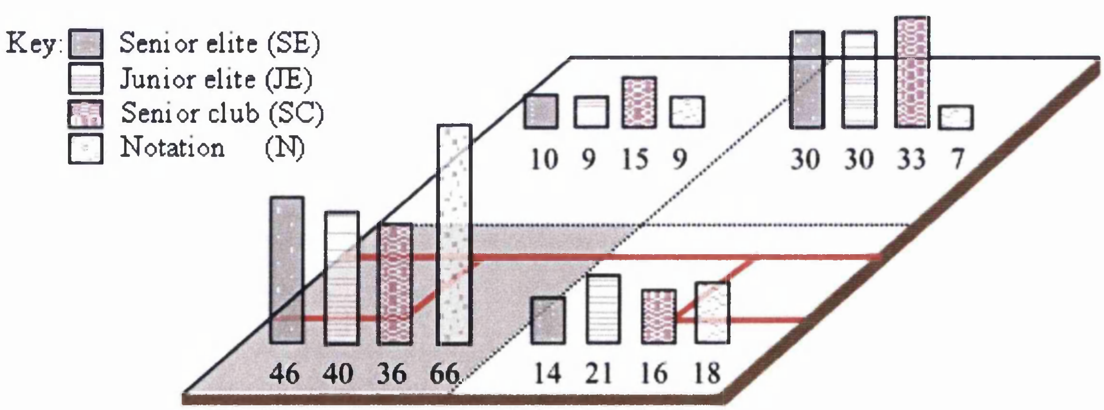

Fig 3.4: Percentage frequency of shot placements from the back left quadrant

A similar pattern occurred for shots played from the back of the court although there were larger differences between sides for the notation. In this instance the notation showed that elite players tend to play the ball back to the same quadrant more than any other quadrant (Figs 3.4 and 3.5) with this tendency greater on the left (typically backhand) side. The pattern of participant responses when incorrect was similar to the notation pattern except that all three standards of squash player tended to over predict the boast or cross court drop shot which would land in the opposite front quadrant at the expense of straight shots.

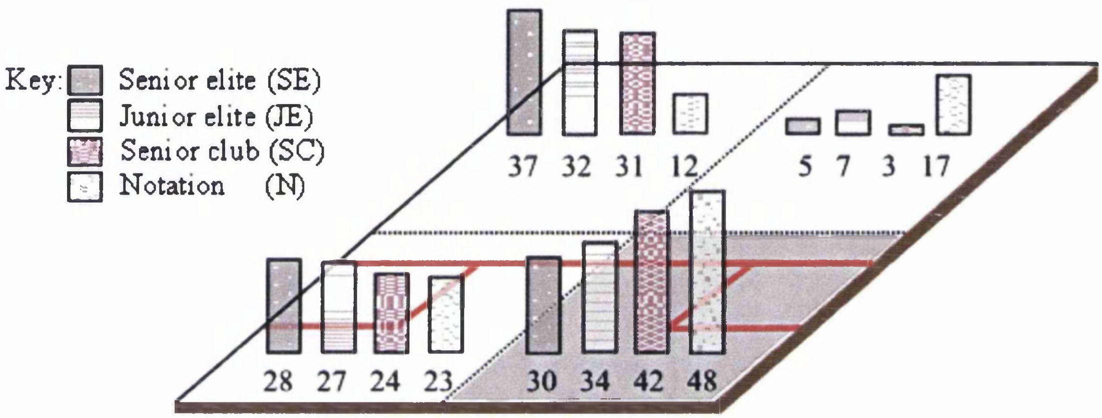

Fig 3.5: Percentage frequency of shot placements from the back right quadrant

To further examine how shot quadrant estimates were derived a secondary response was required of the participants, which was to indicate what they thought was the most ‘tactically sound’ stroke that the player should have played in that situation. This was described to the participants as the stroke that a coach would typically recommend to a player in this situation. It was hypothesised that these tactically sound responses would be based upon the location of the opponent and the ball since the ideal shot was being sought rather than the one which may have been played due to other factors such as the player not getting into position correctly. If the participants’ responses to where the shot was played to was different from this tactically sound response then it was hypothesised that this was as a result of the participants seeing something (visual cues) that enabled them to discriminate a different shot than otherwise predicted based on situational probabilities (ball and opponent positions) alone.

The agreement between quadrant and tactically sound responses tended to increase according to the expertise of the player (Table 3.2) with senior elite players giving the same response 69.69% of the time although this agreement was much higher for clips occluded at 160ms (75.00%) compared to clips occluded at racket ball contact (64.38%). The agreement levels for each standard of player reflected the degree of accuracy in the quadrant selection task (SE mean = 55.31% JE mean = 49.38% and SC mean = 38.50%). Hence it appears that the players were more often able to discern the best shot that should have been played in a given situation (which tended to be the one that the player in the clip chose) but on some occasions chose an alternative shot and hence were incorrect in their quadrant selection. The statement is supported by the fact that when the players did not chose the correct quadrant they were unlikely to give their tactically sound response as their quadrant response (agreement levels between 27.78% and 32.75%, Table 3.2) and in this situation their tactically sound response tended to be correct (between 64.94% and 74.29% correct, Table 3.2).

Table 3.2: The agreement between tactically sound and quadrant responses for the three standards of squash player.

	Senior Elite	Junior Elite	***Senior Club***
Agreement between quadrant response and tactically sound response for clips occluded at racket ball contact	64.38%	59.44%	57.50%
Agreement between quadrant response and tactically sound response for clips occluded at 160ms	75.00%	63.89%	58.00%
Agreement between quadrant response and tactically sound response only for clips where quadrant response was incorrect	29.06%	27.78%	32.75%
The correctness of tactically sound response for clips where quadrant response was incorrect	74.29%	67.40%	64.94%

3.4 Discussion

Each of the three different standards of squash player in this study identified more correct quadrants than would have been expected due to chance alone with increased performance in line with the expertise level of the participant. This supports the findings from previous film occlusion studies (Abernethy 1990a; Abernethy *et al.*, 2001) that have shown expertise related differences in anticipatory behaviour. Taking chance factors into consideration it would seem that the senior elite players could on average identify approximately twice as many correct quadrants as the senior club players. Since this expertise advantage was likely to have been diminished by the nature of the task i.e. de-coupled film task, the conclusion that the discrimination of shot outcomes is related to expertise is supported. However this finding does not shed light on the processes used by the experts to gain this advantage.

When the participants' responses were assessed for different shot difficulties and occlusion periods more subtle differences emerged. This analysis of correct quadrant responses suggested that the general expertise effect was only convincing for hard shots as performance on easy shots appeared similar between expertise groups and at a significantly lower level than that by both groups of elite players for the hard shots. This finding was in line with the prediction that the easy shots would be very difficult to predict since the player making the shot had all shot options available. In contrast, the hard shot, by definition having limited shot options, was therefore easier to predict. The fact that the expertise related advantage was more limited for easy shots, and at a relatively low success rate, suggests that the task of discriminating quadrant outcomes for these shots was difficult, even for the most elite players. This was, however, not too surprising given that the players in the film clips were of a much higher standard than any of the participants.

Renshaw and Fairweather (2000) showed that in cricket, when batsmen were exposed to types of bowling deliveries they had not experienced before their performance was much lower than comparable batsmen who had played against these deliveries before. Renshaw and Fairweather thought that the reason for this difference was that experience of seeing and playing against a particular type of spin bowling delivery was necessary to enable visual discrimination of the early cues emanating from the bowler's body that enable anticipatory performance. This may have been true also for this study. Since all of the participants were of a lower playing standard than the players in the film clips they may have had no or little experience playing against the standard of players in the clips. However, whilst this would explain the comparable low performance on the easy shot clips it does not explain why the experts were able to outperform the lower expertise groups on the hard shots.

It was hypothesised that the easy shot situations in this study would require a visual discrimination of early postural cues since situational information would be limited due to them having unlimited shot possibilities. However the low performance for all participants suggests that visual discrimination of early postural cues does not seem to have happened to any great extent for the easy shot situations. On the hard shot task it was hypothesised that more situational information would have been available since the shot options were limited. It is possible therefore, that it was this situational information that the expert participants were able to utilise to produce their elevated performance, leading to the supposition that the visual cue information available for these shots was also not utilised to any great extent for identification of the shot outcome. Consequently, an explanation for the expertise difference seen for hard and not easy shots is that the experts in this study were more able to utilise the situational information when available during the hard shots and when not available to the same extent during the easy shots could not use the visual cues available any better than the lower expertise groups. This explanation is in line with Renshaw and Fairweather's (2000) contention that not having played against this standard of opposition previously would prevent effective use of the visual cues.

It is contended, therefore, that none of the three different expertise groups could effectively utilise the visual cues related to the player's swing characteristics. Whilst this statement cannot be substantiated at this point in time there are a number of plausible explanations that support this contention. Firstly, the players viewed in the film clips were world class and were likely to have had very difficult to interpret swing characteristics. As James and Bradley (2004) found, visual cues relating to shot outcomes were not present until very late (approximately 70ms before ball contact) for the swing sequence of a player in the top 10 in the world. If this was the case for the players in this study then half of all clips did not contain the important visual information necessary to make anticipatory discriminations as they were occluded at

160ms before ball contact. In further support of the situational information hypothesis the results in fact showed that the elite participants only performed significantly better than the senior club players on the clips occluded at 160ms i.e. clips where the potentially important visual cue information had been occluded and no significant difference existed for the clips occluded at racket ball contact i.e. clips where visual cue information was present.

It was also found that the senior elite players performed significantly better on clips occluded at 160ms compared to at racket ball contact. This does not make sense if the classical explanation of more and more information becoming available as the time to racket ball contact decreases is the comprehensive explanation for anticipatory performance. In this account of anticipatory behaviour, performance would only be expected to improve as more information is provided. How can a performance decrease be explained? One explanation for the decrease found in the elite participants' performance on clips occluded at racket ball contact compared to 160ms prior to this contact could be the ability of the elite players in the film clips to utilise disguise and deception. This would be expected of elite players as it is quite conceivable that they would be trying to prevent their opponents anticipating their intentions. If this was occurring then it is possible that the visual information available to the participants during the 160ms prior to the racket ball contact was actually not very useful to the participants and consequently served to confuse the senior elite participants. It makes sense that this effect only occurred for the senior elite participants if the lower expertise participants could not utilise the visual cues to the extent that any deceptive element in these cues was not perceived.

Support for the contention that the senior elite participants were deceived by the visual cues available in the 160ms prior to racket ball contact comes from the analysis of participants' secondary responses. This response was the shot that participants thought was the tactically sound shot in each situation and was likely to match the actual shot played if the player in the film clip played the best shot in the given situation, as Alain and Girardin (1978) found to be the case. It was found that the senior elite players were more likely to give different responses between where they thought the ball had been played to (their correct quadrant response) and where they thought the best shot in the given situation would have been played to (the tactically sound response) on the clips occluded at racket ball contact. In other words once they had seen the visual information during the 160ms prior to the racket ball contact they were more likely to offer different responses than when they had not seen this information. This suggests that they were using the visual information seen during this time period, possibly to confirm or reject hypotheses formed from predominantly situational information sources occurring previously. If only the senior elite players were able to make any sense of this visual information then it would be expected that only these participants would change their opinions which is what was found as both junior elite and senior club participants had similar agreement rates for clips occluded at the two different time points.

The explanation of the use of visual cues in this study appears to suggest that in this situation these cues were either not useful at all (junior elite and senior club participants) or useful but contradictory (senior elite participants), see McPherson (1999) for an alternative view on the relationship between visual cues and situational information in tennis. Therefore the better than chance performance by all participants is suggested to be largely down to the use of situational information regarding players' position on court and known shot distribution frequencies in these situations. Thus domain knowledge, accumulated through playing squash could have enabled this decision making process. However the significant expertise effect for hard shots, where situational information was thought to be greatest, suggests that domain knowledge of situational probabilities is related to the level of squash experienced and not just the number of year's experience.

If participants were predominantly using domain knowledge regarding players' position on court and known shot distribution frequencies then it would be reasonable to expect the overall pattern of participant responses to closely match the participants' expectations of shot distributions. Of course if the participants had largely been correct in their answers their answers would have matched the typical shot distributions reported in notational analysis research (Hughes and Robertson 1998) as the clips had been selected to reflect this pattern. Hence only erroneous participant responses were examined to see if a recognisable pattern existed that suggested the use of known shot distribution frequencies. This analysis suggested that participant responses conformed to some extent to the shot distribution found by

Hughes and Robertson (1998) although some differences existed. All participants responded to the front quadrant shots with more straight drive responses (back quadrant on the same side of the court) than would be expected if they were using situational probabilities to guide their responses. However this anomaly is not that surprising if one considers that elite players tend to play more straight shots than crosscourt although notational analysis results suggest this is only the case for back of the court shots (Hughes and Robertson, 1998). It is reasonable, therefore, to suppose that if a participant was using situational information to guide their response, based on the assumption that elite players tend to play straight more than crosscourt, then their responses would be as we found.

Participants responded to the back quadrant shots with more crosscourt responses to the front quadrant (boasts or crosscourt drop shots) than would be expected if they were using situational probabilities to guide their responses. The boast is either played as an attacking shot (pushing the opponent forward) or as a defensive shot when the ball has gone behind the player and there is no option but to play this shot. It is possible therefore that the participants underestimated the ability of the players in the film clips and thought that they had to play a defensive boast because of the ball location. However elite players such as these can still play straight shots when lesser players would have had to play the boast. Whilst this explanation is rather speculative the fact that all of the participants responded similarly is supportive of the argument that similar thought processes were used by all participants.

The main conclusion of this study is that participants are thought to have used situational information to a much greater extent than visual cues although to some extent this was expected given the greater expertise of the players being viewed. The expertise level of the participants only influenced their ability to determine where shots were to be played when shots were classified as hard. Since hard and easy shots were differentiated in this study by the amount of useful situational information contained within them, this finding was thought to show that it was the elite participants' ability to utilise situational information that defined their expertise level. However, the fact that this was a film study prevents firm conclusions regarding actual usage of visual cues and situational information in actual match play. A number of factors therefore need to be considered to determine the extent to which the findings from this study transfer to the real world task.

Participants viewed squash action via a perspective set back from behind the court. This meant that the subtle changes in a player's stroke kinematics (especially occurring around wrist according to James and Bradley, 2004) occurring just prior to racket-ball contact may have been concealed. This alone may be responsible for the apparent lack of ability to utilise visual cues in this study. However, whilst Farrow, Abernethy and Jackson (2005) showed similar responses for a coupled interceptive movement (players tested using the on-court perspective) and a behind the court film perspective (simple un-coupled response) it remains questionable whether participants in film studies utilise the same anticipatory responses as they use in the real world. For example the artificial response of selecting the correct quadrant may disrupt this response sufficiently to render conclusions worthless. As long as there are no answers to this question, the film occlusion technique cannot be proposed as the best method for determining the underlying processes of anticipation. Current understanding of anticipatory responses would suggest that only methodologies that assess real world tasks can hope to determine these underlying processes.

This study attempted more than to simply show an expertise related difference in anticipatory behaviour. The film task was constructed to depict a snapshot of world class squash match play that was to some extent representative of the pattern of play rather than just a selection of rallies chosen without such consideration. Players for the film task were selected to minimise the likelihood of an expertise related advantage, as they were of a higher standard than the participants who viewed them, but this did not prevent such an advantage occurring. In-depth analyses suggested prevalence towards using situational information but this need to be confirmed or refuted by real world studies. Future studies also need to consider how different shots and situations can affect the availability of anticipatory information and try to determine the time frames in which such information can be accessed.

