Decision making in tennis: Exploring the use of kinematic and contextual information during anticipatory performance

Georgina Vernon

B Ex. Science (Honours)

Institute for Health and Sport, Victoria University

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

June 2020

Abstract

Expert tennis players are known to anticipate the serve of an opponent using two sources of information from their environment. Kinematic information sources are cues from the action of the server, while contextual information may be any source of information outside of the visual kinematic cues which the expert considers. While previous research has examined the contribution of these two sources on an expert tennis player's anticipation capability, it is still unknown how they interact during the return of serve. Consequently, this thesis had two aims:

1. Investigate the temporal interaction of kinematic and contextual information sources considered by expert tennis players when returning serve.
2. Investigate how changes in kinematic or contextual sources of information alters an expert player's return of serve performance.

The two aims of this thesis were considered to address the current gap in the existing literature, and enhance our understanding about the temporal priority of anticipatory information sources expert tennis players are attuned to during the return of serve.

The three investigations from this thesis revealed a number of important findings about the temporal interaction of anticipatory information sources. Study 1 determined nine higher order themes from qualitative interviews with expert tennis players about their returning experiences in professional matches. These themes were developed into a temporal model that presented the anticipatory information in order of priority during the return of serve. Study 2 found that although expert tennis players discussed the influence of contextual information on their returning behaviour in Study 1, spatiotemporal data from professional matchplay revealed that this only had an influence on their depth position, and not their lateral position. This study also found that the largest variation in return position occurred at return impact, which was important for confirming that significant changes in return position does not occur until ball flight information is available. The final experiment revealed that although expert tennis players are attuned to contextual and kinematic information, this information does not necessarily improve the quality of the return. Contextual information was the priority anticipatory information source until ball toss information became available. The kinematic information from the ball toss is then prioritised by the returners until ball flight information is available, which was found to be the most influential information source for altering returner behaviour. Furthermore, it was found that expert tennis players were not susceptible to a congruence effect as suggested in a number of previous studies.

The conclusion from the experimental series is that a returner's behaviour is influenced by the most reliable source of information available at each moment in time, with ball flight information the most reliable and heavily prioritised source. This finding is important for tennis players and coaches to consider when implementing training strategies for the returners to recognise and respond to the various information sources during a match.

Student declaration

"I, *Georgina Vernon*, declare that the PhD thesis entitled *Decision making in tennis: Exploring the use of kinematic and contextual information during anticipatory performance* is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

Signature: [redacted] Date: 1/07/20

Acknowledgments

Firstly, I would like to thank my supervisory team – Damian, Machar, and Steph. To Damo, I can’t thank you enough for everything you’ve helped me with over the past few years. From developing our initial ideas, all the way through to the final write-up, I am especially grateful for being able to work with you during this time, and you definitely pushed me to get the best out of my research. I have no doubt I wouldn’t have been able to get this thesis to where it is now without your help and guidance, and I’ll always be glad we have been able to work together. To Machar, thank you for all you help as the TA contact, and making sure I kept the practical applications in mind, especially at times when I was getting too caught up in the theory. Thank you also for the opportunities to broaden my practical skills through the National Academy. This time and experience would not have been possible without your help, and I won’t be forgetting this opportunity any time soon. Finally, to Steph, enormous thanks for your help with everything statistics-related in this thesis. My new-found skills in R wouldn’t be possible without you pointing me in the right direction, and I know these skills are only going to help me moving forward.

I must also thank Tennis Australia for not only contributing financially to my PhD, but for also providing me access to coaches, players, and Australian Open data to help me complete my research. The coaches were always available and invaluable to have discussions with about whether I was on the right path in terms of the practical application, and I hope this comes through in my thesis. Enormous thanks must especially go to all the staff and players at the National Academy in Brisbane. Thanks to the coaches for giving up your time, letting me run ideas past you, stealing away your players for testing, helping with serving, and just generally being able to have some robust discussions week in and week out. My thesis definitely would not have been possible without this engaging environment, and I will always remember my time at the NA for helping to develop my research skills and my applied sport science skills.

Finally, and most importantly, immense thanks to my parents and my sisters. I know you didn’t always understand what I was doing, or what I was going through, but your constant support, encouragement, and pride in me kept me determined throughout my PhD. I can never thank you all enough for this support, and you were only ever a phone call away if I needed to chat. I know you all shook your head in disbelief when I said I was thinking about doing a PhD, but I promise I’ll go and get a real job now.

Table of Contents

Abstract .... **i**

Student declaration .... **iii**

Acknowledgments .... **iv**

Table of Contents .... **vi**

List of tables .... **xi**

List of figures .... **xii**

Chapter 1: Introduction **1**

Chapter 2: Review of the literature **9**

2.1 Introduction 10

2.2 Perceptual Expertise – sport and other activities 11

2.2.1 What sets experts apart from novices? 12

2.3 Anticipation in sport 14

2.4 Kinematic information sources 22

2.5 Contextual information sources 28

2.5.1 The congruence effect 33

2.5.2 Methodological considerations 34

2.6 Methods for investigating anticipation 36

2.6.1 Temporal occlusion 37

2.6.2 Spatial Occlusion 39

2.6.3 Gaze tracking 40

2.6.4 Qualitative investigations 42

2.6.5 The importance of perception-action coupling in anticipation research 44

2.7 Summary 45

Chapter 3: A qualitative examination of the interaction of anticipatory information sources used by professional tennis players **47**

3.1 Abstract.. 48

3.2 Introduction 48

3.3 Method.. 53

3.3.1 Participants 53

3.3.2 Procedure..54

3.3.3 Interviews 54

3.3.4 Analysis 56

3.4 Results 57

3.4.1 Anticipation perspectives 60

3.4.1.1 Consciousness.. 60

3.4.1.2 Tactical awareness.. 61

3.4.1.3 Contextual information sources.. 61

3.4.1.4 Kinematic information sources.. 63

3.4.1.5 Mentality/confidence.. 63

3.4.1.6 Returner technique or strategy.. 64

3.4.1.7 Build pressure on server 65

3.4.2 General participant observations 66

3.4.2.1 Returning characteristics 66

3.4.2.2 Practice 67

3.5 Discussion.. 68

3.5.1 The priority of information sources during the return of serve 69

3.5.2 Conclusion..73

Chapter 4: Analysis of player movement during the return of serve in professional tennis match play.. 75

4.1 Abstract.. 76

4.2 Introduction 77

4.3 Method.. 81

4.3.1 Participants 81

4.3.2 Data..81

4.3.3 Pre-processing 82

4.3.4 Analysis 83

4.4 Results 84
4.4.1 Changes to return position over the duration of a match................................84
4.4.2 Changes to return position on break points 90
4.4.3 Individual player examples...91
4.5 Discussion.. 94
4.5.1 What general positioning strategies do players adopt when returning the first serve?...95
4.5.2 Do players adjust their return position according to the scoreboard, or more specifically, on break points? 97
4.5.3 How generalisable or individual is movement behaviour on the return of serve?...100
4.5.4 Conclusion 102

Chapter 5: Understanding the interaction of anticipatory information sources during the return of serve in tennis 103

5.1 Abstract.. 104
5.2 Introduction 105
5.3 Method.. 111
5.3.1 Participants 111
5.3.2 Materials, Apparatus and Set Up...111
5.3.3 Procedure 113
5.3.4 Dependent Measures..117
5.3.5 Data Analysis...119
5.4 Results 120
5.4.1 Congruent points (break points set A) compared to incongruent points (break points set B)...120
5.4.1.1 Response time.. 120
5.4.1.2 Return speed 120
.... 121
5.4.1.3 Return outcome 121
5.4.1.4 Return locations... 121
5.4.1.5 Gaze fixations 122

5.4.2 Congruent points (break points set A) compared to other points 130
5.4.2.1 Response time 130
5.4.2.2 Return speed 130
5.4.2.3 Return outcome 131
5.4.2.4 Return locations 131
5.4.2.5 Gaze fixations 132
5.4.3 Post-experiment qualitative reports 141
5.5 Discussion 142
5.5.1 Return quality 142
5.5.2 Gaze fixations 144
5.5.3 Combining contextual and kinematic information to improve return outcomes 146
5.5.4 Limitations 149
5.5.5 Conclusion 151

Chapter 6: General discussion 152

6.1 The experimental series 153
6.1.1 Qualitative exploration of tennis specific contextual information sources ..153
6.1.2 Quantitative explanation of returner behaviour based on contextual information sources 155
6.1.3 Exploring the temporal interaction of kinematic and contextual information sources during the return of serve task 156
6.2 Conclusions from the results of the experimental series 160
6.2.1 Do returners behave the way they say they do during the return? 160
6.2.2 Returning behaviours and outcomes based on contextual and kinematic changes in match play 163
6.2.3 Overall outcomes from the experimental series 166
6.3 Methodological considerations 167
6.3.1 Qualitative interviews 167
6.3.2 Spatiotemporal player tracking 168
6.3.3 Manipulation of in situ anticipatory information sources 170
6.4 Practical implications 170

6.5 Limitations and future research 172
6.5.1 Limitations..172
6.5.2 Future research considerations 174
6.6 Conclusion 175

References.. 177

Appendix A: Information to participants (Chapter 3) 191

Appendix B: Consent form (Chapter 3) 193

Appendix C: Information to participants (Chapter 5) 195

Appendix D: Consent form (Chapter 5) 198

List of tables

Table 2.1: Pivotal studies which have examined the use of kinematic cues in determining anticipation skill in experts and novices of different sports........................23

Table 2.2: Pivotal studies which have examined the use of contextual cues in determining anticipation skill in experts and novices of different sports........................31

Table 3.1: Nine higher order themes and the corresponding lower order themes resulting from return of serve anticipation interviews...58

Table 4.1 Summary of fixed effects for player and match lateral and depth return position for three time intervals during the return of serve 85

Table 4.2: Summary of random effects for player-match variances for lateral and depth return position for three time intervals during the return of serve...................................87

Table 4.3: Break points added as a fixed effect in mixed model analysis for demonstrating change in return position depth over the duration of a match for each time interval...91

Table 5.1: Serving pattern for Set A and Set B 116

Table 5.2: Proportion of returns by location on break points set A and break points set B 121

Table 5.3: Proportion of returns by location on other points and break points set A....132

List of figures

Figure 2.1: Anticipatory timeline involving the use of kinematic and contextual information sources and their influence on anticipation and action outcomes................20

Figure 3.1: Temporal model depicting the conscious use of kinematic and contextual information sources throughout the process of returning a tennis serve 69

Figure 4.1: a) -1 before serve random effects slope values; b) At serve impact random effects slope values; c) At return impact random effects slope values............................89

Figure 4.2: Tsonga depth returning position across cumulative point count for all three time intervals per opponent 92

Figure 4.3: Nadal depth returning position across cumulative point count for all three time intervals per opponent 93

Figure 4.4: Federer depth return position across cumulative point count for all three time intervals per opponent 94

Figure 5.1: Tennis court equipped with Playsight system with 2 HD cameras and 4 analytical cameras...112

Figure 5.2: One of the participants during the task equipped with the eye-tracking glasses...113

Figure 5.3: Classification of three return locations based on information from high-performance tennis coaches..117

Figure 5.4: Five serving phases adapted from Kovacs and Ellenbecker (2011) 118

Figure 5.5: Response time (ms) break points set A and break points set B per game ..120

Figure 5.6: Average return speed (km/hr) break points set A and break points set B per game 121

Figure 5.7: Heatmap of return locations in a) break points in Set A b) break points in Set B 122

Figure 5.8: Number of fixations break points set A and break points set B..................123

Figure 5.9: Mean number of fixations per service phase break points set A and break points set B 123

Figure 5.10: Mean fixation length (% of total point time) break points set A and break points set B 124

Figure 5.11: Fixation locations per serve phase break points set A and break points set B 126

Figure 5.12: Fixation length over the trial games for each serve phase break points set A and break points set B...129

Figure 5.13: Response time (ms) other points and break points set A per game 130

Figure 5.14: Average return speed (km/hr) other points and break points set A per game 131

Figure 5.15: Heatmap of return locations in a) other points b) break points in Set A...132

Figure 5.16: Number of fixations other points and break points set A 133

Figure 5.17: Mean number of fixations per service phase other points and break points set A..133

Figure 5.18: Mean fixation length (% of total point time) other points and break points set A..134

Figure 5.19: Fixation locations per serve phase other points and break points set A ...136

Figure 5.20: Fixation length over the trial games for each serve phase other points and break points set A 140

Chapter 1: Introduction

"He has tremendous anticipation and quick reactions and like all ultra-talented sportsmen, never looks hurried." – Judy Murray speaking about Roger Federer (BBC Sport, 2008; Jackson & Mogan, 2007; Murphy, Jackson, & Williams, 2019).

In the sport of tennis, the ability of expert players to be able to anticipate the actions of their opponents is critical due to the fast ball speeds seen in the modern professional game. For professional players to serve at over 200km/hr, hit groundstrokes between 113-133km/hr (Kovalchik & Spence, 2016), and still be able to return and rally these high speeds shots, these expert tennis players must be able to anticipate the actions of their opponent to be competitive. A large body of research has shown that expert tennis players have faster response and movement times, and better response accuracy in studies investigating anticipation capabilities compared to novice tennis players (Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996). These results are consistent not only in studies of tennis players, but also across a number of other interceptive sports, such as baseball (Paull & Glencross, 1997), cricket (Müller, Abernethy, & Farrow, 2006), and volleyball (Schläppi-Lienhard & Hossner, 2015). The ability to be able to anticipate the actions of their opponent is therefore not only an important characteristic of expert sports people, but an important skill needed to be successful in their chosen sport.