Chapter 4 – Studies 2a and b

4.1 Introduction

Study 1 evaluated a laboratory-based film occlusion technique (see also Abernethy, 1987a (badminton); Abernethy, 1990a (Squash); Farrow and Abernethy, 2003(tennis)) to see if an expert-novice difference in anticipatory behaviour could be discriminated. A secondary aim was to try to discriminate the sources of information the participants utilised to base their decisions. The results of the study suggested that anticipatory behaviour is dependent on a number of factors, of which shot difficulty was shown to be critical for discriminating levels of expertise. Visual cues were thought to be difficult to interpret in study 1 because of the skill level of the players in the film clips. Hence it was hypothesised that it was the situational information present in the hard shots that discriminated the senior elite players from the others and since this information was not present in the easy shots no expertise discrimination was found for these shots. It was however concluded that the film occlusion task may have contributed to the extent to which situational information was thought to have been used because the film was recorded from a viewpoint behind the back of the court that may have hidden vital cues. Furthermore, film studies break the hypothesised perception action coupling which leads to uncertainty for all conclusions made (see Abernethy *et al.*, 2001; Williams *et al.,* 1999; for discussions on this point). Consequently, study 1 suggested the need for real world studies to assess how different shot situations can affect the availability of anticipatory information and also try to determine the time frames in which such information can be accessed.

The majority of previous real world studies assessing expert-novice differences in anticipatory behaviour have endeavoured to provide support for an expertise related difference but have typically been limited by similar methodological concerns apparent in the majority of laboratory research (see Abernethy *et al.*, 2001; Table 2.4 in Chapter 2). Of major concern is the failure to consider the interaction between situational information and visual cues (see Crognier *et al.,* 2003; for an example that does consider this interaction). Also of concern is the fact that these studies have consistently failed to identify how they have discriminated different situations in matches and how this has determined the sampling of rallies. For example, if the sampling technique only selected relatively easy anticipatory tasks, based on situational information, then the results would not be representative of actual match performance. Thus it is possible that previous studies have found greater or lesser levels of anticipatory performance, perhaps using different types of anticipatory information, as a result of sampling issues (see Williams *et al.,* 1999; for discussion on similar issues).

To highlight the difficulty in correct sampling it is necessary to consider how much variation exists between shots. The following example describes how a situation can rapidly change, even within a single rally, highlighting the different sources of anticipatory information possible.

Consider a rally played between two players ranked in the top 100 in the world. Player A plays a straight drive (forehand side) from the front of the court. Player B volleys a return straight to the back of the court. The ball hits the front wall and travels down the side wall such that it is always touching the wall (referred to as 'tight' in squash terms). Player A, recognising the difficulty he is in, runs to the back of the court so that he may return the ball. Due to the time constraints imposed by the situation he runs directly to the back of the court and consequently arrives in a position which, compared to the ideal situation, is a little too close to the side wall. The consequence of this is that he is limited in the shot that he can play. However given the situation of the ball being tight to the side wall the best shot option is the straight drive. This is because a boast is impossible and the crosscourt shot extremely difficult and tactically inadvisable. Thus player A, about to hit the ball, is probably thinking that he must hit a straight drive given the ball trajectory and player B is probably thinking the same and so positions himself to potentially intercept player A's shot. However as the ball reaches the back wall it hits the join between the side and back walls (all joins between walls are known as the 'nick' in squash) and instead of returning on the anticipated path i.e. back along the side wall, its path alters to 45 degrees to the side and back walls. The point of impact with the nick occurred approximately 60 ms before the point of contact between racket and ball. Player A, at the moment the ball hit the nick, had already positioned his racket at the top of the backswing (there is usually a pause in the swing at this point in expert players) and is waiting to hit the ball. Since he arrived a little close to the side wall the unexpected (although previous experiences of this phenomenon probably allows some expectancy formulation) change in path of the ball resulted in him being far to close to the ball to play a natural shot. He thus flexes his wrist to rapidly adjust the racket head to enable a crosscourt shot to be played. The consequence of the very late ball direction change thus meant that the opponent's anticipatory behavior was incorrect (he was anticipating a straight drive but a crosscourt drive was played). Thus whilst the unfolding visual information was consistent with a straight drive up until about 60 ms before contact this turned out to be incorrect. This, fairly unusual, event is a good example of how late information, the ball hitting the nick, can render previous information incorrect. Obviously if a film clip was occluded just prior to this event then the participants would not be responding to a fair question. The late wrist movement described in the example was seen many times in the James and Bradley (2004) study of one expert squash player. This player used this wrist movement as a mechanism for disguising his intentions. Potentially then, it may be quite common for visual cues available during a shot sequence to be ambiguous or even misleading right up until very soon before ball contact (70ms in the James and Bradley study). It is contended that, at least for some expert players, the ability to utilise wrist movements at the last moments of the swing, probably only for relatively easy shots, that makes information proceeding this event unreliable. Given this scenario it may also mean that expert squash players have learnt to disregard early visual information in some situations as they know it to be unreliable.

The aim of the next two studies (2a and 2b) is two asses the validity of the film occlusion approach by examining expert and near expert performer's utilisation of anticipatory information in situ by occluding information using liquid-crystal occlusion spectacles (Milgram, 1987). The selection of different temporal occlusions should provide differing amounts of visual cue and situational information. By controlling for shot difficulty it may also be possible to hypothesise regarding the sources of anticipatory information. Since these studies involve players on court under match conditions it was thought logical to use matched ability opponents. This was because unequal opponents would mean that sampling hard and easy shots would be difficult and also potentially make the anticipatory task too easy or difficult depending on who was about to play the shot that required the anticipatory behaviour. The two studies involve two different racket sports, badminton and squash, to see if similar mechanisms account for anticipatory behaviour between sports. It was not possible to match the standards of the players between the two studies exactly which meant that direct comparisons between the two studies were inadvisable. The County standard players in the badminton study (2a) were representative of high expertise players although not of the National class standard of the squash players (study 2b). Since both groups of players were playing against similarly ranked players their behaviour may be indicative of typical performance at their respective levels.

4.2. The design of studies 2a and 2b as a consequence of pilot testing

Both studies assessed participant's ability to anticipate forthcoming shots from a matched ability opponent during rallies played in match conditions. There were no limitations imposed on the participants with regard to shot selection although rallies were ended when the experimenter removed vision from one of the participants remotely via the liquid occlusion spectacles. This intervention was under the control of the experimenter who selected shots that fitted predetermined criteria acquired from methodological pilot testing (Appendix 4.1a,b). For the badminton study (2a) only forehand shots about to be played by County standard players from the back of the court were selected. In this situation players could only play smashes, clears or drop shots (James *et al.*, 2004) but since smashes tended to land near the centre of the court these were subsequently discarded from the results as performance was to be assessed in term of correct quadrant responses. Thus smashes were likely to land near the border between the front and back quadrants making correct quadrant response a poor measure. For the squash study (2b) both forehand and backhand shots about to be played by World class players from the back of the court were selected. Backhand shots were selected for the squash study, but not the badminton study, because it was felt that the lower skill level of the badminton players might make the anticipatory task relatively easy compared to the forehand side. Thus if backhand shots had been used in the badminton study a sampling issue regarding variation between shots was predicted that would not be evident in the squash study. All possible shots were used in the squash study although only those that finished in one of the four quadrants (not around borders) and did not involve any late unusual bounces e.g. out of the nick, were selected for analysis.

4.2.1 Classification of Shot Difficulty

Easy and hard shots were similarly defined for both the badminton and squash studies. Categorisation was determined by 3 international coaches associated with each sport, from viewing footage of elite level badminton and squash matches with reference to classifications made by Mitchell (2000) and James & Bradley (2004). Two distinct variables were evident that made some shots harder than others for both sports, called technical and temporal pressures (Mitchell, 2000). Easy shots were thus defined as situations where all shot options were potentially available. These shots involved the racket ball/shuttle contact taking place when the player was not under undue time pressure to make the shot i.e. not overly stretching. A further condition in the squash study was that the ball was not in contact with any wall at the racket ball contact. Hard shots, on the other hand, involved situations where not all shot options were available. This was due to increased shot difficulty due to either the proximity of the ball/shuttle (technical) or time pressure (temporal). Hence the shot was hard if the racket ball contact occurred on or very close to the wall in squash such that the wall influenced the shot options, the ball/shuttle was behind the player or the player had been forced to over stretch.

4.3. Study 2a

4.3.1 Method

4.3.1.1 Participants

Seven male badminton players of matched ability (County 1st Division or National Standard) aged 19-38 years (M ± SD: 26.5 ± 6.30). Each undertook 30 recorded trials of simulated singles match conditions on a regulation badminton court. Length of rallies ranged between 4-15 seconds (M ± SD: 8.2 ± 6.80). Informed consent was gained from the participants prior to the experiment taking place

4.3.1.2 Procedure

Participants undertook a simulated competitive match with one player wearing a pair of PLATO S2 liquid-crystal occlusion spectacles (Milgram, 1987) modified with cloth attached to the rims via Velcro tape to prevent participants from seeing shuttle landing position information in their periphery. Simulated matches were between opponents of matched ability and ranking. Participants were also required to wear EARSOFT FX Earplugs (SNR 39dB) to prevent audio cues that may have helped anticipation.

The liquid-crystal occlusion spectacles permitted the vision of the participant to be rapidly occluded (within a 3ms period) by the remote alteration of the state of the spectacles lens from transparent to opaque. The lenses of the glasses were connected by wire to a control box that was strapped to the participants' waist. The spectacles were activated by a remote trigger that was manually controlled by the experimenter positioned on the side of the court. Simultaneous to the activation of the spectacles a light-emitting diode (LED) was illuminated (using the same radio transmission to ensure synchronisation) in the field of view of a video camera (Panasonic Mini DV NV-DS28) which was focused on the court, operating at 50Hz. Determination of the number of frames between the illumination of the LED (i.e. the same time as the glasses turned opaque) and the racket-ball contact allowed the calculation in seconds (1 frame = 20ms) of the occlusion period.

At various, quasi-random points during rallies, temporal occlusion trials were conducted by triggering the occlusion spectacles. Occluded shots were selected when the opponent of the participant received a shot high to the back of court (following lifts or clears). A minimum of 70 occlusion trials were presented to each participant (approximately 35 for each stroke difficulty) resulting in 527 trials in total. The experimenter attempted to ensure a good spread for the times that the occlusions occurred over both leading up to and following the execution of the opposing player's stroke (actual range was 920ms before contact to 600ms post contact). Trials were disregarded unless a clear or drop shot was played that landed in the appropriate quadrant. Participants were instructed that when their vision was occluded, they should try to complete the return stroke, and then place a marker, which they held in their non-playing hand, on the court where they felt the shuttle would have landed. The experimenter and colleagues then measured the lateral and depth errors associated with the marker placement in comparison to where the shuttle had landed as well as recording the quadrant into which the shuttle had landed.

4.3.1.3 Analysis of Data.

Determination of the number of frames between the illumination of the LED (i.e. the same time as the glasses turned opaque) and the racket-ball contact allowed the calculation in seconds (1 frame = 20ms) of the occlusion period for each trial. Each trial was categorised within the 11 temporal periods suggested by Abernethy *et al.*

(2001) although no data occurred in one of these periods resulting in 10 temporal periods for this study. In an attempt to simplify this categorisation scheme the data was also put into one of four occlusions periods that matched key events (racket-ball contact; top of backswing; opponent movement to ball) that occur in the squash stroke sequence (James and Bradley, 2004). Utilising these temporal points resulted in the following temporal periods: at contact to 160ms after contact (1); 160ms before contact to contact (2); 320ms before contact to 160ms before contact (3); all occlusion times prior to 320ms before contact (4). Normality of the data was assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. Further, descriptive measures of skewness and kurtosis were also inspected. To find whether the data was spherical, Mauchly's Test of Sphericity was inspected and where necessary a Greenhouse-Geisser correction used. An *a priori* alpha level was set at 0.05.

A three way between groups MANOVA (occlusion period (n = 10), shot type (drop, clear), shot difficulty (hard, easy)) was used for mean error predictions (lateral and depth) by County standard badminton players. When significant interactions were found simple main effects (SME) analyses were conducted. Also when interactions narrowly failed to reach significance exploratory SME's were also carried out. A three way between groups ANOVA (occlusion period (4), shot type (2), shot difficulty (2)) was used to assess County standard badminton players' ability to select the correct quadrant of the court. Scheffé post-hoc multiple comparisons were used to assess between group differences for significant main effects.

4.3.2 Results

Mean lateral and depth error predictions by County standard badminton players were categorised into the temporal periods suggested by Abernethy *et al.* (2001). To aid precision errors were measured in centimetres as opposed to Abernethy *et al.*'s (2001) method of categorising the error as being the correct half of the court (depth and lateral). Hence Figure 4.1 replicates the type of figure used by Abernethy to show the typical improvement in prediction accuracy as more information is provided to the participant.

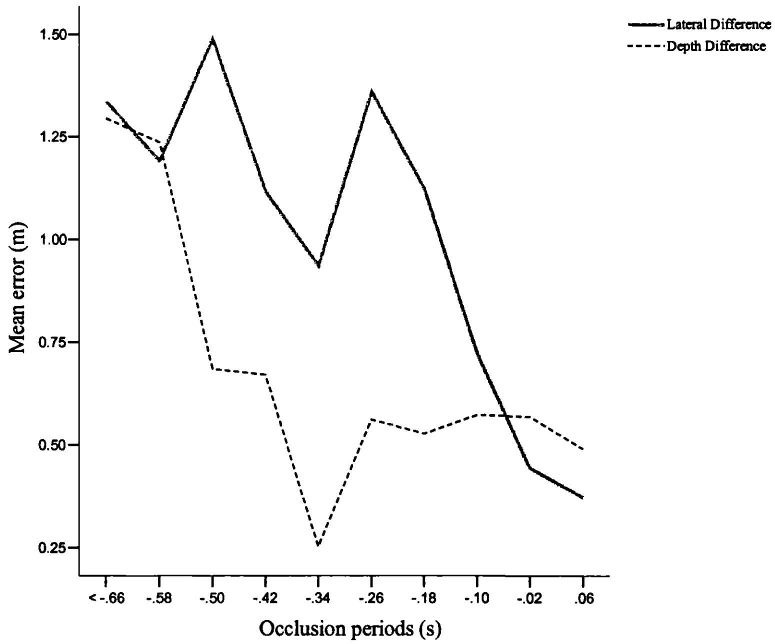

Figure 4.1 Mean lateral and depth errors for different occlusion periods (n = 10, cf. Abernethy *et al.*, 2001).

A three way between groups MANOVA (occlusion period (n = 10), shot type (drop, clear), shot difficulty (hard, easy)) for mean error predictions (lateral and depth) by County standard badminton players revealed one significant interaction between occlusion period and shot type (F = 12.39, df = 9, 487, $p < 0.001$ for lateral errors and F = 8.33, df = 9, 487, $p < 0.05$ for depth errors, Appendix 4.2). There was, however, no significant difference between the two shot difficulties for either lateral (F = 0.12, df = 1, 487, p = .73) or depth errors (F = 0.03, df = 1, 487, p = .86). Simple main effects analysis showed that the only differences between shot types occurred for depth at occlusion period 1 only (Fig. 4.2.) and for lateral error at occlusion periods 1, 2, 3 and 7 (Fig. 4.3.).

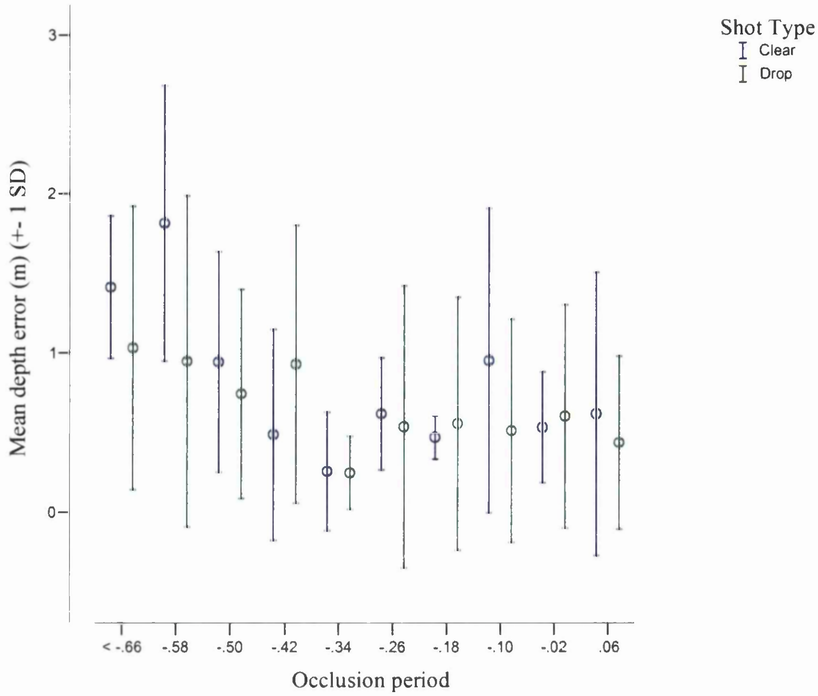

Figure 4.2. Mean depth errors for different occlusion periods (n = 10, cf. Abernethy *et al*., 2001) by shot type (clear and drop).

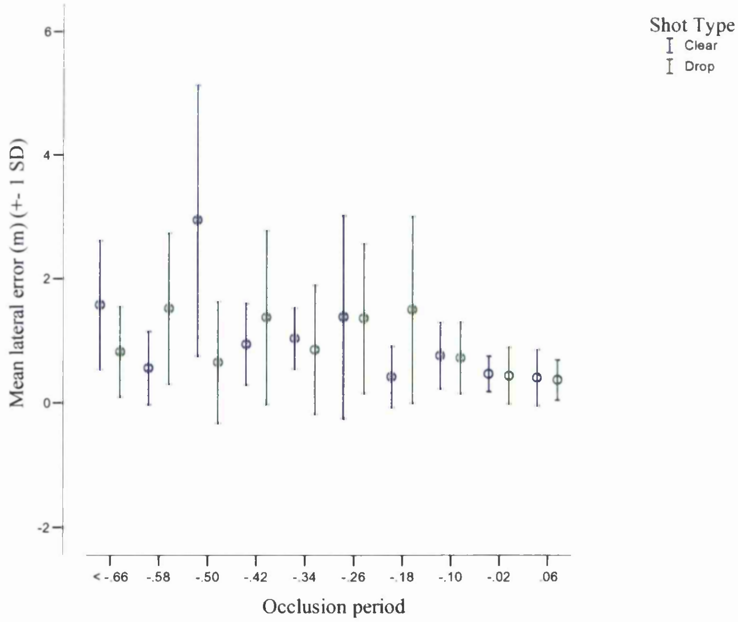

Figure 4.3 Mean lateral errors for different occlusion periods (n = 10, cf. Abernethy *et al*., 2001) by shot type (clear and drop).

A further analysis of the data was undertaken using the correct quadrant response (74.4% of responses were in the correct one out of the four corners) and simpler occlusion categories based upon the timing of action sequences (racket shuttle contact (0ms), start of racket swing (-160ms), average time of initiation of movement to return shot (-320ms)). Hence four occlusion periods were used; at contact to 160ms after contact (1); 160ms before contact to contact (2); 320ms before contact to 160ms before contact (3); all occlusion times prior to 320ms before contact (4)). A three way between groups ANOVA (occlusion period (4), shot type (2), shot difficulty (2)) revealed a significant interaction between shot type and occlusion periods for County standard badminton players' ability to select the correct quadrant of the court (F = 3.63, df = 3, 511, < .05, Fig 4.4; Appendix 4.4). A simple main effects analysis found that the only significant difference between shot types was during the occlusion period between 160ms before contact and contact (F = 17.87, df = 1, 522, p < 0.001, Fig. 4.4; Appendix 4.5) with a drop shot significantly easy to predict than a clear.

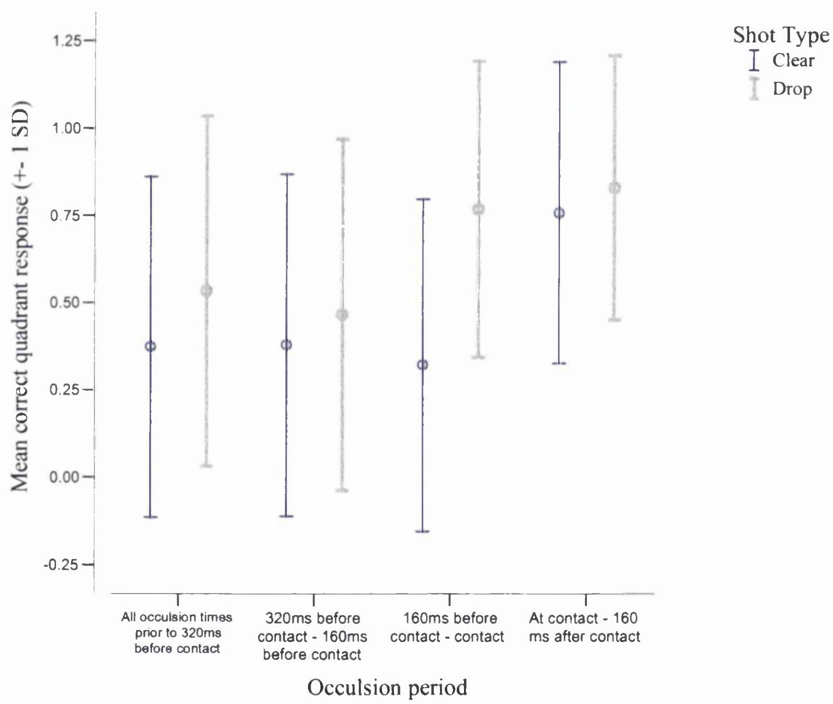

Figure 4.4 Mean correct quadrant response for different shot types (clear / drop) and occlusion periods (at contact to 160ms after contact (1); 160ms before contact to contact (2); 320ms before contact to 160ms before contact (3); all occlusion times prior to 320ms before contact(4))

Scheffé post-hoc multiple comparisons indicated that quadrant responses were significantly more accurate for clears when occluded after contact compared to 160ms before contact to contact (p < . 01); 320ms before contact to 160ms before contact (p

< . 001) and all occlusion times prior to 320ms before contact (p < . 001). For drop shots the occlusion periods prior to 160ms were significantly less well predicted as the periods post 160ms prior to contact (all p < .01, Appendix 4.6).

The three way ANOVA (occlusion period (4), shot type (2), shot difficulty (2)) also revealed a near significant shot type by shot difficulty interaction (F = 3.74, df = 1, 511, p = .054, Fig 4.5). Simple main effects analysis suggested that County standard badminton players found clears more difficult than drop shots for hard shots only (F = 13.08, df = 1, 526, p < .001, Appendix 4.7).

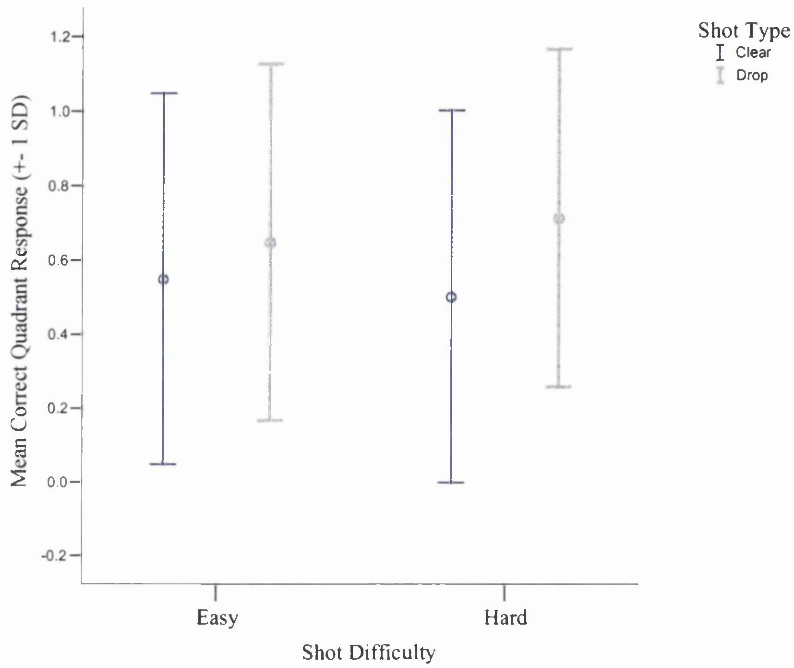

Figure 4.5. Mean correct quadrant responses for different shot types (clear / drop) by shot difficulty

4.3.3 Discussion

As in Study 1 the County standard badminton players' anticipatory ability was shown to exceed chance levels when predicting their opponent's forthcoming shot even when their vision was occluded extremely early in their opponent's movement sequence. Consistent with Abernethy *et al.*'s (2001) finding, as kinematic information related to the stroke sequence became available this anticipatory performance tended to improve. However subtle differences between shot types (as found by Renshaw and Fairweather, 2000; for different bowling deliveries in cricket) suggested that for clears the County standard badminton players needed to see the racket shuttle contact to improve quadrant responses from about a third to three quarters correct. It would seem, therefore, that these players found it difficult to use pre-contact cues, including the visual cues associated with the swing characteristics, to anticipate clears. Since there was also no difference between the easy and hard shots for clears it would appear that these County standard badminton players were also unable to utilise any situational information that may have been present for clears defined as hard shots.

Improvement in quadrant responses for drop shots increased from about a half to three quarters correct for occlusions that occurred after 160ms before contact. Since the time point of 160ms coincides approximately with the top of the backswing it appears that the visual cues associated with the racket swing were useful to the County standard badminton players enabling them to distinguish drop shots. However there was again no difference between hard and easy shots suggesting that any situational information that may have been present was not found to be particularly useful.

These findings suggest that the County standard badminton players were more able to utilise visual cues related to the swing sequence than situational information related to the rally conditions of player and shuttle locations. This is the opposite of what was found is Study 1 where the senior elite squash players were able to utilise the situational information but not effectively utilise the visual cues related to the player's swing characteristics. The most likely explanation for this is that County standard players, probably for all racket sports, are not able to disguise their shot intentions to the same degree as elite players (James and Bradley, 2004) and hence stroke kinematic information is available and can be utilised by this standard of player. The mean correct quadrant responses by the County standard players in this study are similar to those seen for both elite groups in Study 1. This could suggest that the County standard badminton players were as good at predicting forthcoming shots as their elite counterparts were in the squash study but it is more likely that this real world task more accurately reflected the performance standards of these players due to the maintenance of the perception-action coupling. In comparison the film task undertaken by the elite squash players was likely to have under estimated their true ability as suggested by Williams *et al.* (1999); James *et al.* (2004); and Abernethy (1990a, 1990b).

The suggestion that the badminton players in this study were unable to utilise the situational information thought to be present in the hard shots brings into question the appropriateness of this differentiation between shot types. This is particularly so given that there was such a clear distinction in the squash study. However none of the analyses in this study, even the very fine grained lateral and depth error analyses, indicated that the badminton players could anticipate hard shots any better than easy one. Whilst the same definitions were used for hard shots between the two studies it was acknowledged that the two sports have different characteristics, most notably the presence of walls in squash. Thus it may be the case that shot difficulty in badminton is not as clear cut as in squash. In this study only forehand shots from the back of the court were selected which were played in response to lifts and clears. This meant that all shots were being played with the shuttle descending from a reasonable height. Consequently it may be the case that the shot selection procedures adopted in this study were not sufficient to adequately sample hard and easy shots.

Some notes of caution regarding the measurement techniques used in this study are warranted. Some error was inevitable regarding the accurate measurement of the distance of the marker placed by the participant and the actual landing position of the shuttle, determined by the experimenter and his assistants. This was because the experimenter/assistant was, in some instances, up to 5m away from the landing position of the shuttle and so some error in judgement was likely. It is also the case that requiring the participants to place a marker on their predicted landing position potentially breaks the perception-action coupling of the task. This may be enough to disrupt the natural anticipatory behaviour and allow alternative cognitive processes to take place. For example the natural response of hitting the shuttle somewhere in space does not correspond exactly with the location of where the shuttle would land. Thus the shuttle location response requires additional cognitive activity that would not naturally occur although this took place after the natural response and so was not thought to impinge on the normal cognitive processes.

Study 2a has shown that County standard players were able to anticipate their opponent's forthcoming shots at above chance levels even with no stroke kinematic information available. This alone is suggestive of the use of situational information although no difference was found between hard and easy shots indicating that perhaps this study did not adequately sample hard shots. Significant improvements were seen in anticipatory behaviour when stroke kinematic information was made available when drop shots were being played but not for clears. These findings are generally consistent with those expected on the basis of results from Study 1 although it is also necessary to assess elite players to determine realistic levels of anticipatory performance at this expertise level. Consequently this study will be repeated using squash as the medium with elite players playing other elite players.

4.4. Study 2b

4.4.1 Method

4.4.1.1 Participants

Sixteen elite squash players (males n = 9, females n = 7) aged 17 – 25 (M ± SD: 20.08 ± 2.84) with National rankings, were recruited from the Welsh or English Institute of Sport, Squash Units. Informed consent was gained from the participants prior to the experiment taking place

4.4.1.2 Procedure

Participants, as in Study 2a (section 4.3.1.2), undertook a simulated competitive match with one player wearing a pair of PLATO S2 liquid-crystal occlusion spectacles (Milgram, 1987) modified with cloth attached to the rims via Velcro tape to prevent participants from seeing ball landing position information in their periphery and EARSOFT FX Earplugs (SNR 39dB) to prevent audio cues that would have helped anticipation. As previously a light-emitting diode (LED) was placed in view of the camera recording the match, this time behind the transparent back wall.

At various, quasi-random points during rallies, temporal occlusion trials were conducted by triggering the occlusion spectacles. Occluded shots were selected when the opponent of the participant received a shot at the back of the court. A minimum of 30 occlusion trials were presented to each participant (approximately 15 for each stroke difficulty) resulting in 580 trials in total. The experimenter again attempted to ensure a good spread for the timings of the occlusions (actual range was 1400ms before contact to 160ms post contact). Trials were disregarded if the occluded shot did not land in the appropriate quadrant. Participants were instructed that when their vision was occluded, they should try to complete the return stroke.

4.4.1.3 Analysis of Data

Each trial was categorised into one of four occlusions periods as used in Study 2a to match the key events specified by James & Bradley (2004) i.e. racquet-ball contact, top of backswing and the opponent's movement to the ball. Participant responses were assessed in terms of whether they went to the correct quadrant to return the opponent's shot. The same normality tests as in the 2b were used for the data. A two way between groups ANOVA (gender and shot difficulty) was used to assess elite squash players' ability to select the correct quadrant of the court. Secondly a two way repeated measures ANOVA (shot difficulty and occlusion period) for correct quadrant response was conducted. When significant interactions were found simple main effects (SME) analyses were conducted.