The ability of experts to be able to correctly anticipate action outcomes relies on different sources of information uptake by these experts. Firstly, athletes have exceptional perceptual skills and are able to attune to advanced visual cues from their environment, and more often than not, from their opponent(s) (Müller & Abernethy, 2012). These cues are known as kinematic cues, and changes in these cues often result in changes in the outcome of the action being viewed. There has been a large amount of research conducted on the specific kinematic cues for tennis (both serves and groundstrokes), as well as across a number of different sports. For example, when anticipating the tennis serve, it is well documented that experts fixate their gaze on the ball toss, racquet, or swing arm of their opponent's service action in order to correctly predict the direction and type of serve they will need to return (Ward, Williams, & Bennett, 2002). Secondly, anticipation has been found to also be informed by other sources of information, known as contextual cues. Contextual information may be any source of information outside of the visual kinematic cues which the expert considers during their anticipation preparation (Murphy, Jackson, Cooke, Roca, Benguigui, & Williams, 2016). These can include cues such as weather conditions, score, knowledge of their opponent's preferences or tendencies, and the situational probabilities which can be deduced from these cues. Many athletes have referred to using (or at least being aware of) situational probabilities of their sport in post-match interviews or press conferences. These players often talk about an opponent's particular percentage to execute one type of play, a certain serve on break point, or preferred direction when executing a penalty kick (e.g. Gatto, 2018). Research across a number of sports in recent times has focused on how changes in situational probabilities alter anticipation accuracy and movement in skilled athletes.

Kinematic and contextual sources of information which expert athletes use to anticipate certain scenarios in their chosen sport are now increasingly important in the professional sports industry to gain that competitive advantage that is highly sought after. However, there has only recently been a push to increase the amount of research into understanding how contextual information sources are used (Cañal-Bruland & Mann, 2015), how these two different sources are prioritised, and the interaction of these sources during a task which requires anticipation.

The general aims of this thesis were to 1) to investigate the temporal interaction of kinematic and contextual information sources expert tennis players consider when returning serve; and 2) to investigate how changes in kinematic or contextual sources of information altered an expert player's anticipation skills, decision-making and behaviour when returning serve. The specific aims of this thesis are:

1. Determine the specific contextual factors professional tennis players consider when anticipating an opponent's serve during competitive matches.
2. Statistically describe the changes in tennis player's position on the return of serve based on contextual information availability in Grand Slam tournament play.
3. Selectively manipulate the contextual and kinematic information available in an in situ match scenario to determine the temporal priority of such information sources throughout the return of serve.

Three studies were designed to address each aim in succession, and to address the current gaps in the literature regarding the temporal availability and use of kinematic and contextual information sources in anticipation of the tennis serve. Study 1 investigated the use of contextual and kinematic information during anticipation of the return of serve from qualitative interviews with current and former professional tennis players. Study 2 assessed how knowledge of contextual cues alters return behaviour during tennis match play. Finally, Experiment 3 involved the manipulation of contextual information to determine how situational probability information given to skilled tennis players during a return of serve scenario interacted with the kinematic cues of a server's action to influence returner decision-making, behaviour and outcome.

This thesis is organised into six chapters to present the overall results of the research. Chapter 2 reviews the existing literature about anticipation. Specifically, the literature review presents and critiques published works about expertise and experts' perceptual skills in sport, with a particular focus on interceptive sports such as tennis, baseball and cricket. Information about anticipation in sports with a subsequent focus on kinematic and contextual information sources is also discussed. Subsequently, the methods used to investigate kinematic and contextual information sources, both independently and dependently of each other are presented and critiqued, including the importance of perception-action coupling which provides a critical component of assessing the real-life outcomes of anticipation.

Chapters 3, 4, and 5 focus on each of studies 1, 2, and 3 respectively, where the specific experimental methods, hypotheses, data collection, analysis, and a short discussion for each experiment are included in each of these chapters.

Chapter 3 presents Study 1 which examines the use of kinematic and contextual information sources by professional tennis players when anticipating and returning serve during matches. The first study comprises qualitative interviews with current and former professional tennis players about their use of both kinematic and contextual cues during anticipation of the serve. The purpose of this first study was to ascertain the explicit use of these cues and determine the critical cues players attune themselves to when anticipating the serve. The specific research aims for this study are:

1. Determine the kinematic and contextual cues that highly skilled tennis players are attuned to during the return of serve when anticipating direction and type of serve.

2. Investigate the priority of the kinematic and contextual cues before and during the return of serve.
3. Determine how anticipatory information is updated over the duration of a match and the sources of anticipatory information that were prioritised.

This chapter is designed to determine the specific kinematic and contextual information sources used during the return of serve which are required for intervention in the subsequent two studies which investigate the interaction of these kinematic and contextual cues.

Chapter 4 examines how return position changes over the duration of a Grand Slam tennis match. Using the knowledge of contextual cues gathered from Study 1, this investigation explores how these cues influence changes to returning behaviour in the form of the returner's positioning before and during the serve. Through the novel application of three-dimensional ball and player tracking technology, this study also investigates the changes in returner's position during the return of serve with emerging knowledge of opponent's preferences, how knowledge of an opponent, and different opponent's skills, influence changes in a returner's court position. The specific research aims of this study are:

1. Determine how return position of highly skilled tennis players changes over the duration of a match based on specific match and/or opponent factors
2. Determine how return position of highly skilled tennis players changes on break points when situational probability information is high, compared to all other points of a match where there is equal probability of serve direction.

This chapter is designed to determine the changes in return position given the contextual information sources that emerge over the duration of a match. This study is critical for demonstrating the changes to player behaviour with changes to situational probabilities – an important contextual information source for anticipating the serve.

Chapter 5 presents Experiment 3 where situational probabilities are manipulated during a return of serve scenario to examine the changes in gaze behaviour and subsequent influence on return decision-making and outcomes of skilled tennis players. This experiment requires the use of mobile gaze tracking glasses, and manipulation of score scenarios to determine the associated changes in returning behaviour and outcomes. The purpose of this experiment was to determine which anticipatory information sources are prioritised throughout the return of serve when highly skilled tennis players are faced with changes in kinematic or contextual cues. The specific research aims for this experiment are:

1. Determine the differences in response times, return quality and gaze behaviour to a serve on points where congruent contextual and kinematic information is present, compared to points where incongruent contextual and kinematic information is presented.
2. Similarly, determine the differences in response times, return quality and gaze behaviour where congruent contextual and kinematic information is present, compared to points when only kinematic information is present.

This chapter is designed to determine the priority of information sources during the return when highly skilled tennis players are anticipating the serve, and how this information alters returning behaviours.

The final chapter of this thesis (Chapter 6) comprises a general discussion which unifies the key findings from the experimental series. This chapter places a heavy focus on the discussion of the results from the experimental series, and how these results draw upon each other to conclusively determine the temporal priority of anticipatory information sources used by expert tennis players when returning serve. This chapter also presents the implications of these findings and how they fit into the existing literature presented in chapter 2. The discussion will then present the methodological considerations from the experimental series, including advantages and limitations. The findings of this research will then be discussed in terms of translating into practical knowledge about the importance of attuning to specific anticipatory cues in tennis (and by extension, other interceptive sports). The final section of the discussion chapter will focus on limitations of the experimental series and the implications for future.

Chapter 2: Review of the literature

2.1 Introduction

In time-stressed situations where accurate decision-making and anticipation of an action outcome is critical to the success of the response, experts have an advantage over novices in the accuracy and timely execution of the action response. Early research investigating expertise and decision-making has considered domains from chess board recall (Chase & Simon, 1973; De Groot, 1965), tactical military actions (Endsley & Smith, 1996), and sports tasks (Bartlett, 1947). Despite the diversity of these situations, they all require experts to possess highly developed perception, anticipation, and decision-making to perform responses in a timely and accurate manner. Anticipation as an athletic skill has been studied in a number of sports, including team-based sports such as football and basketball, and interceptive sports such as tennis and cricket. Different sources of information feed an expert athlete’s anticipatory capability, namely kinematics which describes an opponent’s movement actions and the possible outcomes of specific kinematic movements; and contextual information sources which describes all cues outside of the opponent’s movement action such as patterns of play in specific scoring situations (i.e., situational probabilities). There have been a number of studies conducted across a variety of sports which has investigated the influences these information sources have on anticipatory skill. Tennis is a good example of a sport where athletes must rely on both kinematic and contextual information sources to inform their anticipation. To investigate these information sources, a number of different methods have been used including temporal occlusion, gaze-tracking, and the manipulation of probability situations. The aim of this literature review is to present and critique research investigating expert anticipatory skill in a number of tasks; the information sources that inform anticipation; how experts (and in particular tennis players) utilise this information relative to lesser skilled performers, and the methods used to investigate this issue.

2.2 Perceptual Expertise – sport and other activities

Investigations into attributes of expert skill has long been a focus of research. Bartlett (1947) reviewed expert human skill during a series of lectures which described that skilled performers know both “what” to do and “how” to do it during a skilled task. However, it is the conscious focus on the “what” of the task, that sets the experts apart from the novices. Often this is due to superior awareness by experts to key information from their environment which they are able to perceive, process and use to help them perform the required skills in a timely and accurate manner. Additionally, Bartlett suggested that experts appeared to have “all the time in the world” compared to novices when conducting the same task, suggesting that by reading the situation, experts are able to prepare earlier than novices and execute a better-timed response. In investigations of expert chess skill, both De Groot (1965) and Chase and Simon (1973) conducted perception and memory tests on expert and novice chess players to compare speed and accuracy between the two groups. The outcome of these studies showed that experts are better than novices at using knowledge of familiar situations to perceive what is in front of them and inform their decisions to improve both their timing and accuracy of their response to the task. In sport scenarios, Williams and Davids (1995) investigated if expert skill and knowledge are a result of experience, or a characteristic of expertise. They found that a larger knowledge base of the expert’s skill is an essential component of skill rather than a by-product of experience, confirming what was found by the expertise research of Chase and Simon (1973) and extending this application into a sporting environment.

2.2.1 What sets experts apart from novices?

Perceptual expertise in sport has long been a focus of many research studies. Attributes such as visual search and attention, anticipation, and decision-making have long been used to compare an expert’s capability to novices from the same sport. Prominent early evidence about the visual perceptual skills of sport experts demonstrated that while expert and novice squash players may have similar visual search strategies, the ability of the experts to extract and use available advanced information is far greater than the novices, and therefore the experts show a superior ability to predict the outcomes of an opponent’s action (Abernethy, 1988). In addition to this, research into how visual search strategies and selective attention to critical cues differ between expert and novice football players has also been conducted (Williams & Davids, 1998). This research found that experienced football players had superior anticipation outcomes (faster response time and response accuracy) and different visual search strategy to novices. In a 3-on-3 scenario when the information from areas other than the ball or the player with the ball was occluded, the experienced players performance decreased, leading the researchers to conclude that the experts were attentive to that information for directing their performance.

These studies concluded that experts are superior to novices at extracting and using relevant visual information during a specific time-stressed sport task, however it is difficult to generalise these results to all sports. This has resulted in a large body of research in perceptual-cognitive expertise to encapsulate the differences between experts and novices of specific sports (Mann, Williams, Ward, & Janelle, 2007). The majority of the research has focused on using response accuracy, reaction times of participants, and visual search strategies to quantify the differences between experts and novices in a variety of sport tasks. The results of these studies have led to a consistent focus on research designed to determine how experts differ from novices in anticipatory tasks, particularly in sports which require quick decision-making in time-stressed scenarios such as in invasion sports (i.e. football or hockey) and interceptive sports (i.e. tennis or baseball).

It has been suggested that the memory and experience of experts in these situations allows for decision-making to occur implicitly during the task (Afonso, Garganta, & Mesquita, 2012). This may also explain how some experts are able to execute a skill using little to no memory sources, and instead rely on automatic processes to respond (Gray, 2015). On the contrary, qualitative interviews with expert beach volleyball players revealed that the conscious awareness of key environmental information influenced decision-making during a time-constrained task and allowed the athletes to have real clarity when it came to determining the appropriate shot to use based on the information they gathered (Schläppi-Lienhard & Hossner, 2015). This suggests that the clarity of the response by expert athletes during this time must consider the environmental information that expert athletes are attuned to. The best possible response to the information available also requires the decision-making process to occur within the time constraints of the task, making the processing of the available information sources even more critical for successful responses (Afonso et al., 2012). This suggests that there may be a mixture of both conscious and implicit processing of information sources which contributes to both the decision-making process and the response execution which require expert athletes to anticipate the outcome due to the severe time constraints of many tasks.

2.3 Anticipation in sport

The ability to predict and interpret an opponent's actions is a critical attribute which expert athletes use when competing in high level competition. Expert athletes in invasion sports must be able to predict the actions of their opponents, not only the player with the ball, but also the other players on the field. The processes underlying the superior anticipatory capabilities of expert athletes include a number of perceptual-cognitive skills which contributes to the ability of experts to predict the outcomes of an opponent's actions. The skills include the ability to pick up advanced postural information of an opponent, identify familiar patterns of play, use an efficient visual search method of available environmental information and consider the most probable options of that scenario (Williams, 2009). These skills work together in a continuous and dynamic way during expert performance to contribute to the anticipation of the particular scenario the expert is assessing. Ward and Williams (2003) assessed anticipation accuracy of elite and sub-elite football players across a range of ages and found a significant effect for elite players over sub-elite players of all ages when anticipating the direction of a pass to a team mate during an 11 v 11 video task. This task presented 10 possible outcomes which could have occurred. The superior experience, knowledge, and recall of the situation which elite participants have over sub-elite participants (Williams & Davids, 1995) contributed to the higher response accuracy seen in the expert group, as they were able to eliminate less probable options and focus on only those highly probable outcomes.

In interceptive sports, such as tennis, there are many options which players must choose between when anticipating a shot or serve. The differences between the anticipation capabilities of experts and novices in sports such as tennis, cricket, baseball, and volleyball, has been studied heavily in recent years. Research into interceptive sports demonstrates the same results as invasion sports, in that experts have superior anticipation capabilities than novices in a variety of sports and specific sport scenarios (Mann et al., 2007). When returning the serve of an opponent in tennis (which can often exceed speeds of 200km/hr in professional men's matches (Cross & Pollard, 2009)), expert players have less than 1 second from the time the ball is struck by the opponent during the serve, and the time the returner has to return the serve (Triolet, Benguigui, Le Runigo, & Williams, 2013). Singer et al. (1996) investigated the accuracy of movement and reactions to a serve stimulus and found that expert tennis player's responses were both more accurate and faster than novices during anticipation tasks regarding the type and direction of the serve.

The sources of information which influence anticipation, has received much research focus in an attempt to determine how experts use this information in their decision-making during a sport task. For an athlete to be able to correctly anticipate an action outcome, they must be able to process two different sources of information which have been shown to contribute to athlete anticipation – kinematic information sources and contextual information sources (Cañal-Bruland & Mann, 2015). Kinematic information sources are cues from an opponent's movement action, for example the location of the ball toss of a tennis serve. Contextual information sources are all cues outside of the opponent's movement action such as patterns of play on specific scores (situational probabilities). A description of the sport specific information sources and how the kinematic and contextual information sources influence anticipation capabilities of an athlete will be discussed in further detail below.

However, much research regarding anticipation during the return of serve in tennis to this point has explored the notion of how expert players are superior to novices at anticipating the serve direction, and investigating the kinematic cues expert players use to anticipate. Expert athletes are able to perform skills over and over again using a highly repeatable and reliable action with only slight variances in action performance based on the experts action outcome (Cotterill, Breslin, & Weston, 2016). In tennis for example, when a player goes through their serve routine, there is often little variation in their execution of that action. When this routine is viewed by a novice who may have little or no knowledge of the execution required for that skill, the kinematic changes associated with changes in serve direction or type, are not seen in the same way as an expert tennis player would see these differences. The awareness of kinematic changes by experts (Sparrow & Sherman, 2001) demonstrates that kinematic cues contribute to correct anticipation of an action and has been demonstrated in a number of studies. Tennis players have been found to focus on the location of the server's ball toss in order to anticipate the outcome of a serve. In addition to this, other kinematic sources such as trunk rotation and the server's grip on the racquet has been found to be used by expert tennis players to anticipate the serve (Goulet, Bard, & Fleury, 1989). Collectively, these studies have determined that expert tennis players are able to extract the most relevant information from the kinematic factors which was found to influence their anticipation capabilities and as a result, response time and accuracy (Singer et al., 1996). In a qualitative study of expert volleyball players, researchers conducted interviews to investigate the conscious cues expert beach volleyball players were attuned to during matches to assist their decision-making (Schläppi-Lienhard & Hossner, 2015). Results demonstrated that there is a general consensus by expert beach volleyball players to follow a gaze strategy of specific visual cues which provides them with information to make decisions about their defensive actions required to respond correctly to an opponent's shot. These qualitative results are supported a number of studies conducted to capture the influence kinematic cues have on anticipation by expert athletes (Loffing & Cañal-Bruland, 2017). By focusing on kinematic information sources and processing the possible outcomes of the cues, expert athletes are able to correctly anticipate the outcome of an action prior to ball flight information becoming available.

In addition to kinematic influences on anticipation, Cañal-Bruland and Mann (2015) recently presented the argument to extend the focus of anticipatory research to the non-kinematic (contextual) cues and investigate how these sources interact with each other during the course of a response action. In addition to kinematic cues as presented above, anticipatory attributes can be influenced by contextual cues such as probability information, opponent tendencies or preferences, score scenarios, weather or environmental conditions, or opponent court position (Abernethy, Gill, Parks, & Packer, 2001; McPherson, 1993). Early research from Alain and colleagues (Alain & Girardin, 1978; Alain, Lalonde, & Sarrazin, 1983; Alain & Proteau, 1977; Alain, Sarrazin, & Lacombe, 1986) presented the idea that anticipation is influenced by probabilistic information in the absence of kinematic information sources. These early studies were pivotal at showing that probabilistic information can influence anticipation in the same way that kinematic information sources influence anticipation and subsequent decision-making. Follow-up studies which investigated additional contextual information sources were not conducted until more recently. Studies from Farrow and Reid (2012), and Gray and Cañal-Bruland (2018) for example, have demonstrated the importance of contextual information sources on anticipatory capabilities of expert athletes in tennis and baseball respectively. Skilled performers are shown to be able to use these contextual information sources, and their experience in sport specific scenarios to initiate a response to the outcome of that action.

There are only a small number of studies which have attempted to capture the interaction of both kinematic and contextual information sources in anticipation research. Due to the temporal availability of information during a time stressed task (e.g. the tennis serve), studies have agreed that contextual information sources are considered to inform anticipatory skill prior to kinematic information becoming available (i.e. when the movement action commences) (Loffing & Hagemann, 2014). Runswick, Roca, Williams, McRobert, and North (2018) found that expert cricket batters used both contextual and kinematic information sources to judge bowlers more accurately than less skilled batters when anticipating a bowler, with higher emphasis placed on kinematic cues in the later moments of the bowling action. Additionally, Gredin, Bishop, Broadbent, Tucker, and Williams (2018) found that the availability of explicit contextual information sources during a football anticipation task, may affect the underlying perception of kinematic information sources. Schläppi-Lienhard and Hossner (2015) also found that, dependent on the situation, expert beach volleyball players were able to prioritise either kinematic or contextual information sources. That is, the athletes described that the availability of both kinematic and contextual information sources altered the priority of which information source to respond to.

While these studies have attempted to describe the interaction of kinematic and contextual information sources during an anticipatory task, it is still not fully understood how this interaction of information sources informs anticipation and decision-making about the likely outcome of the action, and what response is needed to that action outcome. Furthermore, the priority of each information source used by experts to inform their anticipatory skill during different time points during an action response remains poorly understood.

Figure 2.1 below describes this interaction of kinematic and contextual information sources as they sit within the greater timeline of anticipation and the execution of a skill. Müller and Abernethy (2012) developed a model in their review paper of striking sports that showed the evolution of the availability of kinematic and contextual information sources prior to an athlete responding to the outcome of the perceived skill. The research from Runswick et al. (2018) adds to this model which shows that experts using kinematic and contextual information sources during anticipatory tasks is not an “either or” situation, but rather an interaction of these sources which contributes to an expert athlete’s ability to correctly anticipate the action outcome of an opponent, and execute their own appropriate response. It is this interaction of anticipatory sources which is still of current interest to researchers.

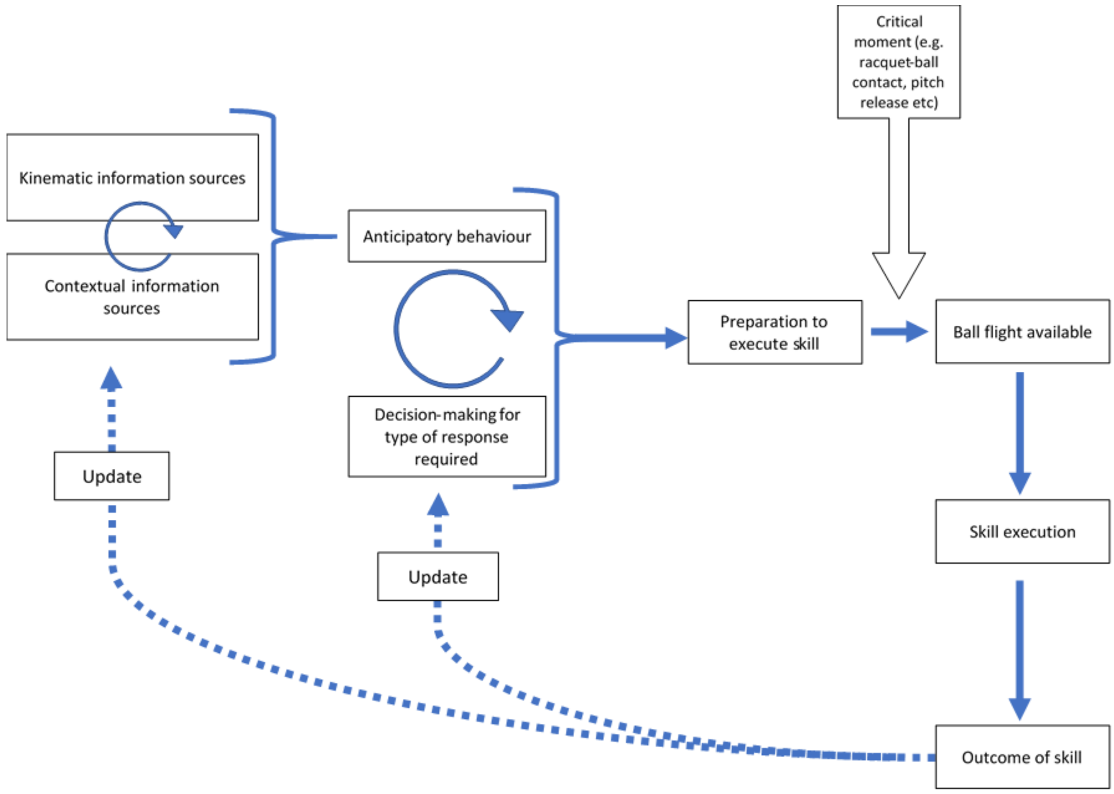


Figure 2.1: Anticipatory timeline involving the use of kinematic and contextual information sources and their influence on anticipation and action outcomes

When experts are under time-stress (such as when returning a serve in tennis), and attempting to correctly respond to the situation using their superior anticipatory capabilities, the availability of kinematic and contextual information sources are present prior to ball flight of the serve (i.e. the critical moment of the server's racquet-ball contact). Once experts have considered both kinematic and contextual information sources and used this to anticipate the possible outcome of the serve, they must then decide on what type of response is needed to correctly respond to that outcome, using the combination of these sources, and previous playing experience (Afonso et al., 2012). Due to the time-stress created by high serve speeds, the filtering of relevant information, assessing the expected serve direction, decision-making about the type of response, and initiation of the return skill must all happen prior to ball flight information becoming fully available in order to successfully return the serve (Crespo & Miley, 1998).

Following the racquet-ball contact of the serve in this sequence, experts are able to use the ball flight information of the serve to make adjustments to their return. Once the outcome of the skill has finished, information from the serve, and whether the outcome of the return was successful, can be fed back into the cycle to further inform the expert's response to future serves.

Interceptive sports such as tennis, cricket and baseball have gathered a large research interest in anticipation and the kinematic and contextual sources mentioned. In baseball, it has been shown separately that pitch probability and kinematic awareness of the pitcher can contribute to expert baseballers being able to anticipate the type of pitch coming to them (Gray & Cañal-Bruland, 2018). This is critical due to batters having approximately 0.5 seconds on average to initiate their swing and hit the ball (Stern, 2018). A baseball batter only has three strikes before they are out, so this ability to anticipate a specific pitch and adjust their swing path accordingly is critical to their innings. In cricket, it is very much similar, with batters only having one wicket to defend during their innings. Batters must be able to initiate some movement of their bat prior to the ball flight information becoming available to them if they wish to make a play at the ball without getting out (Müller et al., 2006). In tennis, anecdotal information and evidence-based research has demonstrated that the serve is important for "setting up" a point for the server, as they are given the opportunity to control the play of the point (Giampaolo & Levey, 2013). The advantage of being able to anticipate the serve and perform a quality return is therefore critical even among expert tennis players. While it is clear that anticipation is important for a number of interceptive sports, the information sources that provide expert athletes the knowledge of what is about to happen is highly sports specific. The specific kinematic and contextual information sources for each of these sports will be discussed in the sections below.

2.4 Kinematic information sources

It is known that kinematic information sources have an influence on the anticipatory attributes of expert athletes. However expert athletes in different sports require sport specific cues to help their anticipatory capabilities. While these cues differ from sport to sport, and the scenarios they are assessing, a common theme among all sports is that experts tend to fixate for longer periods on the key kinematic cues of the action they are viewing. The similarities in the way experts view the visual cues between different sports often follow a chain of events where proximal cues are the initial gaze focus (i.e. trunk and hips), followed by distal cues (i.e. arm or racquet) (Abernethy, 1988; Abernethy & Wollstein, 1989). Novices on the other hand tend to use an exploratory gaze pattern of the action as they are not as attuned to the key kinematic cues for that action, and may not know what outcome results from changes in kinematic information (Mann et al., 2007). A number of different methodologies including temporal occlusion, gaze tracking and qualitative interviews have been used to provide this evidence. These studies have collectively investigated the key kinematic cues required for specific sports, including those sports which require an interceptive action to complete the skill such as tennis, baseball, cricket, and volleyball. In addition to this, some sports that are predominantly invasion sports but have an interceptive component (i.e. a football or hockey goalkeeper attempting a penalty save) have also been studied. Table 2.1 provides a summary of some of the key research articles that have been published in a number of selected sports, the methodology used to produce these findings, and the specific kinematic cues found to influence anticipatory attributes of the experts in these sports.