4.4.2 Results

A two way between groups ANOVA revealed a non-significant interaction between gender and shot difficulty for elite squash players' ability to select the correct quadrant of the court ($F = .95$, $df = 1, 576$, $p = 0.330$, Appendix 4.8). There was however a main effect for shot difficulty ($F = 45.52$, $df = 1, 576$, $p < 0.01$, Fig. 4.6) but no gender difference ($F = 0.28$, $df = 1, 576$, $p = 0.596$).

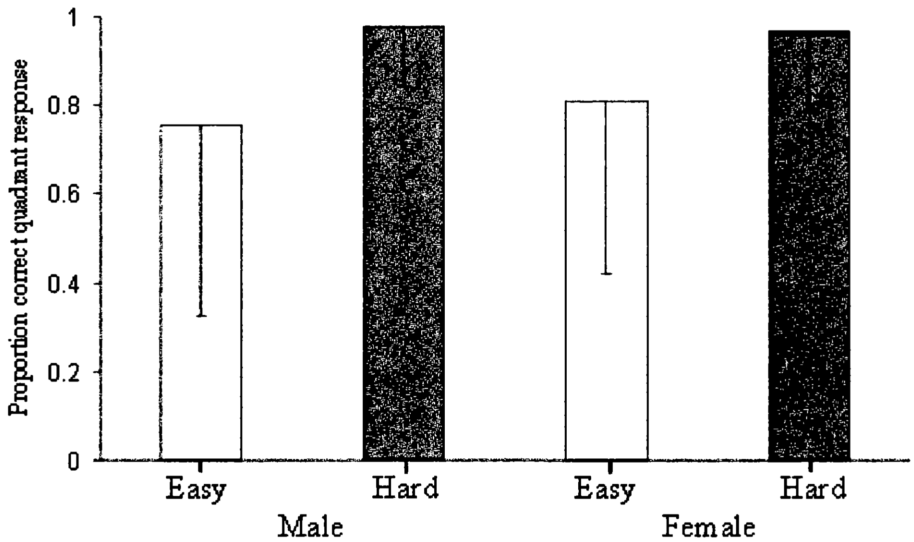

Figure 4.6: Proportion of correct quadrant responses by elite male and female squash players in response to easy and hard shots (error bar represents one standard deviation)

A further two way ANOVA revealed a significant interaction between shot difficulty and occlusion period (F=6.851, df=1, 556, p<0.001 Fig.4.7; Appendix 4.9) for correct quadrant response. Simple main effects analyses revealed highly significant differences between shot difficulties for the occlusion period between 320ms before contact and 160ms before contact ($F_{1,11}$ = 72.02, p < .001, Appendix 4.10) and the period containing all occlusion times prior to 320ms before contact ($F_{1,11}$ = 19.21, p < .001). No differences were significant at the other two time periods (Appendix 4.10).

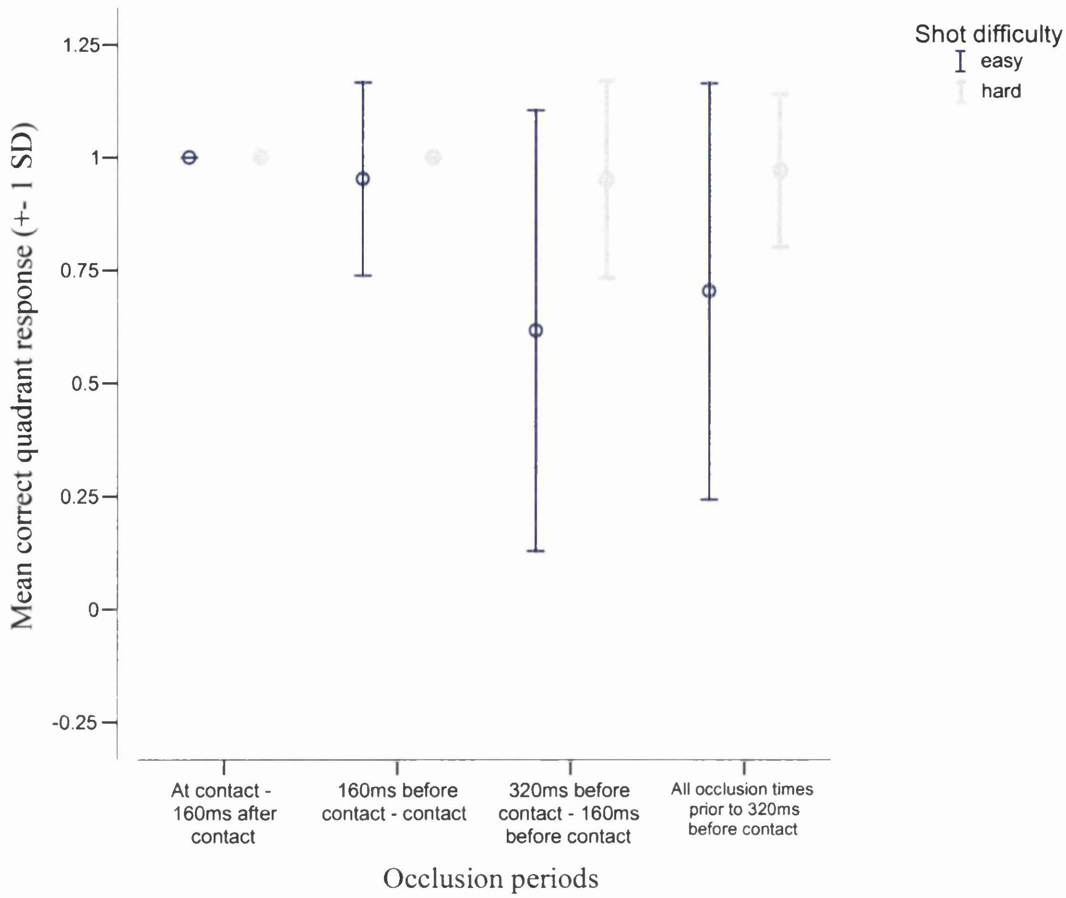

Figure 4.7. Mean correct quadrant response for different shots difficulties and occlusion periods.

Percentage frequency for easy shot placements when participants were unable to determine the correct quadrant revealed that the majority of errors were made when participants were required to anticipate cross court shots (e.g. Cross court drives / lobs / drops or boasts). From the back right court position to the left side 64.7% (front 41.2% & back 23.5%; Fig. 4.8) and the back left court to the right side 68.2% (front 18.2% & back 50.0%; Fig. 4.9).

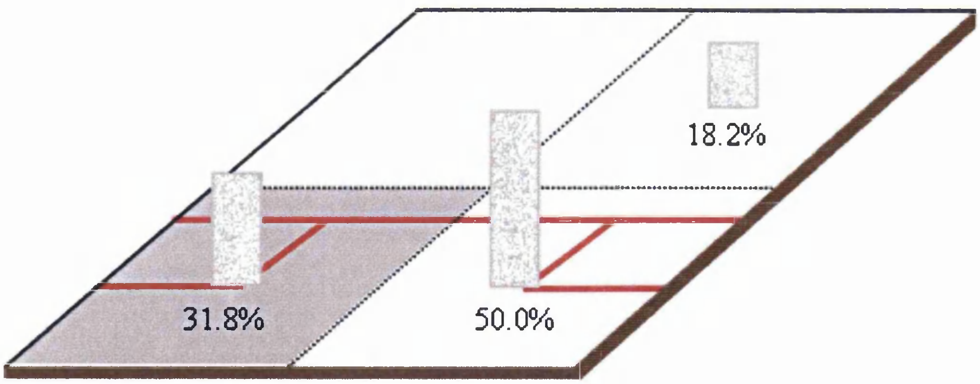

Fig 4.8: Percentage frequency of easy shot placements from the back left quadrant when opponent was unable to determine the correct quadrant

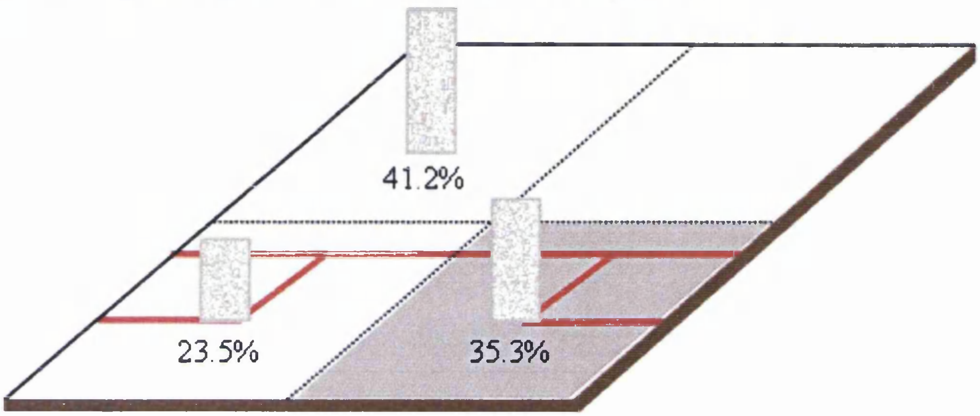

Fig 4.9: Percentage frequency of easy shot placements from the back right quadrant when opponent was unable to determine the correct quadrant

4.4.3 Discussion

The elite squash players' quadrant responses in this study were 78% correct for easy shots and 97% for hard shots with no gender differences evident. However this shot difficulty difference was only evident for shots occluded prior to 320ms before racket ball contact i.e. before any swing kinematic information was available, with hard shots still predicted 97% of the time but easy shots only 67%. These figures compare well with Abernethy *et al.'s* (2001) values of 80-85% accuracy for the identification of the correct half of the court during the same occlusion time frames. However the discrimination of shot difficulty in this study highlights the variability in response accuracy that appears to exist for elite players. It appears that these elite squash players were able to determine at a very early stage what the opponent's shot was likely to be. This decision was typically made prior to the opponent's movements to the ball i.e. when the opponent was standing on or near to the T. Such a decision has to be based on situational information which it appears is very accurate; especially when the opponent's shot is going to be under some pressure. This finding lends support to Girardin & Alain's (1978) view that players were able to predict forthcoming shots with some certainty without the need for confirmatory stroke kinematic or ball flight information.

The elite squash players in this study exhibited far better anticipatory performance than the County badminton players in Study 2a which is to be expected given the robustness of the expertise difference found in previous studies (e.g. Abernethy, 1990b; Abernethy *et al.,* 2001; Singer *et al.,* 1996; Ward *et al.,* 2002). The anticipated shot difficulty difference found here but not in Study 2a tends to confirm the previously held view that the sampling procedures in the badminton study were not sufficiently robust as to enable this discrimination. In the badminton study there was a shot type effect with drop shots being easier to predict than clears. This was thought to be due to swing kinematic information whereas in this study individual shots were not assessed, mainly due to very unequal shot type frequencies rendering this type of analysis unreliable. However, when the incorrect predictions were analysed, easy shots only due to the small number of errors on hard shots, it was found that about 65% of errors were made when players were required to try to anticipate cross court shots. This may be due to these players using rule-based decision making such as utilising their knowledge that elite players tend to play more straight shots than crosscourt particularly when the ball is close to the side wall. It may also be the case that the cross court shots were played in an attempt to disguise their shot direction intentions, as James and Bradley (2004) found, by using subtle wrist movements around 70ms prior to racket-ball contact. Personal communications with elite coaches and players tends to suggest that elite players try to anticipate hard shots, typically when the opponent is under pressure in the back corners, with the prediction that the shot will be played straight. It would not be surprising, therefore, that a counter tactic to this ploy is to over play the cross court shot to attempt to dissuade this anticipatory behaviour. This type of tactical exchange is presumably one of the mechanisms by which the elite game evolves continuously.

4.5 General discussion of the Visual Occlusion Approach

It would seem that the in situ visual occlusion approach was useful for determining the ability of players to anticipate intended shot outcomes. The two studies involved players of different standards with the differing results indicative of differences in ability. The main value of such an approach is the benefit of the natural setting which means that players do not have to alter their cognitive processes to respond e.g. selecting a response on a sheet of paper. Players were able to respond in their customary manner i.e. run to the area in which to play the next shot, although the cessation of vision could have disrupted the underlying cognitive processes. In the badminton study players were required to place an object on the floor after they had undertaken their natural response. This was thought not to impinge on the cognitive processes although this cannot be completely ruled out.

Pilot studies carried out to test the efficacy of the experimental procedures indicated that audio cues enhanced both the elite and County standard performers' perceptual ability dramatically. Indeed it was surprising how easily the badminton players could determine what type of shot had been played purely on the sound of the racket shuttle contact. Clearly then audio cues had to be removed, itself a potential disruption of the perception-action coupling. Previous studies have sounded an unusual audio signal (Crognier and Féry, 2002) to mask these clues, this was considered but it was eventually decided that this would be more likely to disrupt the perception-action coupling than simply preventing the sound using industrial strength earplugs. Whilst pre-experiment testing of these devices suggested they were sufficient for the purpose there remains the possibility that incorrect fitting due to vigorous movement around the court may have enabled some sound to be heard. Whilst participants assured the experimenter that this was not the case there remains the possibility that sub conscious responses to mild sounds could have occurred.

In terms of ecological validity having players on court playing simulated matches would seem to be a highly valid measurement protocol. Of course each disruption has an adverse effect although the extent to which this prevents natural reactions can only be guessed at. The wearing of glasses and their accompanying paraphernalia could have been distracting to players; indeed a few did mention this. However the main concern regards whether this distraction actually disrupted the cognitive processes rather than just being a bit of a nuisance. Whilst the answer to this conundrum cannot be ascertained with any certainty it was felt that wearing glasses would not materially affect cognition (Abernethy *et al.*, 1990). Indeed current rules in squash mean that all juniors playing in sanctioned events are required to wear protective glasses suggesting that the rule makers do not think so either.

Whilst the two visual occlusion studies showed the ability of players to anticipate the next shot it remains to be seen whether this ability is translated into performance during matches. It is therefore necessary to assess actual match play to determine whether players utilise this ability to the extent to which they appear able.

Chapter 5 – Studies 3a and 3b

5.1 Introduction

Studies 2a and 2b suggested that elite and county players were able to anticipate their, matched for ability, opponent's forthcoming shots, without the aid of stroke kinematic information, at better than chance levels. Furthermore, this ability tended to increase as more stroke sequence information became available although this was dependant on shot type in the badminton study and shot difficulty in the squash study. There was no shot difficulty effect in the badminton study although this was thought to be related to the sampling of shots for subsequent analysis. The elite squash players exhibited superior anticipatory performance compared to the County badminton players although the badminton players seemed to make better use of stroke kinematic information. This was thought to be due to the elite squash players being more able to disguise their shot intentions and hence reduce the usefulness of stroke kinematics. Whilst the two visual occlusion studies showed the anticipatory ability of players, there is limited literature supporting the actual use of anticipatory movements (Williams *et al.,* 1999), therefore, it remains to be seen whether this ability is translated into performance during matches. The aim of the next two studies therefore is to assess actual match play to determine whether players utilise this ability to the extent to which they appear able.

Previous non-invasive research in squash using high speed cameras has been conducted by Howarth *et al.* (1984) and James and Bradley (2004) (see section *2.4.2* for a review of this literature). The former study showed a significant earlier first move, defined as '*the first displacement of the receiver's body in the direction necessary to intercept the oncoming stroke*' for expert players compared to their lesser skilled counterparts. The authors suggested the subtraction of a 0.2s reaction time latency period which then indicated that elite players based their decision upon advance cue information i.e. information prior to racket ball contact. However the County players in this study, using the same calculations, were shown to require post racket ball contact information to intercept the oncoming stroke. More recent research by Bootsma & Wieringen (1990) has suggested, however, that the reaction time latency period my well be reduced in sport specific situations, their finding were in table tennis, to around 0.12s prior to racket ball contact.