Sport	Article	Study aim	Methodology	Cues
Baseball	Takeuchi and Inomata (2009)	Examine the differences in visual search strategies between expert and novice baseball batters during preparatory phase of pitching.	Gaze tracking	Experts had more fixations on pitching arm in final phase of pitch. Gaze shifted from proximal areas of the body (head, chest, trunk) to distal areas (pitching arm, release point).
Tennis	Ward et al. (2002)	Manipulate the perceptual cues available and examine the effect this has on visual search strategies when anticipating groundstrokes.	Gaze tracking	Experts had more fixations and for longer on head/shoulder and trunk/hip regions (proximal cues).
	Singer et al. (1996)	Determine visual search strategies by monitoring eye positions when viewing groundstrokes and serves.	Gaze tracking	Experts had more fixations on proximal cues (trunk/hip/arms) than distal cues.
	Farrow and Abernethy (2003)	Determine prediction accuracy when viewing an opponent's serve at various time intervals using coupled and uncoupled responses	Temporal occlusion	Experts were able to pick up advanced perceptual information from earlier time windows during both coupled and uncoupled responses using cues available from ball release to server's racquet-ball contact.
Cricket	Müller et al. (2006)	Examine the ability of expert and novice batsmen to pick up advanced visual information to use in anticipating type and length of swing and spin bowlers.	Temporal and spatial occlusion	Experts were able to pick up advanced information from cues early in the bowling action. Bowling arm and hand were proximal cues experts used to anticipate swing type and spin length and type in highly skilled groups.
Volleyball	Schläppi-Lienhard and Hossner (2015)	Determine the kinematic factors that influence decision-making of expert level beach volleyball players during defensive actions.	Semi-structured qualitative interviews	Visual cues include the focus on reception, set, hand, and ball. Interactions occur between gaze behaviour, visual information, and domain-specific knowledge.

	McPherson and Vickers (2004)	Examine the gaze behaviours of highly skilled volleyball players and whether this reflected pre-task verbal reports.	Gaze tracking and verbal reporting	Gaze was fixated on server's head and the ball during the serve phase.
Football	Dicks, Button, and Davids (2010b)	Examine gaze behaviours of expert goalkeepers in video and in situ conditions during penalty kicks.	Gaze tracking	Gaze was fixated longer on lower non-kicking leg in video tasks compared to verbal and intercept in situ tasks, and on the ball in in situ intercept tasks compared to all other tasks.
Squash	Abernethy (1988)	Compare visual search characteristics of expert and novice players when predicting squash strokes.	Gaze tracking	Fixation on proximal cues (trunk) to fixation on distal cues (racquet or arm) over the time of the kinematic changes in stroke production.
	Abernethy et al. (2001)	Compare prediction accuracy of squash players using film display or point-light display scenarios.	Temporal occlusion	Experts were able to pick up advanced information from cues in the earliest time windows to increase prediction accuracy of shot direction using kinematic cues up to racquet-ball contact.
Badminton	Abernethy and Zawi (2007)	Examine the perceptual expertise in in situ tasks and how this is linked to pick-up of essential display kinematics during badminton shots.	Temporal occlusion	Prediction error of experts during the time windows where maximal racquet kinematic changes occurred was significantly better than non-experts.

Table 2.1: Pivotal studies which have examined the use of kinematic cues in determining anticipation skill in experts and novices of different sports

Initial research into identifying specific kinematic information sources focused on breaking down the phases of the opponent's action to determine the key kinematic information sources. Temporal occlusion has been a prominent method for a number of researchers to investigate how response accuracy changes when different time points of an action are visually obstructed. A number of sports including squash (Abernethy et al., 2001), cricket (Müller et al., 2006), and tennis (Farrow & Abernethy, 2003) have benefited from this type of methodology to determine anticipatory skill in experts in their respective sports. Temporal occlusion relies on the concept of obstructing either all or parts of a visual stimulus during specific time points of a task to determine whether the information up to the occluded point is important for correctly responding to a task (for more details see section 2.6 methods for investigating anticipation below). Results show that experts are better than novices at using earlier kinematic information sources to correctly respond to the outcome of the action compared to novices in the same task, meaning they are able to extract more task relevant information earlier during the viewing action. While it is important that research has been able to identify the periods in which key kinematic information sources are extracted by expert athletes, specific kinematic sources during these time windows are more accurately determined by determining the focus of the expert's gaze of specific areas on the opponent's action.

As can be seen from Table 2.1, the key kinematic influences in a number of interceptive sports have been investigated in numerous studies to date. Many studies have compared experts with novices to determine the difference in the pick up and use of advanced kinematic information. These studies have found that both response accuracy is significantly higher, and response times are significantly faster in expert groups compared to novice groups (Mann et al., 2007). This is consistent across a number of sports including baseball, tennis, and cricket. Specifically in tennis, it has been found that a focus on kinematic cues such as the ball toss, trunk, and hips have been used by experts in anticipatory tasks (both the serve and groundstrokes) (Ward et al., 2002). These findings indicate that by expert tennis players fixating their gaze on these areas of interest, they are able to extract relevant information from these cues which can effectively be used to anticipate an action outcome. Therefore, subsequent studies which attempt to investigate anticipation in tennis must keep in mind that these cues may be prioritised during a time stressed task.

Various other methods such as qualitative interviews and verbal reporting have recently been explored as options to further investigate how kinematic information sources impact anticipation skill, and whether experts are attuned to using this information during anticipatory tasks. While qualitative methodologies are not new, they are under-utilised when it comes to investigations in skill acquisition. Most recently, Schläppi-Lienhard and Hossner (2015) used qualitative interviews with expert beach volleyball players to discuss the gaze patterns and advantages of attuning to this information when anticipating actions and how this affects resultant decision-making during elite level beach volleyball defensive anticipation. The results found that decision-making is influenced by opponent specific factors, external context, situational context, opponent’s movement, and intuition, and that optimal gaze strategies to focus on specific visual cues is necessary for decision-making in high level beach volleyball. Further to this, post-experiment qualitative questionnaires and verbal reporting have been used in a number of studies to determine whether the participants of these studies were explicitly aware of the kinematic information sources they needed to be attuned to in order to anticipate correctly and whether this compares with visual search data. The study from Roca, Ford, McRobert, and Williams (2013) used this combination of methodology techniques in assessing perceptual-cognitive skills during a football sequence. Gaze tracking found that expert football players are attuned to the postural information of an opponent, and confirmed this pick up of information in post-experimental verbal reports.

Finally, some researchers have used a number of methods within a single examination in an attempt to more thoroughly capture how visual perception of kinematic cues by experts contributes to anticipation. For example, Williams and Davids (1998) successfully conducted three experiments using a combination of methods to examine the relationship between visual search strategies and selective attention in expert and novice football players. Using gaze tracking to determine search strategies when viewing various football scenarios as well as spatial occlusion and verbal reporting, they were able to highlight the superior differences of experts over novices in selective attention, visual search strategies, anticipation performance, and attunement to these cues during a football specific task. These conclusions allow researchers to confirm that the visual gaze results are a true reflection of the pick-up of key kinematic information sources which contribute to anticipation by expert athletes. Without this information, research has only been able to assume that visual search strategies used by expert athletes result in the key kinematic cues contributing to anticipation performance. The introduction of these additional methodologies in this research provides evidence that can verify the use of specific kinematic information sources during anticipation. While this information is critical for assessing the influence kinematic information sources have on anticipation, it must be noted that the influence of contextual information sources is also still critical during anticipation tasks.

2.5 Contextual information sources

As it is with kinematic information sources, contextual information sources also have an influence on anticipatory outcomes. Again, contextual information sources are highly sport specific, however there are broad similarities which can be drawn between different sports. One contextual information source is the use of situational probability. Situational probabilities, a term popularised by Abernethy et al. (2001), refers to the probability of a certain action outcome occurring at a specific moment in time. Situational probabilities have been found to have an influence on anticipatory capability of experts in the absence of kinematic information in a number of sports scenarios. In one of the first studies to determine the use of situational probabilities in the absence of kinematic information, Alain and Proteau (1977) required participants to hit a suspended squash ball when presented with a flashing light stimulus 2 metres from a starting location both with and without probability trials. This study was important in highlighting that highly probable scenarios are consciously picked up by the majority of novices, which resulted in faster reaction times. While reacting to a light stimulus is useful for assessing reaction and movement time, many sports tasks are far more complex. While the presence of situational information has been the main focus of studies which have investigated this source of contextual information in experimental series as described above, there have also been a number of studies conducted across different sports. For example, Murphy et al. (2016) conducted studies where participants were given probability information about the outcome of a task to determine an expert's capability to use contextual information without the use of kinematic information. The researchers found that in a simulation task, skilled tennis players were able to judge the ball bounce location of an occluded shot more accurately than novice tennis players when only contextual information was available.

Similar to kinematic-focused anticipation research, studies of interceptive sports such as tennis, baseball, and cricket have again been prominent sources for these studies. A summary of some of the key research that have been published on each of the selected sports and the specific contextual cues found to influence anticipatory attributes in these sports can be found in Table 2.2.

As can be seen in Table 2.2, numerous studies which have investigated specific contextual information sources, have found that probability information is a common contextual information source across a number of different sports. Participants in these studies are either provided with probability information of the task to help their decision-making during the task (for example, Alain et al. (1986) provided participants with 80/20 probabilities of particular squash shots in their study), or they are not provided with probability information, and whether they become attuned to this information is assessed as part of the study. Research which asks participants to report on whether they are aware of the probability information and whether they use this to inform their decision-making of their response during the task are often combined with their response accuracy and reaction times to the stimulus of the task (Farrow & Reid, 2012; Murphy et al., 2016). In such research where participants are given probability information, experts are likely to use this to improve their response accuracy and have a faster reaction time than novices in the same task. Experts typically show a biased preparation time in conditions where the probability of an event occurring is higher than a lower probable event (Alain et al., 1986). In studies where probabilities have been manipulated, generally the split of probabilities at 80/20 (or higher) of an action outcome resulted in biased preparation to that outcome by the experts. Therefore, it appears that the threshold for experts to change their behaviour based on probability information would occur when the probability of situation is 80% or higher.

Sport	Article	Study aim	Methodology	Cue
Baseball	Gray and Cañal-Bruland (2018)	Examine how manipulating pitch probability conditions and visual trajectory information integrates to guide motor behaviour in baseball batting.	Temporal occlusion combined with different probabilities	Kinematic changes of the batters occurred earlier during the swing phase when pitch probability varied. Later occlusion times and higher probabilities showed the greatest proportion of hits.
Tennis	Farrow and Reid (2012)	Examine the differences in how manipulated situational probabilities presented to older and younger groups of tennis players contributes to anticipatory response.	Manipulated situational probabilities	Older participants picked up the serve probability of the manipulated serve by the ninth game of the task after which response times improved.
	Loffing and Hagemann (2014)	Determine if skilled tennis players can accurately anticipate shot direction of a forehand using only on-court positional information.	Point light display videos combined with temporal occlusion	Skilled tennis players were able to accurately anticipate a forehand shot in the absence of kinematic information using on-court positional information.
	Murphy et al. (2016)	Examine the importance of contextual information in anticipation tasks where postural information is either present or absent in skilled and less skilled tennis players.	Postural and probability videos and probability only videos	Final shot in a rally of groundstrokes could be anticipated in contextual only scenario meaning skilled tennis players were able to accurately anticipate based on only contextual information of a tennis rally.
Volleyball	Schläppi-Lienhard and Hossner (2015)	Determine the contextual factors that influence decision-making processes of expert level beach volleyball players during defensive actions.	Semi-structured qualitative interviews	Opponent specifics, external context, situational context, opponent movements, and intuition as contextual elements were discussed by the expert participants as

				factors which they would consider during volleyball defence.
Football	Navia, Van Der Kamp, and Ruiz (2013)	Examine the contribution of situation information of player preferences and the gaze behaviours of goalkeepers during penalty kicks.	Manipulated situational probabilities	During high probability scenarios, goalkeepers had higher accuracy moving to the correct side of penalty kick.
	Gredin et al. (2018)	Assessed how congruent and incongruent situation-specific information influenced action tendencies in a match play task	Manipulated prior situational information	Prior contextual information influenced final judgements in expert footballers.
Squash	Alain and Proteau (1977)	Examine how event probabilities affect response outcomes in squash reaction and movement times.	Movement and reaction times on various probability scenarios	Higher probability scenarios (90/10) caused significant decrease in reaction time.
	Abernethy et al. (2001)	Assessed response accuracy on video, point light displays, and match play scenarios of squash shots.	Temporal occlusion combined with shot preferences and sequences	Expert's superior response accuracy higher than chance levels prior to kinematic cues becoming available.

Table 2.2: Pivotal studies which have examined the use of contextual cues in determining anticipation skill in experts and novices of different sports

In addition to studies where probability information has been provided, researchers have also conducted research where participants have had to attune themselves to the contextual patterns of the task, and base their responses on the collection of this information. Farrow and Reid (2012) presented participants with manipulated probabilities of the first serve in a series of trials where the outcome of the serve was the same. By the 9th game of serves, experts had attuned themselves to this information and response time of the first serve significantly improved. These results collectively demonstrate that in high probability scenarios, experts attune themselves to this information and are able to adjust their response accordingly, whether they are provided with these probabilities at the start of the trials, or whether it is learned from exposure to the task. The results of research which do not provide probability information during the task, also suggests that experts are still capable of determining the situational probabilities of the task themselves and use this gathered information to inform their response to the task. However, research has demonstrated that the situational probability of the task may need to be as high as 90/10 before performance is altered based on experts determining this information on their own (Alain & Proteau, 1977).

2.5.1 The congruence effect

In addition to experts being able to identify certain situational probabilities, it must also be noted that there is some evidence to suggest that their responses to an action outcome may be susceptible to the congruence effect (Mann, Schaefers, & Canal-Bruland, 2014). This effect refers to a phenomenon whereby participants who have been exposed to expected situational information, may respond to this expectation, even though the actual outcome of the action is incongruent with this expectation. This behaviour may be detrimental to performance should a participant execute their response based on this information alone (Murphy et al., 2019). It has been found that experts are particularly susceptible to incongruent information, more so than novices, and that it causes a direct decrease on performance outcomes in anticipation tasks (Loffing, Stern, & Hagemann, 2015). In a study from Mann et al. (2014), participants in a handball goalkeeping task achieved lower response accuracy in task sequences where the action outcomes differed from the expected action outcomes, compared to tasks where the action outcomes continued with the expected outcome. Similar results were found in a baseball batting task, where batting accuracy decreased with a change in the pattern of the pitch types, however if the pitching pattern continued, batting accuracy improved (Gray, 2002a). This susceptibility of expert athletes to situational information suggests that even when provided with high probability situational information, experts must not be solely reliant on this information. Experts must therefore be attuned to both contextual and kinematic information sources to correctly inform their anticipation capabilities in order to perform a successful response outcome. While Gredin et al. (2018) investigated this prioritisation of information sources using incongruent conditions in a soccer-based anticipation task to success, no such study has been conducted on an in situ tennis return of serve task.

2.5.2 Methodological considerations

While the studies presented in this section have highlighted the important contextual information sources of specific sports, there are some methodological issues which may mean that contextual information sources have not been able to have been captured in isolation to kinematic information sources. For example, Farrow and Reid (2012), investigated the influence of probability information in a tennis return of serve task and manipulated the serve type and location to be the same on the first point of each game.

Verbal report data was collected in this study to determine the sources of information the participants used to respond to the serve. 93% of the participants in the older group reported that they were aware of the repeating pattern on the first serve location, while only one participant in the younger group reported being aware of the pattern. This was a critical part of the methodology to determine if the participants were attuned to this information, and also if score was an important contextual information source in tennis returning. However, the presence of pre-contact kinematic information of the server may have had an implicit influence on the older participants to accept or reject their knowledge of the probability information which they did not report.

Schläppi-Lienhard and Hossner (2015) highlighted the implicit knowledge of anticipatory cues in their interview-based study of professional beach volleyball players. Some of the participants in this study discussed how their defensive strategies would be based on intuitive knowledge (or "feel" for which ball is coming) of the particular situation of the match. In addition to these players who used intuition during their defending, participants also referred to their ability to "read" the game and extracting crucial cues from specific scenarios during the game. While studies which have attempted to assess the pickup of probability information have been difficult to equate in sport-specific scenarios, it appears that the qualitative approach taken in the study from Schläppi-Lienhard and Hossner (2015) has provided a good starting point to determine how experts of certain sports are able to use probability information to inform their anticipation and subsequent decision-making.

While the amount of research about contextual information usage in anticipation attributes of expert athletes has increased in recent years, the number of studies which have assessed these contextual factors completely independently of kinematic influences are low. Nevertheless, recent improvements in technology and computer simulations have allowed this type of research to progress, and sport specific contextual factors have been able to be determined without the influence of kinematic information. A recent study from Murphy et al. (2016) using a computer simulation of an actual tennis rally which excluded kinematic information revealed expert tennis players were able to correctly respond to the simulation task accurately above chance levels. The expert group of participants also provided verbal reports of using contextual information to inform their responses more so than the less-skilled participant group, which is consistent with previous qualitative research (Schläppi-Lienhard & Hossner, 2015). A more thorough presentation of the advantages and disadvantages of the methodologies used to investigate contextual information sources can be found in the section below.

2.6 Methods for investigating anticipation

The complexity of investigating anticipatory capabilities in sport means that a variety of methods have been used in an attempt to capture this information. While it is known that both kinematic information sources and contextual information sources are used for anticipating the outcome of a sport task, the interaction of these two sources during an anticipatory task is largely unknown. The methods discussed below have all been extremely useful for providing answers to questions about kinematic and contextual information usage separately, but it has been difficult to capture the interaction of both sources using these methods. In addition to this, the perception-action coupling required for successful completion of a task in real-world scenarios is absent in some of these methodologies which may affect the results of the studies (Farrow & Abernethy, 2003). Nevertheless, the following methodologies have been of use to investigate anticipatory attributes of experts and novices of a number of sports.

2.6.1 Temporal occlusion

In one of the first studies to investigate anticipation in time constrained sport scenarios, Abernethy (1988) used a temporal occlusion methodology to investigate the error rate of expert and novice squash players anticipating a squash shot. Since then, a number of other sports have utilised this method (for example badminton (Abernethy & Zawi, 2007); baseball (Paull & Glencross, 1997) ; cricket (Müller et al., 2006); and tennis (Goulet et al., 1989)). Temporal occlusion involves presenting a participant with vision of a task, traditionally on a computer or television screen from the perspective of the performer. Typically, the participant watches the task and is asked to respond to the outcome of the task they are watching (either by verbal response, enacting the full action required to respond to the task, or in some cases by moving a joystick in the direction of the response). The display of the task is cut off at pre-determined time points for the remainder of that particular trial. For example, during a squash task, five time frames were chosen as the occlusion point in relation to the racquet-ball contact - T1: 160ms prior to racquet-ball contact; T2: 80ms prior to racquet-ball contact; T3: at racquet-ball contact; T4: 80ms after racquet-ball contact; and T5: no occlusion (Abernethy, 1988). The occlusion windows varied depending on the task being viewed and attempts to break the task into key kinematic components. When response accuracy is high during particular time windows, it is assumed key kinematic cues must have been available prior to the occlusion point, where participants were able to extract information and allow them to respond to the task correctly. A general outcome of the extensive temporal occlusion research is that as the amount of kinematic information that is displayed, increases over subsequent occlusion windows, response accuracy increases in both expert and novice participants (Abernethy & Zawi, 2007).This information has resulted in conclusions being made about the key kinematic cues which may be used in anticipation of the task outcome.

In addition to this, Baker, Farrow, Elliott, and Anderson (2009) demonstrated that information pickup of participants when viewing a traditional temporal occlusion task was similar to that obtained using a moving window occlusion task. Where traditional temporal occlusion means viewing periods get progressively longer as each time window presents additional information, a moving window condition requires that viewing time is of a fixed duration, and the start of the window shows only that fixed window of time during specific phases of the action being viewed (Farrow, Abernethy, & Jackson, 2005). This methodology demonstrates that experts are still able to anticipate accurately above chance levels based on information being presented during a fixed duration over a moving window, as well as information becoming progressively available (i.e. in traditional occlusion tasks).

While temporal occlusion allows researchers to identify time frames when key kinematic cues contribute to anticipatory response accuracy, the limitations of this method must be acknowledged. As many early studies using temporal occlusion have been conducted using a computer or television screen, participants were often required to use verbal reporting, direct a joystick, or mark the location on a scaled representation or touch screen to indicate their response to the task outcome. To overcome this limitation, and more accurately replicate real-life tasks, many studies began to utilise liquid crystal occlusion spectacles to conduct temporal occlusion studies in real-life tasks (Farrow et al., 2005). These types of studies have furthered the knowledge of the actual perceptual processes used by experts during anticipatory tasks.

2.6.2 Spatial Occlusion

Spatial occlusion is a similar methodology to temporal occlusion in anticipation research. Where temporal occlusion cuts off the action at specific time windows, spatial occlusion instead removes features of the action being viewed, in order to determine if this influences prediction accuracy. During spatial occlusion tasks, when response accuracy is high during trials where particular features are present, it is assumed that these features are key for participants to be able to extract information to respond correctly to the action outcome. Studies which have used spatial occlusion in their methodologies have been able to confirm the results of studies using temporal occlusion, regarding the key kinematic information which experts are able to attune to, in order to accurately predict the outcome of the action being viewed.

In a study from Müller et al. (2006), the researchers used spatial occlusion to demonstrate that expert cricket batters were able to extract early relevant information from the bowler's hand and arm that less skilled batters were not able to. Hagemann, Strauss, and Cañal-Bruland (2006) were also able to use spatial occlusion in a badminton task to determine that up to 160ms prior to contact of the shuttle, proximal visual cues such as the trunk, can be used by experts to predict direction or an overhead shot. Specifically in tennis, studies from Huys, Cañal-Bruland, Hagemann, Beek, Smeeton, and Williams (2009) and Williams, Huys, Cañal-Bruland, and Hagemann (2009) showed that a global perceptual strategy of viewing the stroke of a tennis figure increased prediction accuracy in expert tennis players. These results across a number of different sports are important for demonstrating that experts are able to attune to key areas to extract relevant kinematic information early in the action being viewed, and use this to improve their anticipation capabilities.

As discussed above, spatial occlusion has been shown to be useful for determining key areas of interest which improve prediction accuracy during anticipatory tasks of experts. However, Hagemann and Memmert (2006) also demonstrated that spatial occlusion can be used as a valid method for training anticipatory skill. In a badminton task, the researchers found that highlighting the key areas of interest of the action the participants were viewing improved their prediction of the shuttle’s landing location, significantly more than the control group with no training. In an additional study, Hagemann et al. (2006) specifically demonstrated that expert badminton players were able to improve their prediction of the depth of an overhead shot the most, by drawing the attention of the participants to the key spatial areas during the training protocol. These results have positive implications for training perceptual awareness in experts in order to improve their anticipatory capabilities of their chosen sport tasks.

While spatial occlusion studies have been shown to be a valid method for training anticipatory skills, it also confirms the results of studies which use temporal occlusion, however, the same limitations of this methodology still exist. These limitations include using point light displays and video or computer screens to remove key areas or interest, thus reducing the real-life representativeness of this method. However, research from Panchuk and Vickers (2009) have attempted to overcome this limitation using physical screens to occlude key areas of an ice-hockey player attempting to score against a goalkeeper. Despite this attempt to use spatial occlusion in situ, there is still further work to be done to improve the use of spatial occlusion in ecological investigations.

2.6.3 Gaze tracking

Studies of natural gaze behaviours in sports have come a long way from the initial studies which assessed visual search paths, thanks in a large part to mobile eye-tracking technologies (Kredel, Vater, Klostermann, & Hossner, 2017). Over time, studies have used both natural and video tasks to capture eye movements and fixations, often using fixation point and fixation time of the eye as the measure. Modern gaze tracking uses mobile eye tracking devices, usually in the form of glasses which track the fovea of the eye to determine a fixation point at any given time. The data collected from the eye tracking devices include saccades, blinks, and fixations which allows researchers to determine how these eye movements can show the points of interest focused upon by the participant. Fixations are defined as the maintenance of a steady gaze for a minimum of 80-150ms (Carpenter, 1988). The number of fixations during a task, and the amount of time a certain area of interest is fixated upon is of importance to researchers. It is generally agreed that visual search strategies of experts which involve fewer fixations of longer duration are superior to novices search strategies which may not fixate on areas of interest for long enough to extract the required amount of information needed to anticipate or predict an action outcome (Mann et al., 2007).

In order to be successful in the majority of scenarios which require anticipation in sport performance, experts must be able to extract relevant information from the fixation points, which can be captured by gaze tracking glasses (Mann et al., 2007). Using gaze-tracking technologies is the preferred method at capturing the fixation points of kinematic focus by expert athletes despite some limitations. Gaze tracking technology, as advanced as it has become over the years, still only captures foveal focus, and while visual search behaviour and cue usage may be interactive, gaze tracking glasses may not capture all sources of information that are used by the athlete (Williams, Janelle, & Davids, 2004). As discussed by Panchuk, Vine, and Vickers (2015) attention can move independently to eye movements, thereby the attention of the subjects in research studies may be internal to focus on their own actions, and eye fixations may not actually correlate with the participant being attuned to that area of fixation. It is also possible that the peripheral intake of visual information is neglected in gaze analysis, which is not yet fully understood how this may influence perception of an action being viewed. Furthermore, experts may not be explicitly aware of their movements (including eye movements, which fixation data captures), and therefore fixation data may not accurately represent the focus on the kinematic cues needed in anticipating an outcome. However, as presented above, experts have demonstrated that they are consciously aware of the kinematic cues required to accurately anticipate an outcome. By conducting qualitative interviews with participants of these studies, researchers are able to address the kinematic information sources the experts are attuned to during the task and whether this aligns with the fixation data determined from mobile-eye trackers.

2.6.4 Qualitative investigations

Using qualitative methods in scientific research is not a new approach. However qualitative methods in sport science, and in particular, skill acquisition research has been relatively limited. Qualitative investigations allows researchers more scope to examine participant's thoughts, and generate deeper insights into their research questions (Pitney & Parker, 2001). Many qualitative interview studies allow researchers to code answers from the participants and categorise these into a conceptual model which may be used to answer their research question (Straus & Corbin, 1998). In skill acquisition research, qualitative methods have been used to investigate expertise of sports tasks such as cricket batting (Weissensteiner, Abernethy, & Farrow, 2009), the dynamics of talent development (Phillips, Davids, Renshaw, & Portus, 2010), coaching relationships and methods (Bennie & O'Connor, 2012), or use of anticipation sources (Schläppi-Lienhard & Hossner, 2015).