James and Bradley (2004), in a similar study to Howarth *et al.* (1984), assessed three opponents (their highest world rankings in the previous two years were 4, 61, 76) of an elite player (World Ranking 15 during data capture, but just prior to this was ranked in the top 5 for 1 consecutive year) responding to relatively easy shots. The players' first movements in the direction of the ball's finishing location were predominately over 0.2s after ball contact. This was much later than found by Howarth *et al.* (1984) where their experts moved towards the ball far earlier (0.11s). James and Bradley suggested that it was likely that the sampled shots in the Howarth *et al.* study were more difficult because the player making the shot was probably under more pressure given that the player was playing against a better player. This would have resulted in greater situational information, i.e. hard shots are more predictable due to limited shot options, hence allowing earlier anticipatory movements. A further methodological difference was observed between the two studies by James and Bradley who noticed that Howarth *et al.* did not mention the split jump technique used by all of the players in their study. Consequently James and Bradley suggested that this may have been indicative of skill level differences between the studies or perhaps even a source of measurement error.

James and Bradley (2004) conducted a more qualitative assessment of the elite player in training situations where the player was able to hit the ball to any part of the court at will whilst returning easy shots. The authors concluded that clear differences in stroke type, stroke kinematic information, only become apparent between 0.07s and 0.03s prior racket-ball contact. It should be noted however that this player was recognised by the best players in the world as possessing a swing that was very difficult to interpret. Consequently it was suggested that if players try to anticipate a player of this ability, playing easy shots, then the chances of being deceived would be quite high. A final point made in the James and Bradley study was that they noticed that players moved to slightly different areas around the T depending on the location of the opponent's forthcoming shot. This was suggested to be indicative of using situational information as opposed to being temporally based on visual cues as these movement differences occurred prior to any swing information.

The aim of the next two studies (3a and 3b) is to determine the actual anticipatory behaviour shown by expert and near expert performers' in badminton and squash. Anticipatory behaviour during real competitive matches will be examined using a high speed camera to accurately measure timings of movements. In light of the previous findings, using players of a similar standard to these, it is expected that shot difficulty will have a significant impact on the anticipatory behaviour of the elite squash players (Study 3b). However it is also expected that the elite squash players would move earlier than the County badminton players, although since their task is more difficult i.e. they are playing against more skilful opponents, this may not be the case. Methodological concerns regarding the sampling of easy and hard shots in the previous badminton study (2a) limit the predictions for the County badminton players in Study 3a, although the same definitions will be used to see if, in match conditions, any differences exist. Shot type had been shown to influence anticipatory behaviour in the previous badminton study (2a) and so this was expected to occur again (Study 3a). Previously no shot type distinction had been used in the squash study (2b) because unequal shot type frequencies had rendered this type of analysis unreliable. Hence in the squash study (3b) rather than consider shot type the different shots will be categorised as being played to the front or back of the court. This may result in adequate sampling although this is unknown presently.

5.2 Study 3a

5.2.1 Method

5.2.1.1 Participants

Ten County (6 male and 4 female; aged 22 to 31 years $M = 25.9 \pm SD = 3.1$) badminton players having an average of 15 years ($SD = 6.54$) experience between them participated in the study. Informed consent was gained from the participants prior to the experiment taking place.

5.2.1.2 Procedure

Participants undertook a five-minute warm-up period before playing competitive matches, undertaken during County squad training sessions. A high-speed camera (Motionscope PCI 1000s, Redlake Imaging Corporation, Morgan Hill, USA) was set up to capture rally sequences at 250 frames per second. The camera operated continuously in conjunction with a PC such that when triggered the four seconds (approximately 1000 frames) of data prior to the activation of the trigger were recorded to the hard drive of the computer. Having the trigger occur after the event allowed the experimenter to observe the desired stroke before then recording it. The camera was positioned at the back left-hand corner of the court so that both players were in view with the exception of shots played from the extreme back right-hand corner. In addition to the badminton court lights being on, three high powered lights (Hedler Turbo Lux Profi; Helder USA Lighting Systems, Massapequa Park, USA), operating at 1250 watts were used to allow a clearer image to be captured by the camera.

Rally sequences were chosen on the *a priori* basis that they included a shot that was either relatively easy or difficult (see section 4.2.1 Classification of Shot Difficulty). Easy and difficult shots were again chosen because of the hypothesised degree of situational information available for each difficulty level. A minimum of 50 occlusion trials were presented to each participant (approximately 25 for each stroke difficulty) resulting in 520 trials in total.

5.2.1.3 Analysis of Data

Quintic™ Biomechanics software version 3.05 (Quintic Consultancy Ltd., Coventry, UK) enabled frame-by-frame analysis of each clip. Accurate timings for the player's movements: *initiation* and *landing of the split-step* and the *first movement towards the shuttle*; in response to the selected shot were calculated with respect to the time of the racket-shuttle contact. *First movement* towards the shuttle was defined as the first displacement of the receiver's body in the direction necessary to intercept the oncoming shot (as used by Howarth *et al.*, 1984). In order to predict when the players made their anticipatory decision, two different reaction time latency periods were subtracted from the times of the first movements, 0.2s (as reported by McLeod, 1987) and 0.12s (based on Bootsma and Wieringen, 1990 calculation of between 0.105s and 0.122s).

Inter- and intra- reliability tests revealed maximum discrepancies between two timings of 0.012s and 0.008s respectively. Normality of the data was assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. Further, descriptive measures of skewness and kurtosis were also inspected. To find whether the data was spherical, Mauchly's Test of Sphericity was inspected and where necessary a Greenhouse-Geisser correction used. An *a priori* alpha level was set at 0.05. First movement towards the shuttle, initiation of split step and end of split step were assessed via two way between groups MANOVAs [(shot type (drop, clear), shot difficulty (hard, easy)].

5.2.2 Results

A two way between groups MANOVA [(shot type (drop, clear), shot difficulty (hard, easy)] for first movement towards the shuttle, initiation of split step and end of split step revealed no significant shot type by shot difficulty interaction ($F = 0.42$, $df = 1, 516$, $p = 0.518$) or shot difficulty effect ($F = 0.83$, $df = 1, 516$, $p = 0.364$, Appendix 5.1) for first movement towards the shuttle. However there was a significant difference ($F = 13.65$, $df = 1, 516$, $p < 0.001$) for shot type whereby the first movement in relation to racket-shuttle contact occurred significantly later for clears ($M = 0.285$ s $\pm$ $SD = 0.20$) compared to drop shots ($M = 0.220$ s $\pm$ $SD = 0.20$) shots, see initiation of movement response in Fig 5.1).

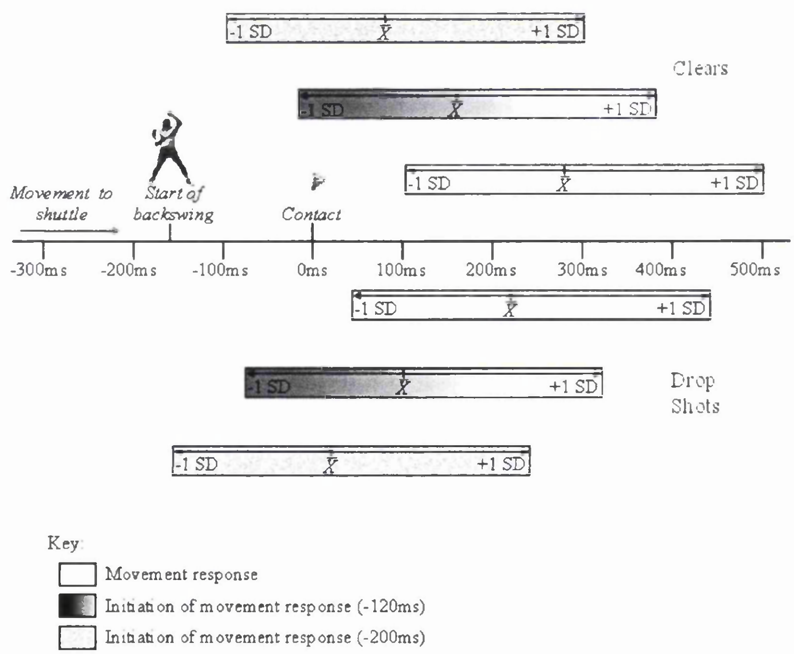

Figure 5.1. Schematic representation of movement responses to clears and drop shots with estimates for the initiation of these responses based on predicted reaction times

When the two reaction time latency periods were subtracted from the first movement towards the shuttle (initiation of movement response, -120ms and -200ms;

Fig. 5.1); estimations of whether the player had anticipated the shot were possible. Hence it was estimated that the County badminton players decided where the shuttle was going before racket shuttle contact between 18.6% and 34.8% of the time for clears and 28.9% and 45.5% for drop shots. Using these parameters it was also possible to calculate that these players decided where the shuttle was going before the swing kinematic information (estimated as -0.16s) between 7.3% and 12.3% of the time for clears and 9.6% and 17.7% for drop shots.

The MANOVA also showed that the initiation of the split step was not affected by the shot played (either shot type or shot difficulty, see Appendix 5.1) with the split step occurring on average 0.054 s before racket shuttle contact (SD = 0.214 s). Furthermore the end of the split step was also not affected by the shot type or shot difficulty (Appendix 5.2) and thus the split step duration did not differ between shots and averaged 0.26 s (SD = 0.02). The initiation of the first movement to return the shuttle was more likely to occur after the end of the split step for both easy and hard shots for both clears (Chi square = 0.13, df = 1, p = .715) and drop shots (Chi square = 0.46, df = 1, p = .498) although this tendency was more evident for clears (Table 5.1).

Table 5.1: Observed frequencies of first movements in relation to the split step for easy and hard shots by shot type.

			First move	
Shot type	Difficulty		Before end of split step	After end of split step
Clear	Easy	N	9	107
		%	7.76	92.24
	Hard	N	13	131
		%	9.03	90.97
Drop	Easy	N	45	71
		%	38.79	61.21
	Hard	N	50	94
		%	34.72	65.28

5.2.3 Discussion

County badminton players were seen to perform a split step prior to them moving to intercept the shuttle. It had been hypothesised that if a player was able to anticipate, drop shots more easily than clears for example, they may well cut down the duration of their split step to allow a quicker movement towards the ball. This did not appear to be the case however with the split step movement shown to be relatively stable in duration lasting about 0.26s. The first movement towards the shuttle then typically occurred after the end of this split step movement (0.28s for clears, 0.22s for drop shots). These values were higher than reported for elite squash players (0.20s) responding to easy shots played by another elite player (James and Bradley, 2004) but very similar to the Grade D squash players in the Howarth *et al.* (1984) study (0.28s).

The difficulty of the opponent's shot did not significantly affect these findings (as was found in Study 2a) suggesting that these players did not utilise this factor as an aid to anticipation. However the type of shot resulted in significant differences in the first movement towards the shuttle with movements occurring later for clears. Since the first movement towards the shuttle is likely to occur some time after the decision was made to make the move, due to reaction time limitations, calculations were made to assess when the County badminton players were able to distinguish likely shot directions. Based on one high and one low estimate for the players' reaction times (0. 20s and 0. 12s) it was suggested that these players knew the intended shuttle direction before the racket shuttle contact approximately a quarter of the time for clears and around a third of the time for drop shots. Assuming the racket swing started 0.16s earlier it was further hypothesised that these players knew the intended shuttle direction before the racket swing took place approximately 10% of the time for clears and around 15% of the time for drop shots. These values indicate that in the majority of instances County badminton players are likely to base their movement responses on some shuttle flight information, as predicted for Grade D squash players by Howarth *et al.* (1984) and lesser-skilled ice hockey goal tenders by Salmela and Fiorito (1979).

Study 3a has shown that County standard players were likely to have been able to anticipate their opponent's forthcoming shots, prior to stroke kinematic information being available, on 1 or 2 shots in every 10. This corresponds to the above chance level finding for the same thing in Study 2a and suggests that County levels players can use situational information although infrequently. Once stroke kinematic information became available these players were more likely to anticipate the forthcoming shot to the extent that as many as 4 shots in every 10 may be anticipated by this level of player. Similar to Study 2a this improvement was more noticeable for drop shots in comparison to clears. These findings are, therefore, generally consistent with the previous studies and it is therefore predicted that the analysis of elite squash players will also provide more detailed but confirmatory results.

5.3 Study 3b

5.3.1 Method

5.3.1.1 Participants

Eight elite squash players (males n = 4, females n = 4) aged 17 – 24 (M ± SD: 20.13 ± 2.99) with International or National rankings, were recruited from the English Institute of Sport, Squash Unit. Informed consent was gained from the participants prior to the experiment taking place.

5.3.1.2 Procedure

Participants undertook the same procedure as those in Study 3a (see section *5.2.2).* Data was collected from matches that were played during a training camp of the English squash squad. The lengths of matches were determined by the coaches which meant that the numbers of trials per participant could not be tightly controlled. The camera was similarly positioned at the back left-hand corner of the court so that both players were in view with the exception of shots played from the extreme back right-hand corner. No additional lighting was required for this study as the squash court lights were adequate for subsequent analysis of the film. Rally sequences were again chosen on the *a priori* basis that they included a shot that was either relatively easy or difficult (see section 4.2.1 Classification of Shot Difficulty). A minimum of 16 occlusion trials were presented to each participant (approximately 8 for each stroke difficulty) resulting in 153 trials in total.

5.3.1.3 Analysis of Data

The same procedures described in Section *5.2.2* were followed. Inter- and intra-reliability tests revealed the same maximum discrepancy between two timings of 0.008s. The same normality tests were used for the data. Independent samples T-tests were used to examine differences for the first move towards the ball and the initiation of the split step, both in relation to racket-ball contact, between easy and hard shots.

5.3.2 Results

5.3.2.1 Squash movement analyses using high speed camera

An independent samples T-test revealed that there was a significant difference in the first move towards the ball in relation to racket-ball contact between the easy ($M=0.251$ s $\pm$ $SD = 0.172$) and hard ($M=0.134$ s $\pm$ $SD = 0.184$) shots ($t_{(151)} = 4.05$, $p < .001$, see initiation of movement response in Fig 5.2).