While the number of qualitative studies using interview methods to investigate decision-making and anticipation in time-restricted sports tasks is small, some positive results from studies in sports coaching may encourage increased use of this method. Schläppi-Lienhard and Hossner (2015) were one of the first teams to use qualitative interviews to investigate the use of kinematic and contextual information sources of expert beach volleyball players. This study allowed the researchers to determine common kinematic cues players said they were consciously attuned to, the influence and priority of other sources of information they used during an anticipation task, and how this would affect their subsequent decision-making. Specifically, this study found that experts were aware of the kinematic cues required to effectively anticipate both the serve and attacking shots in beach volleyball. Furthermore, the researchers and participants also discussed the different tactics and strategies used by the experts to help them respond correctly to the anticipated shot, whether this was adjusting their position on the court, moving earlier to the anticipated direction, or conversely, still trying to cover another likely outcome (so as to not commit fully to one direction or another too early). While qualitative interviews only allow researchers to capture the conscious awareness of this type of information, it is an excellent starting point for determining sport specific information sources which may be a priority for experts when competing. If results suggest that experts are consciously attuned to specific sources of information, then it allows researchers to be able to empirically manipulate these sources in in situ investigations in order to determine what change in anticipatory responses or decision-making this may create.

2.6.5 The importance of perception-action coupling in anticipation research

Van der Kamp, Rivas, Van Doorn, and Savelsbergh (2008) argued that visual anticipation requires the interaction of the brain's ventral system for perception and the dorsal system for action. The tendency for studies to use screen-based temporal occlusion in their methodologies thus eliminating or reducing the use of the dorsal system means that movement control of the participants in these studies is overlooked. Furthermore, while these studies have still provided us with critical information regarding response accuracy and timing, the type of response used in these anticipation research tasks can include movement responses (in situ tasks), shadow movements, joystick responses (computer/television screen-based tasks), or verbal responses (i.e. left, right etc). These responses can potentially influence the results of anticipation outcomes by removing this coupling of perception and action in laboratory-based investigations (Gibson, 2014). One of the first studies to investigate the differences in coupled and uncoupled response in a tennis anticipation task was Farrow and Abernethy (2003), who found that experts have superior response accuracy during coupled responses, compared to uncoupled responses. They also found that experts may have different perceptual processes during coupled responses, compared to uncoupled responses, meaning that they may be attuned to different sources of information when replicating a response to a real-life task. This finding is critical as it highlights the need for real-life, representative design in anticipation research, which is important for extending research into practice using real-life experimental techniques.

The different techniques used to investigate an anticipatory response allows researchers to measure response time and response accuracy of these tasks, and how this relates to anticipation skill. For example, in studies where response time is measured, an initiation of movement measured in any of the ways above, registers as the response time, usually relative to the availability of ball flight information. Therefore, a negative response time indicates that the participants movement response is initiated prior to ball flight information becoming available in the task. These results show that anticipation of the action contributes to early decision-making about the correct direction of movement relative to the outcome of the action. Given the recent advances in the technology used in in situ anticipation research to measure kinematic cues (e.g. mobile eye-tracking glasses) and response timing and accuracy (high-definition spatiotemporal data), has enabled researchers to investigate anticipation outcomes which more closely replicates a real-life task. The use of these techniques and methodologies are the future for anticipation researchers to attain better practical implications for experts in their chosen sport.

2.7 Summary

The purpose of this literature review was to present the current research about anticipation of task outcomes in time constrained sports such as tennis. The importance of anticipation during the return of serve in professional tennis matches is highlighted anecdotally by experts appearing to have all the time in the world.

The conscious and implicit processing of kinematic and contextual information sources, and how and when they contribute to anticipation and decision-making during a time constrained task such as returning a tennis serve, is not yet well understood. It is hoped that through this thesis, this information will become clearer by investigating the actions of expert athletes in the period of time prior to a response being initiated. The skill of returning the serve in tennis requires players to be able to anticipate the type, speed and direction of the serve prior to ball flight information becoming available, and respond accurately to the anticipatory information. It is known from a number of previous studies conducted in tennis that kinematic and contextual information sources are used by expert players during anticipation of the return of serve. The return of serve has therefore been chosen as the vehicle for determining the interaction and priority of kinematic and contextual information sources in this thesis, which has previously been unable to be determined.

The overall aim of this thesis is to determine the priority of the kinematic and contextual information sources used by expert tennis players during anticipation of the return of serve. Furthermore, knowledge about how the use of these information sources influence the decision-making process and the response to the serve will also be analysed. This thesis aims to determine how expert tennis players consider both kinematic and contextual information sources during the return of serve. Investigations into the changes in performance outcomes based on manipulation of these information sources will be conducted in order to determine the priority of their usage.

Chapter 3: A qualitative examination of the interaction of anticipatory information sources used by professional tennis players

3.1 Abstract

Previous research has largely focused on the individual contributions of either kinematic or contextual information sources to the anticipatory skill of an expert athlete during a time-stressed situation. Very little research has considered how these two sources of information interact with each other to influence anticipation. The current study used a qualitative interview methodology to investigate this interaction. Eight former or current top 250 professional male tennis players participated in a 30-60 minute interview about the interaction of kinematic and contextual information sources and their influence on anticipation. Using an open-coding analysis approach, codes were identified by each researcher from the transcribed interviews and then brought together to identify common themes. The primary themes were consciousness, tactical awareness, contextual information sources, kinematic information sources, mentality/confidence, returner technique or strategy, and build pressure on the server. Secondary themes coded from the participants were returning characteristics and practice. Consequently, a temporal model was developed from these themes which demonstrated the sequence and interaction of both kinematic and contextual information sources known to influence expert tennis players anticipation.

3.2 Introduction

In professional sport, one skill that sets the experts apart from the novice athletes is the capacity to more efficiently anticipate, react and move efficiently in response to game situations (Cañal-Bruland & Mann, 2015). Anticipatory information is available in the form of kinematic and contextual information sources that become available to a performer at various times prior to an opponent making contact with the ball in time-stressed game situations. How such information influences anticipation skill in expert and novice athletes has been of interest to researchers for some time (Müller & Abernethy, 2012). While the results of such work has demonstrated that experts display superior anticipation capabilities compared to novices (Mann et al., 2007), current research has largely failed to consider how both kinematic and contextual information sources are integrated or prioritised by an athlete (see Schläppi-Lienhard and Hossner (2015) as one exception). However, recent research in this area now demonstrates that experts display superior anticipatory capabilities when using both sources of information during an anticipatory task (rather than relying on either contextual, or kinematic). This additive effect determined in a number of different sport tasks (for example, baseball (Gray & Cañal-Bruland, 2018), cricket (Runswick et al., 2018), and tennis (Murphy et al., 2016)) has furthered interest in this area, and it highlights the importance of understanding how the two anticipatory sources interact during an interceptive task to enhance an expert's already superior anticipatory skill.

In interceptive sports, such as tennis, the most widely examined source of anticipatory information has been the kinematics presented by an opponent (Goulet et al., 1989; Jackson & Mogan, 2007). For example, a tennis server may serve with a ball toss which reaches a zenith more on the left side of a right-handed player than the right, which suggests that a wide serve is the most probable serve due to the kinematic constraints of that action (Reid, Whiteside, & Elliott, 2011). The influence of kinematic information on anticipation has been supported by anecdotes of professional players, whom have variously attributed their success on return of serve to being able to extract meaningful information from the service actions of their opponents. For example, one of the game's current best returners, Andy Murray, attributed an upset loss to the speed of his opponent's arm action on serve which made it difficult to pick up (Schlink, 2017). The efficacy of specific kinematic information sources predictive of serve direction have been empirically examined using a combination of temporal and spatial occlusion methods (Farrow & Abernethy, 2003) and gaze-tracking (Goulet et al., 1989). The ball toss, trunk rotation and arm rotation are all suggested to be important information sources used by an expert returner that lesser skilled performers are not attuned to (Jackson & Mogan, 2007; Singer et al., 1996; Ward et al., 2002).

Anticipatory responses informed by contextual information sources have also been examined (Crognier & Féry, 2005; Farrow & Reid, 2012; Loffing & Hagemann, 2014; McRobert, Ward, Eccles, & Williams, 2011). Contextual information sources relate to the “probabilistic information that is independent of the observed movement and the visual information from the observed movement” (Cañal-Bruland & Mann, 2015, p. 1). That is, contextual information describes all non-kinematic information sources present to help athletes anticipate the outcome of an opponent’s action. This includes information such as the game situation (i.e. the score), an opponent’s court position, an opponent’s perceived strengths and weaknesses, in addition to external factors such as wind direction or court surface. The influence these contextual factors have on anticipation has been examined in a variety of ways. For example, Farrow and Reid (2012) manipulated the probability of tennis service direction based on the score and found older more skilled players were more attuned to this information and were able to prepare their response earlier than younger, less skilled players (see also (Loffing et al., 2015). Similar findings have been demonstrated in other sports such as baseball, where contextual information sources based on particular score scenarios influences the type of pitch to be thrown (Cañal-Bruland, Filius, & Oudejans, 2015) and how batters handle this information on different pitch counts (Paull & Glencross, 1997). Alain et al. (1983) were one of the first research teams to examine the influence of contextual information or the phenomenon of players building knowledge of their opponent's previous shot into their decision-making. Alain et al. (1983) also reported that as participants perceived the probability of a shot occurring to increase, so too did their number of biased preparations. This manifested itself in the players "setting-up" for the shot they most expected to receive in advance of their opponent striking the ball. Alain et al. (1983) also demonstrated that athletes who were aware of the situational probabilities of events occurring responded faster to the more likely event. While the focus of many of these studies was to assess the influence of contextual information, the presentation of the viewing source still involved some element of kinematic presentation. Murphy et al. (2016) found that independent of kinematic information sources, contextual information could be used to by expert tennis players to anticipate the depth and location of a tennis groundstroke. However, it was found that this accuracy was not to the same level as the expert when they were provided with both kinematic and contextual information in the same task. In the context of the current study, these results highlight the salience of contextual information in the decision-making processes of skilled players, in addition to the kinematic information available to them.

While a great deal has been learned from the collective body of experimental work that has considered the influence of kinematic and contextual information sources, there has been relatively little investigation into how a performer may selectively use both information sources, despite this being the norm in the performance setting (Cañal-Bruland & Mann, 2015). Schläppi-Lienhard and Hossner (2015) utilised a qualitative approach to address this issue as it relates to the decision-making of expert beach volleyball players during defensive actions. They considered the respective contribution of visual perception skills such as gaze behaviour, as well domain-specific knowledge such as tactical insight. A key finding from this work, was the prioritisation players gave to different information sources dependent upon the situation. For instance, when the situation was largely predictable, or as expected by the player, they tended to rely on their tactical knowledge, whereas in situations where an opponent was out of position and needing to adapt, they tended to analyse the specific situation by reading their opponent's movement. In addition to this, key findings confirmed the importance of this information in influencing an expert's decision-making capabilities and subsequent responses. The richness of information captured by Schläppi-Lienhard and Hossner (2015) demonstrates the value in using a qualitative research approach to investigate the complex interaction between contextual and kinematic information sources. Consistent with the extant quantitatively focused literature on anticipation (e.g., Farrow and Reid (2012)), domain and task specificity is likely to be a prominent influence on any qualitative insights collected. Consequently, the current study sought to extend and generalise the findings of Schläppi-Lienhard and Hossner (2015) within the sport of tennis through examination of the most influential situation in the game, the return of serve. Through the specific exploration of the interaction between kinematic and contextual information sources on anticipation in tennis decision-making, it is suggested a framework for future quantitative research to selectively manipulate and examine the influence of both information sources in situ can be provided. This in turn can then provide empirical support to the insights offered by expert performers.

In summary, the extant research has largely focused on the kinematic or contextual influences on anticipatory performance in isolation from each (Cañal-Bruland & Mann, 2015). It is argued that we need to consolidate our understanding of these two information sources to better inform the future study of anticipation in time stressed sport situations. Hence the current study sought to determine the information sources current or former expert professional tennis players used and prioritised to help them anticipate serve location, type and speed when returning in tennis matches. To achieve this aim, a semi-structured interview approach was adopted, as such techniques are increasingly being used in athlete and coach settings to provide a deeper understanding and perspective on how such information sources are used in time-stressed sport situations (Schläppi-Lienhard & Hossner, 2015; Weissensteiner et al., 2009). It has been argued that this method of naturalistic inquiry can generate deeper insights into the explored question over quantitative research which may exclude certain information needed to explore this research empirically (Pitney & Parker, 2001), such as consideration of the wider influences on an athlete's anticipation performance due to psychological and physical factors.

3.3 Method

3.3.1 Participants

The participants were eight (8) former (n = 6) and current (n = 2) Association of Tennis Professionals (ATP) male international tour players known to the research team through their work for the national tennis association. Four of these participants were regarded as being renowned for their return of serve skill, while four athletes were known more for their serve skill (as identified in media by expert tennis coaches and commentators). Peak career singles rankings of the players ranged from 44 to 152 (M_{rank} = 75.38, *SD* = 46.02) in the world. Participants at the time of interview were aged from 27 to 55 years (M_{age} = 41.75 years, *SD* = 9.53) and had competed professionally for 7 to 18 years (M_{comp} = 13.50, *SD* = 3.85), between 1978 and 2017, with a mean number of professional singles titles of 4.88 (*SD* = 5.57). Former and current players were not treated separately in the analyses as the interview context was focused on their reflections as a player.

3.3.2 Procedure

Participants were invited to complete a semi-structured interview that ranged from 30 to 60-minutes where they detailed the key factors they considered when anticipating a serve during their professional careers. A suitable time and place was organised to meet with the researcher/s where the interview could be conducted without distraction. The interviews were recorded using an Olympus VN-741PC digital voice recorder. Interviews were then transcribed verbatim to be used for analysis. Prior to the interviews commencing, each participant had reviewed an information sheet concerning the purpose of the research and signed a consent form. Institutional ethical approval was granted prior to the study commencing.

3.3.3 Interviews

The interview guide was developed by the researchers prior to the interview period commencing. The main bulk of the interview guide asked each participant the same broad questions and was relatively unstructured. This was to allow for probes and follow-up questions to the participants responses in order to gain an in-depth understanding of what the participants were discussing (Hardy, Barlow, Evans, Rees, Woodman, & Warr, 2017). This method of interviewing allowed the responses from the participants to be consistent across all interviews, but also allowed the participants to discuss and interpret the questions in their own way (Mishler, 1986). This also allowed the researchers to probe and clarify pieces of information given to them by the participants to ensure all aspects of the questions had been covered, however, it allowed the participants the freedom to answer the questions based on their own interpretation. After piloting the interview questions with two coaches who were also retired professional players (though not at the level of those included in the final sample) the finalised interview guide can be found below:

As a (former) professional player, we are wanting to get your thoughts on serve returns in tennis matches, and different factors around what makes a good return. The interview will focus on the characteristics you think comprise a good returner. In particular, we are interested in the factors, which help players make decisions in advance about the type/location of the serve they are likely to return.

Qu: Can you think of examples of past or present players who are/were good returners?

Qu: When you were returning, did you consider contextual information (e.g. score, court side, handedness, wind etc.) to help predict an opponent serve when competing?

Qu: What role did kinematic information (e.g. ball toss, trunk rotation, head position etc.) play in helping you anticipate or predict the serve? Was it more important than the contextual information? Why?

It should be highlighted that the second component of this question was particularly critical in addressing our primary research aim and was probed more extensively than other questions to ensure any content the participant possessed about how the two information sources interacted was collected.

Qu: If you utilised such contextual information how did you update it over the course of a match? For example, how many times did a player have to serve to the same spot on big points before you considered this a trend and adjusted your response accordingly?

Qu: Today, we have asked you to think back to when you played. Now that you're more involved in coaching, has your thinking or philosophy regarding what factors are important on the return changed at all?

Qu: Given the role of the return in tennis, can you comment on how it is practiced?

Probes were used at the end of each question as necessary to gather further details about the answer.

3.3.4 Analysis

Using an open-coding analysis approach (Straus & Corbin, 1998), the transcribed interviews were individually coded, sentence by sentence, by the three researchers separately to draw upon the emerging themes from the participants responses to the interview questions. The three researchers who conducted the analysis have both research and practical experience in skill acquisition and tennis analysis which was useful in being able to extract and interpret tennis specific jargon from the transcribed interviews. Sentences of the interviews were given tags which related to codes that emerged during the coding process. Themes were included based on common tags from each researcher which were mentioned multiple times in the interviews. Common themes that emerged from this process between each interview were categorised into higher or lower order themes. Some tags resulted in an accumulation of similar meaning labels and were categorised into the same relevant theme. The resultant codes from the thematic analysis from each researcher were drawn together to determine like themes across the researchers (for the frequency of each theme that is explored in the interview process, see results section). In the case of differing themes between the researchers, findings were compared and discussed, and where appropriate, re-analysis of the related tags was undertaken until consensus was achieved among all researchers. Quotes from the interviews were extracted to provide examples of responses which related to each higher and lower order theme and provide evidence that the themes were relative to returning serve in professional tennis matches. Using this approach allowed the researchers to build upon the anticipation research already conducted by elaborating on the quantitative results of previous studies in anticipation. A grounded theory approach was used to then develop a model which combined the emerging themes of the current study with known data from previous research (Straus & Corbin, 1998). Specifically, Farrow and Abernethy (2003) used viewing windows of 300ms intervals in their temporal occlusion research of a tennis serve. Each 300ms time interval is known to contain important anticipatory information and will be used as the template for the temporal model developed in this study.

3.4 Results

The thematic analysis which occurred from the transcribed interviews generated nine higher order themes relating to the return of serve process in tennis matches. These themes were generated using an aggregation of terms and codes from the analysis of the interviews. Throughout the results, counts of the number of participants who discussed these themes are included to demonstrate this. The themes which emerged describe both a temporal approach and specific informational content used by players to inform their decision-making as they attempt to return the serve of their opponent. Each of the themes is summarised in Table 3.1 and then further detailed below. The results are presented in two sub-sections. The first section reports the themes that were derived from the participant's first-person perspective as a returner, while the second section reports themes that were considered subjective theories about the behaviour of returners more broadly. Similarly, while the primary aim of this research was to understand anticipation of the return of serve, participants were also invited to discuss the return of serve more broadly. This discussion and resulting themes contributed to contextualising the overall research question.

Higher Order Theme	Lower Order Themes
Consciousness	Anticipation: - *See the ball early off the racquet* - *Look for signs/information sources about the type of serve* Pattern recognition: - *3 service games/halfway through first set to recognise patterns* Watching pre-match, warm-up and during match for opponent's strengths/weaknesses; figure out information sources and update information during the match Some "gut" returning early in matches Interaction of conscious and non-conscious returning Awareness of contextual and kinematic information sources Limitations of server: - *Handedness* - *Weaknesses*
Tactical awareness	Awareness of contextual and kinematic information sources Calculation about what serve is coming Playing the percentages Constantly updating probabilities Handedness: - *E.g. Left-handed server's preference for sliders on Ad court*
Contextual information sources	Server preferences: - *On score lines (e.g. break point, 30-30)* - *Court side* Weather: - *Wind conditions across/down court* Surfaces: - *Grass* - *Indoor* - *Clay* Handedness Situational information

	Court slope Play percentages but must be aware of the context of the moment
Kinematic information sources	Server position on the baseline Ball toss Server's grip on their racquet Torso rotation Server action: - *Shoulder over shoulder* - *Corkscrew*
Mentality/confidence	Making returns early in the match Clarity of returning: - *Confidence in execution of returns* Critical for being a good returner "The bluff" Switched on/focused
Returner technique/strategy	Return to large targets/locations on court Adapted return swings: - *Compact swing* - *Grip changes* - *Double handed backhand better option than single handed backhand* Protect returner's weakness Confidence in own returning ability Ball tracking/recognition Hit the return across the body
Build pressure on server	Making a lot of returns to force server to over-serve Feel presence of returner "The bluff": - *Returner moves laterally/forward/back before serve to get inside server's head* - *Shows the server that as a returner, you know where the serve is going*
Returning characteristics	Aggressive returners: - *Stands up in court* - *Returns well on big points* - *Tees off* Neutral returners: - *Returns serve-by-serve* - *Just aims to get ball back into court* Counter-puncher returners: - *Makes high percentage of returns to increase pressure on server* - *Not aced a lot* Consistency Fast feet Picks up information sources/signs/ball earlier Quick hands to recognise the serve and adjust grip/racquet position to hit quality return Agility: - *Explosive* - *Quick feet* Take the ball early Forward momentum Set-up:

	- *Adjust returner's court position relative to server's*
Practice	Not practiced enough Not specific enough Best practice via exposure to different servers, serves, handedness, ball toss Doubles practice useful for gaining tactical experience

Table 3.1: Nine higher order themes and the corresponding lower order themes resulting from return of serve anticipation interviews

3.4.1 Anticipation perspectives

3.4.1.1 Consciousness

All eight participants agreed that they were conscious of the various information sources they needed to be aware of in order to anticipate and correctly perceive the type of serve they needed to return during a match. The notion of conscious detection of these information sources was a common theme throughout all interviews. When discussing the detection of kinematic and contextual information sources of a server, participant 6 said "if you know a guy prefers a certain serve on a certain point… then you can take a calculated risk or a guess that you can maybe sit a little more on that one. But personally, I also get a feel and a read for guy's techniques and I'm able to see pretty quickly which serves they'll be able to hit at a higher percentage when they really need them according to their technique". This comment shows that tennis players are consciously aware of various contextual and kinematic information sources that would result in a particular serve outcome. This awareness would help them anticipate particular types of serves. This conscious gathering of information appears to continue during the match and be constantly updated based on new cues from the information sources from their opponent throughout the match. All eight participants were in agreement that "if you're switched on enough you can probably work it out in the first two or three service games" (participant 8) when determining the kinematic and contextual information sources of their opponent if they had not played against each other before. All eight participants suggested that this collection of information may also occur in the days or hours prior to the match. This includes information about the server given to them by a coach, other players, by watching their opponent's previous matches, or during the warm-up.

3.4.1.2 Tactical awareness

Being tactically aware about the high percentage plays used by a server also demonstrated that the players were conscious of potential contextual and kinematic information sources that they could attune to, to help them anticipate the direction and location of a serve. Respondents in the interviews frequently spoke about updating probabilities of certain serves throughout the course of a match and making calculations about what serve they were about to return. "You've got to know, particularly on big points, break points, crucial points, the more important points in the game, you've got to be very very aware of what your high percentage plays are" (participant 4). Having good tactical awareness when returning a serve meant being aware of the many contextual and kinematic factors which would useful for anticipating a high percentage situation. Participant 4 said that "you've got to know, particularly on big points, break points, crucial points, the more important points in the game, you've got to be very, very aware of what your high percentage plays are".

3.4.1.3 Contextual information sources

All eight respondents cited that they used various contextual information sources to help anticipate a serve in tennis matches, and that it generally only took two to three service games from their opponent for them to be aware of the server's preferences. The most common contextual information source participants used was known server preferences on score (most predominantly, on break point or game point). Participant 1 discussed that "on a big point, they [the servers] are going to want to hit their favourite serve most likely. I'm going to make sure I don't get aced by that, I'm going to try and cover that favourite one at least". Additionally, other contextual factors which the players considered during the return of serve, were factors which could not be changed or updated prior to, or over the course of a match, such as weather conditions, court surface, indoor or outdoor conditions, handedness of the server and the court slope. These factors were listed by five of the eight participants as factors which needed to be carefully considered when playing a match. Participant 8 spoke of how different court surfaces affect the serve and the return "on clay, you probably see that a little bit more where they maybe go out to the backhand side, they hit a kick serve generally. They want to get more angle to hit a forehand off the next ball". One criticism of using contextual information to return serve by some of the respondents, was that, although they were always aware of the probabilistic information at a given time during the match, this information would not negate the other information they were aware of at the time, such as kinematic information sources. Participant 5 described this as "I think that obviously, myself, when you're up against a big point, you want to go to your favourite serve…You can't take that as religion, but it does help to know that they're more likely to go there". In most cases, it appeared that the kinematic information was the factor which either confirmed or changed what the returner knew from the contextual information.

3.4.1.4 Kinematic information sources

Kinematic factors were commonly mentioned by all participants when anticipating a serve during a match. The most common factor mentioned by the eight participants was the ball toss of the serve; participant 4 said that “I suppose I would look mainly at the toss. The action generally from player to player isn’t going to change that much. The toss obviously changes, so you’re trying to get little cues out of the toss”. Other kinematic factors that were mentioned were the server’s grip on their racquet, the server’s position on the baseline, torso rotation during the serve, and the type of service action of the server. Two types of service action were mentioned by participant 5 who described it as “the old school corkscrew service action, which is where they get their power and their rotation, isn’t shoulder over shoulder, it’s torque rotation where your shoulders are actually moving in a semi-circle almost. When that happens, I feel like that those guys are a lot more susceptible to cut, have good cutting serves, sliding the ball. Shoulder over shoulder, they have much more ability to hit that flat serve”. These discussion points make evident that returners are very much attuned to kinematic information sources during the return of serve, and that it contributes to their ability to anticipate the serve before ball flight information becomes available.

3.4.1.5 Mentality/confidence

In order for tennis players to anticipate a serve and use the anticipatory information, they must be confident that the information they are perceiving is sufficiently reliable for them to act upon before ball flight information is available. Six of the eight respondents said that being focused on the anticipatory information sources they were looking for, was key for having the confidence to execute a return from an anticipated serve. Participant 8 said it was important for players to have clarity in their decision-making when attempting to return a serve. Participant 8 described that "it really comes back to preferences under pressure for a lot of these players. And then having the ability to back that as well. You can say that you're going to do it, and know that it's going to happen, but then you've actually got to try and be leaning that way, and actually have the conviction in your head that that's the way he's going to actually serve it". Another strategy participant 7 discussed to build confidence in returning ability was to execute these types of serves early in the match, so the returner had already experienced the types of serve they may be expecting when it was most crucial (i.e. on break points or late in a set). For example, "early in a match… I would always hit a return up the line early to free up because when it gets tight, it's harder to hit the more difficult returns. If you haven't done it, then mentally you won't take it on, you'll go back to safety".

3.4.1.6 Returner technique or strategy

An effective returning technique that emerged from the responses was to ensure that the returner had compact swings off both the forehand and backhand sides (due to the time constraints of a returning task) as well as aiming to large targets or locations at the other end of the court. Participant 3 compared hitting a return to hitting a baseball: "not taking big swings. I refer to it a little bit as, sometimes on a big serve you can bunt the ball like a baseball where you don't take a big follow through because when the ball's coming really fast and you're taking a complete swing, there's more chance of an error". Additional strategies include hitting the return across the body so it passes over the lowest part of the net, protecting the returner's own weakness, and being confident in their ability to hit the return where they wanted to, using their preferred technique. As participant 6 said, "I think statistically, there'd still be some foundational things that work better than others, or history would show things work better than others, for example, returning over the lower part of the net, or returning to big spots in the court".