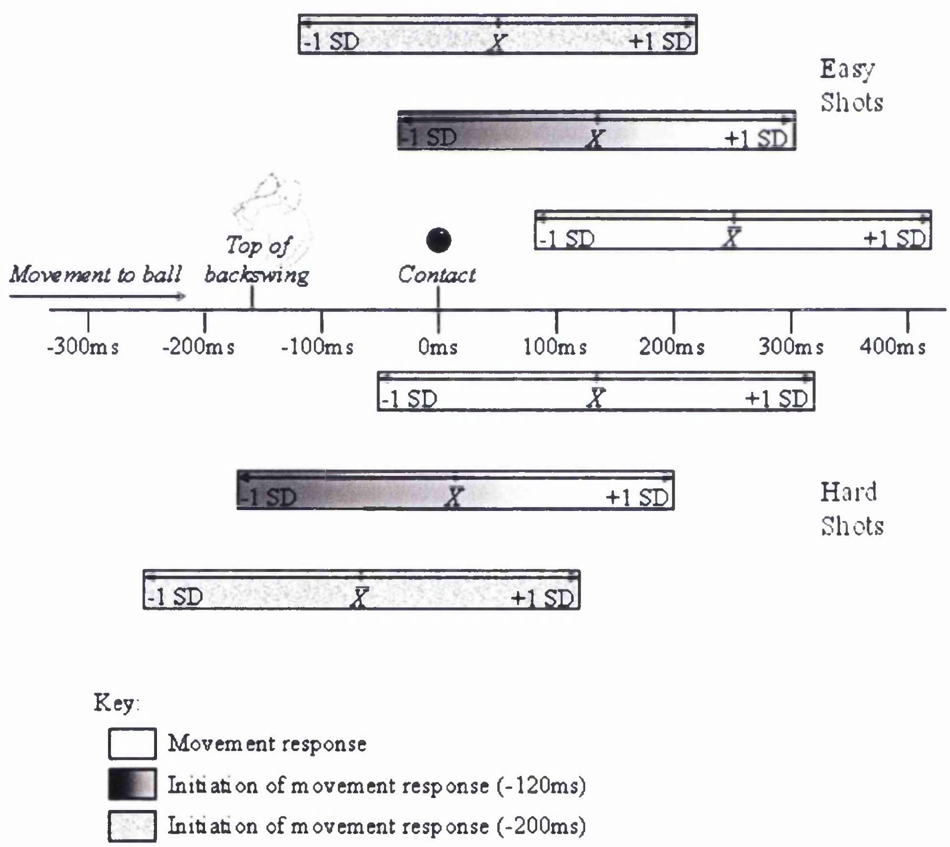

Figure 5.2. Schematic representation of movement responses to hard and easy shots with estimates for the initiation of these responses based on predicted reaction times

When the two reaction time latency periods were subtracted from the first movement towards the ball (initiation of movement response, -120ms and -200ms; Fig. 5.2); estimations of whether the player had anticipated the shot were possible. Hence it was estimated that the elite squash players decided where the ball was going before racket ball contact between 16.2% and 31.1% of the time for easy shots and 63.3% and 77.2% for hard shots. Using these parameters it was also possible to calculate that these players decided where the ball was going before the swing kinematic information (estimated as -0.16s) between 9.5% and 13.5% of the time for easy shots and 29.1% and 40.5% for hard shots.

Since studies 2a and 3a had suggested differences according to shot types in badminton, therefore the movement responses were re-examined for shots played to the back of the court against shots played to the front. However since there were only 34 instances of shots played to the front this data was not statistically examined but presented visually (Fig 5.3). However the data for the shots to the back of the court (n = 119) suggested that players were far more likely to move earlier ($t_{(117)} = 4.37$, $p < .001$) for hard shots (M=0.114 s ± SD = 0.161 s) than easy shots (M=0.249 s ± SD = 0.176 s).

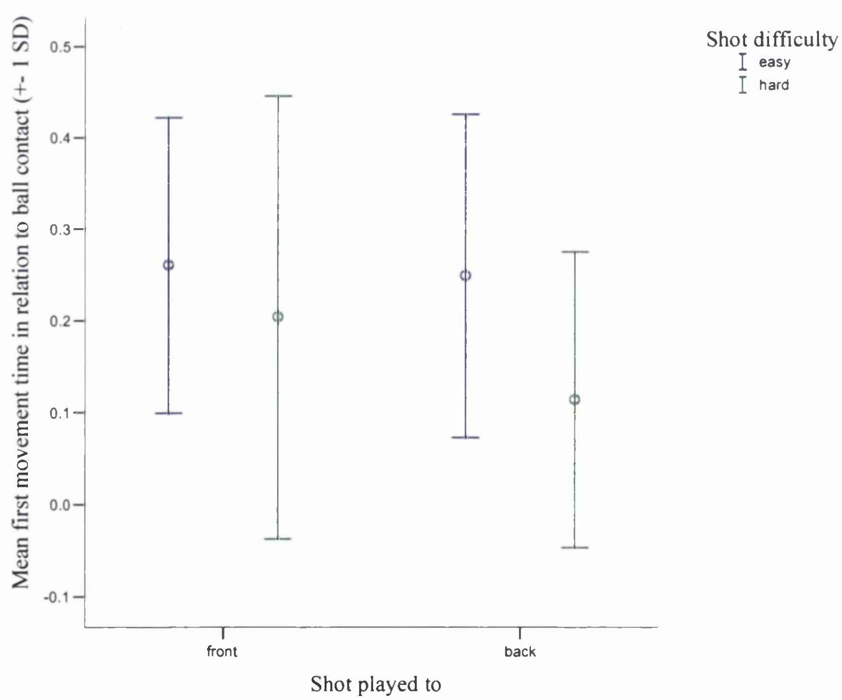

Figure 5.3. Mean first movement times for easy and hard shots played to the front and back of the court.

An independent samples T-test revealed that there was a small but significant difference in the initiation of the split step in relation to racket-ball contact between the easy (M = -0.04 s ± SD = 0.08) and hard (M = -0.09 s ± SD = 0.07) shots ($t_{(124)}$ = 3.18, p < .01). Split step durations did not differ for easy and hard shots ($t_{(124)}$ = 1.17, p = 0.24) and averaged 0.24s (SD = 0.07). When a split step did occur (82.8%) the initiation of the first movement to return the ball was significantly more likely to occur (Chi square = 18.12, df = 1, p < .001) after the split step had finished for easy shots (77.27%) than for hard shots (40%, Table 5.1).

Table 5.2: Observed frequencies of first movements in relation to the split step for easy and hard shots.

		First move	
		Before end of split step	After end of split step
Easy shots	N	15	51
	%	22.73	77.27
Hard shots	N	36	24
	%	60.00	40.00

5.3.3 Discussion

Elite squash players were seen to perform a split step about 80% of the time with this typically occurring before they moved to intercept the ball for easy shots. However, when facing hard shots, they were more likely to initiate the first movement before the split step had finished, if they used a split step at all. It had been hypothesised that since players were likely to be able to anticipate hard shots more easily than easy shots either the duration of their split step may have been reduced to allow a quicker movement towards the ball or the split step started earlier. The duration of the split step did not appear to change however, with the split step movement shown to be relatively stable in duration lasting about 0.24s. The data did suggest that the split step may have been initiated slightly earlier for hard shots, about 0.09s before racket ball contact compared to 0.04s for easy shots but this difference is only just larger than the sampling rate at which the camera was operating (0.04s) suggesting caution should be applied when considering this difference. The likelihood of the first movement to return the ball occurring before the end of the split step was 60% for hard shots and about 20% for easy shots whereas in the badminton study less than 10% occurred at this time for clears and about 35% for drop shots. It appears then that there are subtle differences in movements that distinguish elite from sub-elite players with the split step appearing to be a controlling technique that probably enables the optimisation of the timing of the first movement towards the ball or shuttle.

The first movement towards the ball typically occurred 0.25s after racket ball contact for easy shots and 0.13s for hard shots. These values were comparable to those reported for elite squash players responding to easy shots (0.20s) played by another elite player (James and Bradley, 2004) and similar to the Grade A squash players in the Howarth *et al.* (1984) study (0.11s). These results clearly suggest that the Howarth *et al.* study sampled shots that were difficult for the opponent resulting in the Grade A players producing earlier responses than if more general sampling techniques had been used. It would seem, therefore, that elite squash players only move early when they are confident, with this confidence being derived from the limited shot availabilities open to their opponent. It also seems plausible, therefore, to suggest that elite players find themselves in a position of limited shot options far less than lower standard players do because of their superior movement and racket skills. Hence it is suggested that one explanation for a novice expert difference in squash is that the range of shot options increases with expertise level (see James and Bradley, 2004 for similar conclusions)..

Calculations for reaction time were applied to the first movement towards the ball times (as in Study 3a) to assess when the elite squash players were able to distinguish likely shot directions. Based on reaction time estimates of 0.20s and 0.12s it was suggested that these players knew the intended ball direction before the racket ball contact approximately a quarter of the time for easy shots but around two thirds of the time for hard shots. Assuming the racket swing started 0.16s earlier it was further hypothesised that these players knew the intended ball direction before the racket swing took place approximately 10% of the time for easy shots and around a third of the time for hard shots. These values indicate that for about 75% of easy shots elite squash players are likely to base their movement responses on some ball flight information. In contrast, Study 2b had found that comparable elite squash players knew which quadrant the ball was going to 78% of the time for easy shots when vision was occluded prior to any racket kinematic information. This conspicuous disparity suggests that elite squash players may have a good knowledge of where the ball is likely to go (78% of the time for easy shots) but are reticent to act upon this information (only 25% of the time for easy shots). This anticipation rate is similar to that found for the County badminton players in Study 3a which provides further confirmation of the previous hypothesis that elite squash players only move early when their opponent has limited shot availabilities open to them.

Whilst anticipatory responses were far more likely to occur for hard shots a similar picture to that shown for easy shots was present in that the elite players demonstrated anticipatory behaviour that was lower that may have been predicted by the results from Study 2b. In that study 97% accuracy was found for hard shots when visual occlusions took place around 320ms before racket ball contact i.e. before any swing kinematic information was available. Players in this study, who were of the very highest level, only appeared to act on this knowledge, presuming it was present, about one third of the time before swing kinematic information and two thirds of the time when this swing information was present i.e. before racket ball contact.

James and Bradley (2004) suggested that the reason expert squash players did not make anticipatory movements prior to racket ball contact during easy shots was that elite players are able to disguise their intent sufficiently to prevent the opponent utilising advance cues. However, the authors did note that some spatial adaptation occurred around the T, indicating that situational probabilistic information was being utilised to some extent. Incorporating the findings from Studies 2b and 3b into these assertions it may be hypothesised then that elite players have very good knowledge of the situational information, hence the movement adaptation found by James and Bradley (2004) and the very high performance in Study 2b, but because of the possibility of their elite opponent being able to disguise their intentions (James and Bradley, 2004) elite players are more circumspect and do not anticipate to the level at which they may be capable (Study 3b). This tends to confirm Alain and Proteau's (1978) idea that players attribute certain probabilities of events occurring but only make an early movement if this probability was greater than a certain percentage. They suggested 70% although Studies 2b and 3b would tend to question this value.

5.4 General discussion of the high speed camera approach

It would seem that the high speed camera approach was useful for determining the incidence of players' anticipatory movements. The two studies involved players of different standards with the differing results indicative of differences in ability. The main value of such an approach is the benefit of the completely natural setting which means that players are not influenced in any way. Consequently the main concerns are whether the sampling of rallies was adequate to address the factors that may influence the results and whether the measures used were appropriate for the aims of the study.

The factors thought to be important in the high speed camera studies were level of expertise, shot difficulty, shot type and occlusion period. In terms of expertise two levels of what most experimenters would call elite players were used, as the County players were of a very high playing standard. Consequently the findings are limited to these higher levels of performance but of more importance was the fact that opponents were matched in terms of expertise. This is bound to influence the behaviour of the players to a large extent as playing inferior or superior players will determine the types of rally played and therefore the sampling of data would be skewed towards one level of difficulty. Many previous studies have not been so explicit in the details regarding the "other player" and consequently these findings are susceptible to being skewed in one direction. This is not such a problem if the details are known but when general statements are made regarding performance of so called experts then the lack of detail can lead to misleading figures. It is contended, therefore, that a strength of these studies is the explicitness of the expertise levels of the participants and as such conclusions drawn are straightforward.

A great deal of attention was given to shot difficulty effects which proved to be a major factor in the squash study but not so in the badminton study. The fact that the elite squash players responded consistently differently to different shot difficulties supports the concept in principle. However since this was not replicated by the lower expertise level badminton players it is tempting to suggest that they were simply not expert enough to make use of the extra information available during the hard shots.

However this would be contentious as it cannot be ruled out that the sampling procedures were not rigorous enough. It must be said that one major difference between squash and badminton is the presence of walls in squash. This adds a difficulty factor not present in badminton and may be the explanation for the badminton results i.e. hard shots were not as difficult as they were in squash.

Shot type was found to be an important factor in badminton whereas sampling issues meant that the squash studies did not contain enough data for each shot type. This was predominantly due to the large array of squash shots as a result of all shots being played as both volleys and ground shots (not an issue in badminton) and the inclusion of shots played off the side wall (boasts). This meant that many shot types were only sampled infrequently with the consequence that any analysis would have been indecisive. Some efforts were made to categorise shots into straight and crosscourt or short and long but similar problems arose. This could have been alleviated with more data but the squash data was collected during an English squad meeting and as such was under the control of the coaches. Whilst this as unavoidable and impossible to predict how much data would be gathered, it was felt that access to such players (most were top 10 and all top 30 in the World) overwrote these concerns.

The high speed camera studies assessed anticipation via the first movement towards the ball. There are clearly methodological concerns about this measure not least regarding the accuracy of the experimenter's judgement in determining this. To try to put this issue into perspective the film clips were assessed on a number of occasions to try to determine likely error rates. These were typically very low, usually one or no frames difference between the two observations, which translates to typical errors of up to 0.004s. When this error is compared to the findings there does not appear to be a problem. However other concerns have been raised regarding the extent to which the first movement towards the ball relates to the anticipatory behaviour. Firstly the reaction time of an individual is unknown and is likely to vary between individuals. The decision made regarding this issue was to provide two values likely to be higher and lower than the actual reaction times of participants. Whilst this is not perfect, the use these time periods meant that the conclusions drawn were reasonable and defensible. A second concern regarding the link between movement and decision time concerns the manner in which information is processed. These studies have assumed that the performer acts as an essentially linear and serial processor of information. Thus information is identified, some decision-making takes place to select a response and then a response is initiated. In a complex environment such as playing a racket sport however, this process is more likely to be a continuous cumulative process as multiple sources of information are processed. Hence as Miller (1982) proposed some aspects of the movement response may have commenced before the final response selection takes place. In other words some movements could take place before the decision making process has completed, and hence before knowledge of the intended shot direction is known. Evidence in support of this theory, in the setting of a squash or badminton player anticipating ball trajectories, would be movements in the wrong direction that are quickly corrected. This type of movement was seen, although very infrequently (n = 3 out of 156 rally sequences in squash and was not seen in badminton rallies). This suggests that the first movement could, on a small number of occasions, take place before decision making had completed. On these rare occasions the movement time would not reflect when the player knew where the ball or shuttle was going. This therefore adds a small amount of error into the data since it is possible that some of the trials were inconsistent with the hypothesis that the time of the first movement reflected anticipatory behaviour. However this error was not deemed significant enough to invalidate the results.

Chapter 6 - General discussion

The concluding discussion consists of three sections. First, the principal findings of the three studies conducted are discussed in relation to the overall thesis aims and objectives. Second, the practical implications of these thesis findings for coaches and analysts working within racket sports are provided. Finally, the limitations of the thesis are explored with directions highlighted for future research in the area of anticipation in racket sports.

6.1 Thesis Findings in Relation to the Thesis Aims and Objectives

This thesis attempted to improve upon previous methodologies to assess anticipation in racket sports, specifically squash and badminton. It was argued that previous research had largely neglected to control for shot difficulty and opponent playing standard. It was also felt that the literature was not very clear on the different information sources available to players when about to return shots. These sources were identified as situational information related to shot probabilities and visual cues emanating predominantly from the swing kinematics. Previous research had utilised a number of different methodologies to investigate this problem with specific issues relevant to each one. Consequently three approaches were adopted; an occlusion film study, occluded simulated matches and no intervention matches.

Study 1 used a film occlusion approach to assess anticipation in squash. A temporally occluded film was compiled from television footage of the final of the 2004 Swedish Open involving two highly ranked players (both top 10 in the world). These players were superior to all of the participants in the study meaning that the task would have been difficult for all of the participants, although the senior elite players may have had limited experience of playing against this standard of player. This main conclusion of this study was that participants were thought to have used situational information to a much greater extent than visual cues which had been expected due to the greater expertise of the players being viewed. The expertise level of the participants only influenced their ability to determine where shots were to be played when shots were classified as hard. Since hard and easy shots were differentiated in this study by the amount of useful situational information contained within them, this finding was thought to show that it was the elite participants' ability to utilise situational information that defined their expertise level. However, the fact that this was a film study prevents firm conclusions regarding actual usage of visual cues and situational information in actual match play. The main conclusion that it was the elite participants' ability to utilise situational information that defined their expertise level must be considered with regard to the fact that the film task involved higher skilled players. This finding may, however, suggest that the ability to utilise situational information is likely to be a by-product of playing racket sports in general. The results from this study also seem to show that playing racket sports will not enable the use of visual cues emanating from swing kinematics of players of a higher ability and thus confirms the conclusions of Renshaw and Fairweather (2000). However the use of these cues against players of a similar or lesser ability, which is much more likely, has not been tested in this study.

Studies 2a and 2b attempted to examine expert and near expert performers' anticipatory ability in simulated match conditions by occluding vision using PLATO liquid crystal occlusion spectacles. County standard badminton players and nationally ranked squash players participated in matches against similarly ranked opponents with vision being occluded at quasi-random points around the point when the opponent of the player wearing the spectacles was playing a shot that was categorised as either hard or easy. Performance was measured in terms of whether the player could determine where the intended shot was going. The elite squash players were able to determine this correctly 78% of the time for easy shots and 97% for hard shots with no gender differences evident. However, this shot difficulty difference was only evident for shots occluded prior to 320ms before racket ball contact i.e. before any swing kinematic information was available, with hard shots predicted 97% of the time but easy shots only 67%. The badminton players on the other hand did not show any difference between easy and hard shots but improved the frequency of their quadrant responses for drop shots from about a half to three quarters correct for occlusions that occurred after 160ms before contact. For clears however they needed to see the racket shuttle contact to improve quadrant responses from about a third to three quarters correct. These findings suggested that the County standard badminton players were more able to utilise visual cues related to the swing sequence than situational information related to the rally conditions of player and shuttle locations. This is the opposite of what was found for the senior elite squash players in Study 1 where these players were able to utilise the situational information but not effectively utilise the visual cues related to the player's swing characteristics. The main explanation for this difference, however, is the skill level of the player being viewed. In Study 1 the player was of a higher skill level whereas in both studies 2a and 2b the player was of a similar playing standard. This means that the player trying to anticipate would have had lots of prior experience of playing against this standard of player, indeed in these studies the opponents were regular opponents of the players. This experience is likely to be useful in familiarising the players to the swing characteristics and hence improve their ability to utilise these visual cues for anticipatory purposes, as found by Renshaw and Fairweather (2000). In Study 2b however the elite squash players typically made their decisions prior to the opponent's movements to the ball (i.e. when the opponent was standing on or near to the T). Such a decision has to be based on situational information as no swing kinematics were available at this time. The results suggested that this situational information enabled very accurate responses particularly when the opponent's shot was going to be under some pressure. This finding does not suggest that visual information pertaining to the swing kinematics were useful or not rather that this information was typically not needed as enough information had already been accumulated. However this finding needs to be considered in relation to the fact that this setting was unnatural to the extent that the players were forced to make responses when vision was occluded. Thus, whilst their performance was very good under these constrained situations, it may be the case that in the actual match setting, when no decision is forced, players are unable to elicit this type of response, even if they could. Hence it was necessary to look at real world, unconstrained situations, to see whether players were able to utilise their anticipatory skills at the levels seen in studies 2a and 2b.

Studies 3a and 3b attempted to determine the actual utilisation of anticipatory movements in match conditions. High-speed camera analysis was used to measure the first movement in the correct direction and split-step timings in relation to shuttle/racket-ball contact of County badminton and expert squash players. Similar to the previous studies the shots sampled were selected for shot difficulty. The squash players were far more likely to make anticipatory responses for hard shots than easy shots but at a much lower level than may have been predicted by the results from Study 2b. Using estimations of reaction times and assumptions regarding the relationship between movement times and anticipation knowledge it was estimated that the elite squash players anticipated the intended direction of the hard shots about one third of the time before swing kinematic information and two thirds of the time when this swing information was present i.e. before racket ball contact. Since the previous visual occlusion study had suggested about 97% accuracy in these situations it was thought that players were not prepared, or were unable, to act on this knowledge. It was therefore hypothesised that elite players have very good knowledge of the situational information, hence the movement adaptation found by James and Bradley (2004) and the very high performance in Study 2b, but because of the possibility of their elite opponent being able to disguise their intentions (James and Bradley, 2004) elite players are more circumspect and do not anticipate to the level at which they may be capable (Study 3b). County badminton players on the other hand were shown to have been likely to be able to anticipate their opponent's forthcoming shots, prior to stroke kinematic information being available, on 1 or 2 shots in every 10. This corresponded to the above chance level finding for the same thing in Study 2a and suggested that County level players can use situational information, although infrequently. Once stroke kinematic information became available, however, these players were more likely to anticipate the forthcoming shot to the extent that as many as 4 shots in every 10 may be anticipated by this level of player. Whilst the results of Studies 3a and 3b provide clear estimates of the incidence of anticipatory behaviour for two different playing standards in two different racket sports some consideration should be given to the fact that in both of these studies the players were familiar with their opponents. This is likely to have aided anticipatory responses due to the familiarity of both the shot patterns (situational information) and the swing kinematics (visual cues). It is thus possible that the predicted anticipation rates shown in these studies over estimate these rates when playing against players of a similar standard but unfamiliar to the player. Further studies are necessary to test this hypothesis however.

This thesis has advanced the literature pertaining to anticipation in racket sports by showing how shot difficulty affects anticipatory performance. Furthermore it has been shown that the playing standards of both the player attempting to anticipate and the player who makes the shot interact to influence this behaviour. It is suggested that any future study must consider carefully the playing standard of all players involved and limit the conclusions to only situations where the playing standards are the same as involved in the study. Since there appears to be a strong relationship between expertise and the use of situational probabilities it is also suggested that the selection of shots to be anticipated in any study should replicate known distributions for players of a similar standard as this information appears to be used to guide anticipatory behaviour. It is possible that this information is even more pertinent when the opponent is familiar to the player and hence future studies should try to assess situations where players are of a similar standard but unknown to each other.

6.2. Practical implications

Anticipatory ability would seem to be a by-product of experience and expertise. This thesis has shown that experts and near experts can anticipate based on both situational information and visual cues although the visual cue information provided by the best players can be deceptive, perhaps to the extent that this information cannot be relied upon. It would seem that situational information alone can be used to enable very accurate judgements of intended shot outcomes although it would seem that this knowledge is not necessarily acted upon. This may be because if elite players try to anticipate hard shots too much the opponent will respond by changing their tactics and play different shots. Anecdotally it appears that when the opponent is under pressure in the back corners, the prediction is that the shot will be played straight as this is the tactically best shot to play. Over anticipating this shot may then induce the opponent to play more cross court shots to render this anticipatory behaviour unfavourable. It seems reasonable to suggest, therefore, that experts have very good anticipatory abilities but for whatever reason, this cannot be acted upon all of the time. It is therefore suggested that elite players should utilise anticipation based on situational information sparingly at times when their opponent is under serve temporal and/or spatial pressure. A pragmatic suggestion to players and coaches therefore is to explicitly develop sub-elite player's knowledge of game-based pressures and the associated usefulness of visual cues and situational information in successful anticipation.

6.3. Thesis Limitations and Recommendations for Future Research

The main limitations of this thesis pertain to sampling issues particularly the limited variability of the participants and differences in levels of expertise across the experimental groups. This is specifically significant with reference to the high speed camera analysis of elite squash players (Study 3b). Unfortunately, only limited data collection could be undertaken at the EIS, the players where preparing for an important tournament in the following week and as such only limited access was granted to the players. These players were also familiar with each other, as were participants in all other studies except Study 1, suggesting that caution is necessary when extrapolating findings.

Specific limitations vary and are explicitly explained within the discussion section of each specific study. However, ecological validity issues remain relevant and will be discussed here. Study 1's design significantly lacked ecological validity (Williams *et al.,* 2003) with the artificial action (viewing a 2D image) and response of selecting the correct quadrant, as opposed to physical responding with a dynamic action to an opponents shot likely to disrupt the participants' cognitive processes sufficiently (uncoupling perception-action response) to render conclusions inadequate. Whilst the case has been made in this study and previously (Abernethy *et al.*, 2001) that this type of study seems to reflect expertise advantages and is therefore a useful experimental setting for evaluating anticipatory behaviour this technique cannot be proposed as the best method for determining the underlying processes of anticipation.

Studies 2a and 2b endeavoured to overcome some of the validity issues present in the first study, by moving to an in-situ assessment of players' anticipation. However, the players were in simulated matches, although instructed to play a competitive match, without the external rewards present, it could be suggested that motivational levels may have been questionable. More importantly the artificial forcing of an anticipation decision may have led to unnatural responses not reflective of normal anticipatory behaviour. The additional equipment (occlusion glasses and associated paraphernalia) may also have proved a distraction, with the masking of audio signals likely to have been a hindrance to some extent. However, the extent to which all of these factors affected the cognitive processes can only be guessed. Whilst the most likely direction of this influence would be to reduce anticipatory behaviour the anticipation levels seen in these studies suggest that this was a fairly small influence.

Although Studies 3a and 3b were non-invasive, similar player motivational issues were present as in the previous two studies. Whilst this was not thought to be of major importance the difference between playing in an important match and a less important one could influence behaviour to the extent that some behaviours are more or less evident. However, it is suggested here that this effect is more likely to influence the incidence of anticipatory behaviour rather than materially affecting it although this would require experimental evidence to substantiate. The fundamental limitation of Studies 3a and 3b relates to using a player's first movement towards the ball to assess anticipatory behaviour. It was argued that this was a valid method although this was not proven. At the very least there remains a need to measure sports specific reaction times (see Williams *et al.,* 2003) to improve the accuracy of this method. However it remains a worthwhile endeavour to investigate new methods for measuring anticipation in a non-invasive manner so that totally natural behaviour can be examined.

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Appendix 1: Application for Ethical Community Approval

Appendix 2: Subject Information and Consent Forms

DEPARTMENT OF SPORTS SCIENCE

SUBJECT INFORMATION SHEET

1. Study title

An investigation into the effects of anticipation and advanced cue utilisation in squash and badminton.

2. Invitation paragraph

You are invited to take part in this study which will attempt to investigate the effect of your skill level upon your ability to anticipate the direction of your opponent's shot. Using a video presentation your ability to use the visual cues your opponent gives off when playing a shot will be assessed. From your responses conclusions will be drawn as to the differences between different standards of player and their ability to use anticipation. All subjects must be over 18 years of age upon commencement of the study.

3. What is the purpose of this study?

The purpose of the study is to build on the previous work involving anticipation and find more robust ways of examining the differences between different skills levels and their ability to use anticipation via visual cues.

4. Why have I been chosen?

You have been chosen to take part in this study due to your interest, ability and current squash ability level. Please note that your taking part in this study is entirely voluntary and that you have the right to withdraw at ant point without reason.

5. What will happen to me if I take part?

You will be asked to watch a still video tape consisting of forty different shots played from all areas of the court. You will then be asked to which court quadrant the ball is hit. The procedure should take approximately half an hour. You are be asked to be fully committed to the study however as stated earlier you have the right to withdraw at ant point without reason.

6. What are the possible disadvantages of taking part?

There are no risks involved with this study.

7. What are the possible benefits of taking part?

This study will give you a greater understanding of anticipation and the use of visual cues within squash.

8. Will my taking part in the study be kept confidential?

All personal data collected will be treated in the strictest of confidence. All published data will not include personal t information such

SPORTS SCIENCE

Subject Information

Name:

Age:

Gender: **Male/Female**

Number of years playing squash:

Highest playing standard:

Current playing standard:

Competitive Record:

Training Regime:

DEPARTMENT OF SPORTS SCIENCE
SUBJECT CONSENT FORM

Contact Details:
Dr. Nic James, Room 716, Vivian Tower
University of Wales Swansea, Department of Sports Science
Singleton Park, Swansea
SA2 8PP Tel. 01792 295075

Tim Caudrelier,
[redacted]

Project Title:
An investigation into the effects of anticipation and advanced cue utilisation in racket sports

Please initial box

1. Date of birth: .../.../... (all subjects must be over 18years of age).
2. I confirm that I have read and understood the information sheet dated ....../....../...... (version number ....) for the above study and have had the opportunity to ask questions. ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐
4. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records. ☐
5. I agree to take part in the above study.

Name of Subject	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

SPORTS SCIENCE

Anticipation & Situational Awareness in Competitive Squash and Badminton

Subject Information Sheet

We are looking to understand how elite players are able to anticipate the trajectory of the ball during a match situation. In order to achieve this we would very much appreciate your assistance.

What is the purpose of this study?

Are squash players able to utilise advance visual cues and/or other sources of information in match situations to anticipate an opponents shot. This will potentially validate previous research that was conducted under laboratory conditions around this area and also provide further support for the theory that players are able to use a range of information sources to base their decisions.

Why have I been chosen?

You have chosen for participation in this study because of your standard of play and experience of squash. Your participation is completely voluntary within the study and you have the right to withdraw at any time without a reason.

What will happen to me if I take part?

You will be required to play up to three matches of squash against an opponent of similar standard. Three separate experiments will be conducted during the three different matches. These will be:

1. *High-speed camera analysis*: During this all you will be asked to do is to play normal competitive games against your opponent.
2. *Simulated matches with visual occlusions and verbal reports*: At specific points during the game, your vision will be restricted by the use of specialised spectacles. At these points you will move to the area of the court you feel you would make you return stroke from. You will also be asked to verbally report how you came to your decision.
3. *Simulated matches with visual occlusions*: At random points during the game, your vision will be restricted by the use of specialised spectacles. At these points you will move to the area of the court you feel you would make you return stroke from.

What are the possible disadvantages of taking part?

As with any sporting situation there is a small possibility of injury, however, every possible precaution will be undertaken to ensure safety. You will undertake normal warm up routines and so this experiment is no more or less hazardous than a normal match.

What are the possible benefits of taking part?

You will gain an insight into how players anticipate forthcoming shots and successfully beat opponents. We will feed back information to you about your performance.

Will my taking part in the study be kept confidential?

Subject confidentiality is a prime concern of this research group and so subject details such as your name will be changed to a 'subject number'. This will mean that prospective readers of the study will not know whom they are reading about.

SUBJECT CONSENT FORM

Contact Details:

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University of Wales, Swansea
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Anticipation & Situational Awareness in Competitive Squash

Please initial box

1. I confirm that I have read and understood the information sheet dated ....../....../...... (version number ....) for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐
3. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records, ☐
4. I agree to take part in the above study.

Name of Subject	**Date**	**Signature**
Name of Person taking consent	**Date**	**Signature**
Researcher	**Date**	**Signature**

SPORTS SCIENCE

Subject Information

Name:

Age:

Gender: **Male/Female**

Number of years playing squash:

Highest playing standard:

Current playing standard:

Competitive Record:

Training Regime:

Appendix 3: Study – Temporally Occluded Film Task

Appendix 3.1. Outcomes from pilot testing for Study 1 (Chapter 3).

Parameter examined	Methods used	Results found	Action
Viewing perspective	1. A squash match was filmed using a Panasonic Mini DV NV-DS28 digital camcorder and transferred to a computer hard drive for viewing via a 17in monitor. 2. Three experienced squash coaches viewed the clips to assess the feasibility of determining anticipatory responses in occluded footage.	Of the 20 clips shown, the coaches were unable to adequately make judgements because the image quality was deemed insufficient on 14 of the clips.	Obtain better quality footage and increase the size of the display
Shot classification	1. A collection of strokes recorded from Sky Sports television coverage of the final of the Swedish Open 2004 was presented to three experienced squash coaches projected on to a 1.00 x 1.50m screen using an Epson PowerLite 820p Projector operating at standard projection speed. 2. The coaches viewed the clips to assess the feasibility of determining anticipatory responses in occluded footage and judged the shots as easy or hard.	Of the 20 clips shown, the coaches were able to make anticipatory judgements on all of the clips. The coaches were in total agreement only for shots that were judged at the end points for the easy and hard classifications (n = 9). Discrepancies were evident on some shots because at least one coach thought the shot was not sufficiently easy or hard as to warrant the classification.	Only select shots that are at the end points for the easy and hard classifications.
Coach's response	1. A collection of easy and hard strokes (at the end points only) recorded from the final of the Swedish Open 2004 was presented to three experienced squash coaches as previously. 2. The coaches viewed the clips to assess the shots as easy or hard and to determine whether they could suggest	The coaches were in total agreement for shots difficulty classifications (n = 60). Where discrepancies were evident for the most appropriate shot to play a debate ensued and consensus achieved otherwise	Only clips where consensus was achieved were deemed eligible for the study. Hence only 40 clips were used to ensure a balanced

	the most appropriate shot to play in the context shown.	the clip was removed (n = 13).	design for easy and hard.

Appendix 3.2: ANOVA summary table for correct responses of shot directions for different occlusion periods and shot difficulties by senior elite, junior elite and senior club squash players.

Source	Sum of Squares	df	Mean Square	F	p
Between Subjects					
Playing standard	52.82	2	26.41	13.01	< .001
Error	46.69	23	2.03		
Within Subjects					
Shot difficulty	19.50	1	19.50	11.23	< .01
Shot difficulty x playing standard	9.027	2	4.51	2.60	.096
Error	39.944	23	1.74		
Occlusion period	9.647	1	9.65	2.93	.100
Occlusion period x playing standard	21.12	2	10.56	3.21	.059
Error	75.62	23	3.29		
Shot difficulty x occlusion period	.99	1	.99	.50	.488
Shot difficulty x occlusion period x playing standard	.97	2	.48	.24	.786
Error	45.62	23	1.98		

Appendix 3.3: Simple main effects summary table for correct responses of shot directions for playing standard at hard and easy shots.

Source	Sum of Squares	df	Mean Square	F	p
Playing standard by easy shots	11.29	2	5.64	3.17	.061
Error	40.89	23	1.78		
Playing standard by hard shots	50.56	2	25.28	12.71	< .001
Error	45.75	23	1.99		

Appendix 3.4: Simple main effects summary table for correct responses of shot directions for shot difficulty at senior elite, junior elite and senior club standards.

Source	Sum of Squares	df	Mean Square	F	p
Shot difficulty by senior elite	22.78	1	22.78	13.12	< .01
Shot difficulty by junior elite	3.13	1	3.13	1.80	.193
Shot difficulty by senior club	.90	1	.90	0.52	.479
Error	39.94	23	1.74		

Appendix 3.5: Simple main effects summary table for correct responses of shot directions for playing standard at 0ms and 160ms occlusion times.

Source	Sum of Squares	df	Mean Square	F	p
Playing standard by occlusion at 0ms	3.90	2	1.95	0.60	.556
Error	74.43	23	3.24		
Playing standard by occlusion at 160ms	70.04	2	35.02	16.82	< .001
Error	47.89	23	2.08		

Appendix 3.6: Simple main effects summary table for correct responses of shot directions for occlusion period at senior elite, junior elite and senior club standards.

Source	Sum of Squares	df	Mean Square	F	p
Occlusion period by senior elite	16.53	1	16.53	5.03	< .05
Occlusion period by junior elite	8.00	1	8.00	2.43	.132
Occlusion period by senior club	3.60	1	3.60	1.09	.306
Error	75.62	23	3.29		

Appendix 4: Studies 2a and 2b – Real World, Liquid Occlusion Spectacles

Appendix 4.1a. Outcomes from pilot testing for Study 2a (Chapter 4).

Parameter examined	Methods used	Results found	Action
Shot type classification	1. A simulated badminton match was filmed using a Panasonic Mini DV NV-DS28 digital camcorder. One participant wore liquid occlusion spectacles. 2. The experimenters remotely triggered the spectacles prior to the non-spectacle wearing player making different types of shot. 3. The participant placed a marker where they thought the shuttle had landed.	1. A large difference was seen between occluded forehand and backhand shots such that backhands were much easier to anticipate. 2. Issues regarding peripheral vision (landing position of the shuttle was sometimes reported as being seen) and auditory cues were apparent. 3. Camera view restrictions meant that some shots were not adequately captured.	1. No backhand shots to be included as too easy to anticipate (90% success rate). 2. Solutions to vision and auditory problems needed. 3. Only shots played from central areas of the forehand court to be used.
Peripheral vision and auditory cues	1. The same method as described above was used with modifications to the occlusion spectacles (towelling was attached via Velcro strips) and industrial strength earplugs worn.	1. The landing position of the shuttle was not visible. 2. Audible cues were reported as not being present.	

Appendix 4.1b. Outcomes from pilot testing for Study 2b (Chapter 4).

Parameter examined	Methods used	Results found	Action
Filming angle	1. A simulated squash match was filmed using a Panasonic Mini DV NV-DS28 digital camcorder. One participant wore liquid occlusion spectacles. 2. The experimenters remotely triggered the spectacles prior to the non-spectacle wearing player	1. All previous techniques utilised in Study 2a seemed to transfer adequately. 2. Camera view restrictions meant that only shots on one side of the court were adequately captured.	1. The camera needs to be repositioned during testing to adequately sample both forehand and backhand shots. .

	making different types of shot. 3. The participant attempted to play a shot in response to the occluded shot.		

Appendix 4.2: MANOVA summary table for lateral and depth mean errors made by sub-elite badminton players for different occlusion periods (n = 10, *cf.* Abernethy *et al.,* 2001), shot type (clear and drop) and shot difficulty (easy and hard shots).

Source		Sum of Squares	df	Mean Square	F	p
Occlusion time	Lateral Difference	100.958	9	11.218	17.237	< .001
	Depth Difference	23.903	9	2.656	6.323	< .001
Shot type	Lateral Difference	4.481	1	4.481	6.885	< .01
	Depth Difference	.673	1	.673	1.603	.206
Shot difficulty	Lateral Difference	.081	1	.081	.124	.725
	Depth Difference	.012	1	.012	.029	.864
Occlusion time x shot type	Lateral Difference	72.552	9	8.061	12.387	< .001
	Depth Difference	8.328	9	.925	2.203	< .05
Occlusion time x shot difficulty	Lateral Difference	4.127	9	.459	.705	.705
	Depth Difference	2.687	9	.299	.711	.699
Shot type x shot difficulty	Lateral Difference	.512	1	.512	.786	.376
	Depth Difference	.673	1	.673	1.602	.206
Occlusion time x shot type x shot difficulty	Lateral Difference	5.718	9	.635	.976	.459
	Depth Difference	3.728	9	.414	.986	.450
Error	Lateral Difference	316.926	487	.651		
	Depth Difference	204.549	487	.420		

Key: The 10 occlusion periods were: all occlusion time less than -620ms (1), -620ms to -540ms (2), -540ms to -460ms (3), -460ms to -380ms (4), -380ms to -300ms (5), -300ms to -220ms (6), -220ms to -140ms (7), -140ms to -60ms (8), -60ms to 20ms (9), 20ms to 100ms (10); (based on Abernethy *et al.*, 2001 except that Abernethy did not include the first category and included two additional categories of 100ms to 180ms and 180ms to 260ms).

Appendix 4.3: Simple main effects summary table for lateral and depth mean errors by occlusion periods (n = 10, *cf.* Abernethy *et al.*, 2001), and shot type (clear and drop).

Source		Sum of Squares	df	Mean Square	F	p
Shot type x	Lateral Difference	3.48	1	3.48	4.16	< .05
Occlusion time 1	Depth Difference	2.40	1	2.40	5.24	<.05
Shot type x	Lateral Difference	7.20	1	7.20	8.60	<.001
Occlusion time 2	Depth Difference	0.71	1	0.71	1.54	.215
Shot type x	Lateral Difference	20.17	1	20.17	24.09	<.001
Occlusion time 3	Depth Difference	0.46	1	0.46	1	.319
Shot type x	Lateral Difference	0.85	1	0.85	1.01	.316
Occlusion time 4	Depth Difference	1.37	1	1.37	2.98	.850
Shot type x	Lateral Difference	0.42	1	0.42	.50	.478
Occlusion time 5	Depth Difference	0.02	1	0.02	0.03	.853
Shot type x	Lateral Difference	2.48	1	2.48	2.97	.086
Occlusion time 6	Depth Difference	0.14	1	0.14	0.30	.583
Shot type x	Lateral Difference	11.75	1	11.75	14.03	<.001
Occlusion time 7	Depth Difference	0.01	1	0.01	0.02	.883
Shot type x	Lateral Difference	0.35	1	0.35	0.42	.518
Occlusion time 8	Depth Difference	0.82	1	0.82	0.39	.189
Shot type x	Lateral Difference	0.11	1	0.11	0.13	.721
Occlusion time 9	Depth Difference	0.18	1	0.18	0.39	.534
Shot type x	Lateral Difference	2.59	1	2.59	3.09	.079
Occlusion time 10	Depth Difference	0.90	1	0.90	1.95	.165
Error	Lateral Difference	432.17	516	0.84		
	Depth Difference	236.82	516	0.46		

Appendix 4.4: ANOVA summary table for correct quadrant responses by sub-elite badminton players in response to different shot difficulties (easy and hard) and types (clear and drop) at four different occlusion periods (at contact to 160ms after contact (1); 160ms before contact to contact (2); 320ms before contact to 160ms before contact (3); all occlusion times prior to 320ms before contact (4)).

Source	Sum of Squares	df	Mean Square	F	p
Shot type	4.129	1	4.129	20.091	< .001
Shot difficulty	.025	1	.025	.124	.725
Occlusion period	12.581	3	4.194	20.408	< .001
Shot type x shot difficulty	.769	1	.769	3.743	.054
Shot type x occlusion period	2.237	3	.746	3.629	< .05
Shot difficulty x occlusion period	.227	3	.076	.368	.776
Shot type x shot difficulty x occlusion time	.790	3	.263	1.282	.280
Error	105.006	511	.205		

Appendix 4.5: Simple main effects summary table for correct quadrant responses by sub-elite badminton players in response to different shot types (clear and drop) at four different occlusion periods (at contact to 160ms after contact (1); 160ms before contact to contact (2); 320ms before contact to 160ms before contact (3); all occlusion times prior to 320ms before contact (4)).

Source	Sum of Squares	df	Mean Square	F	p
Shot type x occlusion period 1.	0.37	1	0.37	1.61	.205
Shot type x occlusion period 2.	0.05	1	0.05	0.23	.632
Shot type x occlusion period 3.	4.08	1	4.08	17.87	<0.001
Shot type x occlusion period 4.	0.69	1	0.69	3.04	.082
Error	119.28	522	.23		

Appendix 4.6: Post Hoc analysis (Scheffe) summary table for correct quadrant responses of drop shots at different occlusion periods (n = 4)

	320ms before contact - 160ms before contact	160ms before contact - contact	At contact - 160 ms after contact
All occlusion times prior to 320ms before contact	NS	< .01	< .001
320ms before contact - 160ms before contact		< .001	< .001
160ms before contact - contact			NS

Appendix 4.7: Simple main effects summary table for correct quadrant responses by sub-elite badminton players in response to different shot types (clear and drop) and shot difficulties (hard and easy).

Source	Sum of Squares	df	Mean Square	F	p
Shot type x easy shots.	0.58	1	0.58	2.52	.113
Shot type x difficult shots	3.01	1	3.01	13.08	<0.001
Error	120.81	524	.23		

Appendix 4.8: ANOVA summary table for correct quadrant responses by elite male and female squash players in response to easy and hard shots

Source	Sum of Squares	df	Mean Square	F	p
Shot difficulty	5.35	1	5.35	45.52	< .001
Gender	.03	1	.03	.28	.596
Gender x shot difficulty	.11	1	.11	.95	.33
Error	66.45	576	.12		

Appendix 4.9: ANOVA summary table for correct quadrant responses by elite players in response to easy and hard shots at four different occlusion periods (at contact to 160ms after contact (1); 160ms before contact to contact (2); 320ms before contact to 160ms before contact (3); all occlusion times prior to 320ms before contact(4))

Source	Sum of Squares	df	Mean Square	F	p
Occlusion period	3.672	3	1.224	11.889	< .001
Shot difficulty	2.268	1	2.268	22.030	< .001
Occlusion period x shot difficulty	2.116	3	.705	6.851	< .001
Error	57.239	556	.103		

Appendix 4.10: Simple main effects summary table for correct quadrant responses by elite players in response to easy and hard shots at four different occlusion periods (at contact to 160ms after contact (1); 160ms before contact to contact (2); 320ms before contact to 160ms before contact (3); all occlusion times prior to 320ms before contact(4))

Source	Sum of Squares	df	Mean Square	F	p
Shot difficulty by occlusion period 1	0.17	1	0.17	1.55	0.213
Shot difficulty by occlusion period 2	0.20	1	0.20	1.86	.173
Shot difficulty by occlusion period 3	7.85	1	7.85	72.02	<0.001
Shot difficulty by occlusion period 4	2.09	1	2.09	19.21	<0.001
Error	60.91	11	.11		

Appendix 5: Studies 3a and 3b – High Speed Camera Analysis

Appendix 5.1: MANOVA summary table for the first move towards the shuttle and the initiation of and end of split step by sub-elite badminton players for shot type (clear and drop) and shot difficulty (easy and hard shots).

Source		Sum of Squares	df	Mean Square	F	p
Shot type	First move	0.555	1	0.555	13.649	< .001
	Initiation of split step	0.025	1	0.025	0.548	.459
	End of split step	0.031	1	0.031	0.685	0.408
Shot difficulty	First move	0.037	1	0.0337	0.827	0.364
	Initiation of split step	0.037	1	0.037	0.806	0.370
	End of split step	0.041	1	0.041	0.912	0.340
Shot type x shot difficulty	First move	0.017	1	0.0170	0.419	0.518
	Initiation of split step	0.010	1	0.010	0.216	0.643
	End of split step	0.018	1	0.018	0.403	0.526
Error	First move	20.989	516	0.041		
	Initiation of split step	23.614	516	0.046		
	End of split step	23.171	516	0.045		

Appendix 5.2: Table showing means and standard deviations for first move in relation to contact, initiation and end of split steps for sub-elite badminton players by shot type and difficulty.

Shot type	Difficulty		First move (s)	Initiation of split step (s)	End of split step (s)
Clear	Easy	Mean	0.30	-0.03	0.23
		N	116	116	116
		SD	0.19	0.20	0.20
	Hard	Mean	0.27	-0.06	0.20
		N	144	144	144
		SD	0.21	0.21	0.22
Drop	Easy	Mean	0.22	-0.06	0.20
		N	116	116	116
		SD	0.20	0.21	0.21
	Hard	Mean	0.22	-0.06	0.20
		N	144	144	144
		SD	0.20	0.22	0.22

Appendix 5.3: Observed frequencies of first movements in relation to the split step for easy and hard shots by shot type.

			First move	
Shot type	Difficulty		Before end of split step	After end of split step
Clear	Easy	N	9	107
		%	7.76	92.24
	Hard	N	13	131
		%	9.03	90.97
Drop	Easy	N	45	71
		%	38.79	61.21
	Hard	N	50	94
		%	34.72	65.28