3.4.1.7 Build pressure on server

Many returners say that they would prefer to hit a second serve as opposed to a first serve in a match, as second serves are often more predictable and slower than a first serve. While this is very server-determined, participants discussed the tactic of attempting to force pressure onto the server in order to bluff them into serving either a slower-paced first serve, of a fault which would then result in a second serve. Participant 3 said that "second serves are notorious where people can get a bit nervous on them and serve double faults, so if you can play with their head a bit, you can get a few free points, so that was always important, or get them to start slowing down their first serve because they're worried on big points, of hitting a second serve". Using kinematic and contextual information sources to position themselves in a way which shows the server that they know which direction the serve will be coming, means the returner is building pressure on the server. This tactic forces perceived pressure onto the server who either has to block out this change in position from the returner and serve as they were planning to, or adjust their serving tactics and change their planned serve direction. Participant 5 said that "I want the server to think about me returning as much as possible. Because anything that will slightly throw them off that rhythm on that serve will be the difference of getting a second serve on a big point as opposed to a first serve. I'm a big fan of getting in the head of the server if I feel like they're winning that battle. So, I'll definitely stand around, and that's where that [statistical] data comes into play. I might go and really show him that I think that down the tee serve is your favourite serve".

3.4.2 General participant observations

3.4.2.1 Returning characteristics

Three types of returners were described by the participants. Aggressive returners were able to set the point up with their return, a high starting return position in the court (i.e. inside the baseline) and by doing so, were able to build pressure on the server. Participant 2 described aggressive returners as “It’s not so much it comes at your toes every time, it’s just the fact that you never get any free points. The accumulation of pressure on the server developed by very good returners on their second serves is pretty telling”. Counter-puncher returners have the ability to build pressure on the server, similar to the aggressive returner, however they did this by making a high percentage of returns back into the court and were said to be more consistent. This type of returner was described as being very frustrating to play against as the server was unable to win a free point from an ace or unreturnable serve. These two returner types were summarised nicely by participant 7 who said that there are “the returners who hit aggressive and who (have) the ability and making good returns at set points or on big points. And then there’s the returner who makes every ball back into play and is more of a counter-puncher returner”. The third type of returner was a neutral returner who was characterised by their ability to simply return each serve back into the court on its own merits without considering kinematic or contextual information sources. While three distinct returner types were identified from the responses, there was consensus among all participants who added that adaptability and consistency were important characteristics which good returners must possess regardless of returner type. Participants said that when talking about players reacting to a serve that, “there are some players who will pick up the signs better, have better reactions, they’re sharper, their eyes work quicker picking up balls" (participant 3). This demonstrates that reaction capabilities of players, as well as their capability to anticipate a serve is important to executing a quality return of serve. Good returners in this area were said to have quick, reactive hands which allowed them to react and adjust the grip on their racquet to hit a quality return.

Participants noted that great returners were able to see and anticipate a serve early, but quick movement to the anticipated serve was critical. As participant 7 described, "I think the best returners in the world are the ones that have the ability to take the ball on the rise and move into the court when it's a bigger point". This also requires returners to have good forward momentum moving into the court when returning. "Best returners play the ball. And that fundamentally is a very simple breakdown of body weight forward into the return, you've got a good chance of making it and making a better return because you can get a piece of it with some pace on it" (participant 7). Not only this, but participants also discussed the ability of the returner to use the information sources to anticipate where the serve was going and using their movement and return positioning, they were able to position themselves to hit a quality return.

3.4.2.2 Practice

All participants said that the return of serve is practiced proportionately less than the serve and is often incorporated into point or match practice during training sessions. However, it was becoming a more important aspect of training. "It's probably one area that tennis players don't practice enough. They practice their serve a lot, you'll practice your serve way more than if you go and practice your return of serve. I think it's something that could be practiced more" (participant 3). Participants did say that in the future, a focus on the return of serve was something they would consider in coaching to expose younger players to more variety of serves and serving styles to develop their awareness of kinematic and contextual information sources. As participant 4 said "I think we can do a better job of actually practicing different return positions better than what we do. Whilst clarity is a big thing, and you're going to have your favourite position as such, I think it's important to be adaptable and be flexible with that you can do as a returner".

3.5 Discussion

The current study aimed to investigate the interaction of kinematic and contextual information sources on the return of serve. Using an open coding approach to analyse the participant's responses, nine higher order themes were found from common responses across the participants. These themes were consciousness, tactical awareness, contextual information sources, kinematic information sources, mentality/confidence, build pressure on server, returner technique or strategy, returning characteristics and practice (Table 3.1). Using a grounded theory approach, these higher order themes and the specific circumstances and types of information considered by the players was aggregated to develop the model which depicts the timeline of the priority of information during the serve and return in a tennis match (Figure 3.1). This model commences with match preparation within the day prior to a match and concludes with the execution of the return shot by the player. A significant feature of the model is its cyclical nature. That is, the actual serve direction and the outcome of the return (type and quality), subsequently influences the preparation for the next return of serve. Over a number of points and games, this feedback begins to weight decisions made and which source of information is prioritised when similar situations are experienced.

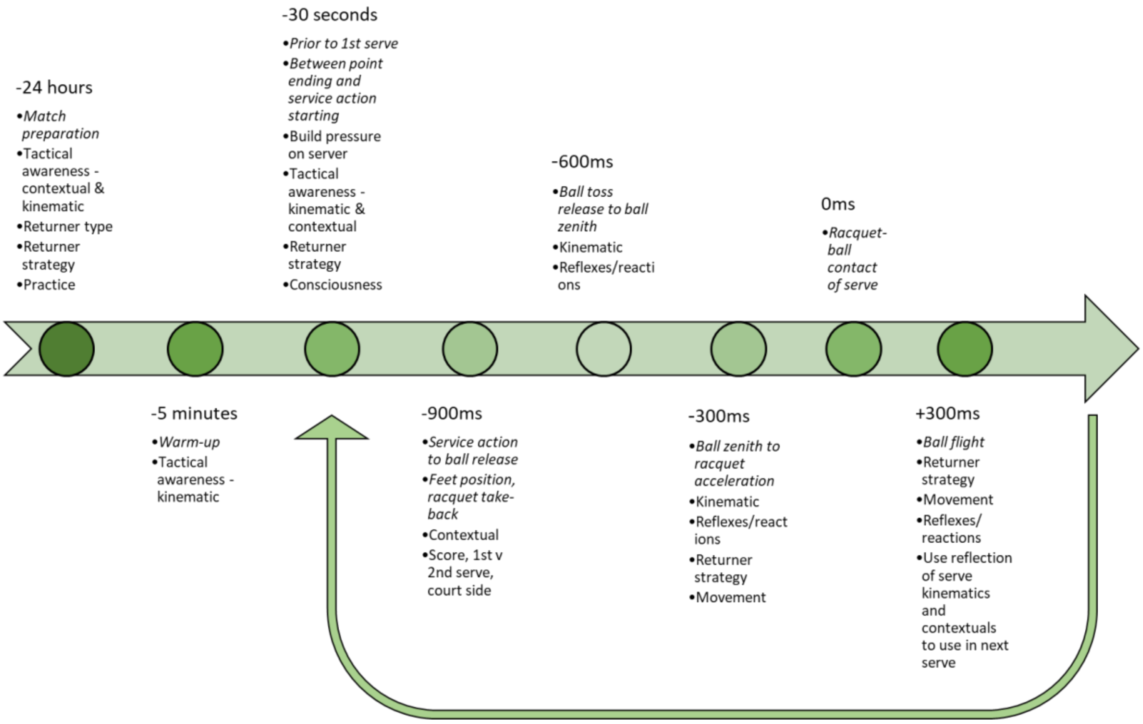


Figure 3.1: Temporal model depicting the conscious use of kinematic and contextual information sources throughout the process of returning a tennis serve

3.5.1 The priority of information sources during the return of serve

The timeline of serve and return events (Figure 3.1) commenced the day before the match, with one respondent suggesting that they would undertake some type of analysis to determine the specific contextual and kinematic information sources unique to their future opponent they needed to be attuned to. “You had your coach or yourself watch [your opponent], and say, “look I think they favour this”. But also base it on technique, for example, Boris Becker, he had a forehand grip [on serve], could he go wide to second court? Absolutely, but I still felt like his inconsistency was enough so you might say “well that’s the highest part of the net”, or his forehand grip negated him from have a great swinger down the tee” (participant 1). Returner type was also included in pre-match considerations to allow players to adapt their planned returning strategy based on their returning skill and the tendencies of their opponent. Throughout the match, players have approximately 30 seconds between the last point ending, and when the server needs to initiate their service action to start the next point. Participants said they were able to use this time to prompt themselves of the contextual and kinematic information sources they needed to be attuned to during the next serve, and undertake an analysis of the updated information sources which have been presented up to that stage of the match. This demonstrates the constantly shifting weighting of contextual information used throughout the match. Having an understanding of the key information sources allowed players to use the time between points to set up their return position with the aim of building pressure on the server by demonstrating, through their court positioning, they knew where the serve was going. A good explanation of this was given by participant 7 who said "let's say on a break point, their best serve was down the tee, [I would] cover more of that and force them to go more to that one that they don't want to under pressure like that". This was a conscious decision by the player in an attempt to force their opponent to over-serve, or doubt their serving strategy, resulting in a fault, or an easier or slower serve to return.

The commencement of the physical return of serve goes through distinct stages outlined by the timeline in Figure 3.1. The time intervals presented have been borrowed from conditions used in earlier temporal occlusion research (Farrow and Abernethy (2003) where consideration had been given to the kinematic sequence of the service action. The time intervals up to -600ms is when participants stated that contextual information is used as the predominant anticipation information source. This includes factors such as score, side of the court, weather conditions or server preferences. This is consistent with previous empirical work that demonstrated older, more experienced tennis players are attuned to patterns in serve direction based on score information that younger, less experienced players are not (Farrow & Reid, 2012; Stern, Loffing, & Hagemann, 2016). This was nicely illustrated by participant 8 who stated; “You look for patterns in the serving. Obviously, guys under pressure, that’s the biggest key, under pressure where they serve those balls… if you’ve done your homework, generally you can be leaning one way or the other knowing that they’re going to serve that serve under pressure”.

The time key information appeared in the event sequence and hence its relative importance in the returners decision-making process was summarised by participant 4; “you may know the opponent well. You may have played them before and so that obviously helps to get a bit of a rough guide as to where they’re potentially going to serve on big points. I suppose on top of that, you’re looking at just trying to read little things into their toss. Trying to pick up any cues possible that you can to try to get a slight lead on a serve”. This is a good illustration of how contextual information sources are initially considered in the early stages of the serve (i.e. stages prior to -600ms), but then the probability of that serve is either confirmed or rejected by the key kinematic information from the service action in the time window from -600ms through to racquet-ball contact. This is similar to the model developed by Müller and Abernethy (2012) which demonstrates that contextual information is the early influence on returning behaviour. In addition to this, there are also an increased number of kinematic information sources that become available throughout the service action, and therefore anticipation of the action outcome becomes predominantly influenced by kinematic sources as they emerge.

With the service action phase from -600ms through to racquet-ball contact, there are a variety of specific kinematic events which are known to contribute to anticipation. These include the lateral position of the ball toss, depth of knee flexion and arm and trunk rotation of the serving player (Ward et al., 2002). The results of this study confirm that expert players consider the ball toss to be the most influential kinematic information source used to anticipate a serve. This is demonstrated by participant 3's comment: "I suppose I would look mainly at the toss…The toss obviously changes, so you're trying to get little cues out of the toss". While some previous research (Loffing and Hagemann (2014) suggests that contextual information may still be prevalent during these later time intervals, the current results suggest that expert tennis players are seemingly consciously attuned primarily to the kinematic information sources from the opponent's service action in this period. Furthermore, this period of focus on both contextual and kinematic information also confirms research regarding attentional control and automaticity. This research explains how expert athletes are superior at being able to conduct their responsive movements automatically, therefore freeing up attentional control to attune to the key information sources (Gray, 2015).

Following these periods of attention to anticipatory information sources, once the server makes contact with ball, the ball flight information overrides all previous contextual and kinematic information, as the most reliable source of information for the returners to respond to. As participant 5 stated, "what I really try to put an emphasis on, is really try to pick it [the ball] up early off the racquet so therefore I can react a little bit quicker". This aligns with the in situ observations of Triolet et al. (2013), who suggested that in the majority of cases, return responses of expert tennis players are largely based on ball flight information.

Re-adjusting one's intent or initial movements based on anticipatory information was also highlighted as a key skill by participants. The returner's own reactions, movement and returning strategy and execution are considered all critical factors in this regard.

Empirical work has demonstrated, that the reactions of returners are faster during the first serve compared to the second serve (Filipcic, Leskosek, & Filipcic, 2017), which is clearly in part due to the temporal stress of the first serve relative to the second serve (i.e. significantly higher serve speeds on first serve compared to second serve). In particular, it has been demonstrated that split step reaction time and movement speed are also critical to accurately respond to a first serve (Avilés, Benguigui, Beaudoin, & Godart, 2002). Following the completion of a point, and prior to the commencement of the next point, the returner has time to briefly reflect on the presented kinematic and contextual information sources relative to the actual serve hit and consequently update their predictions for following serves. This process was reported as taking at least three service games for them to feel comfortable that any changes in the likelihood of a particular serve are genuine, and not simply due to chance. As participant 8 explained "if you didn't [know your opponent], sometimes even as much as the second or third service game, because it would be a bit of a test even, because you would take a calculated risk and test them to see if they had the courage to hit certain serves under pressure". This observation is akin to the early work of Alain and colleagues who suggested that the probability of a specific event needed to be as large as 90% probable before a performer would anticipate its occurrence and alter their response with confidence (Alain & Proteau, 1977).

3.5.2 Conclusion

In conclusion, the results of this study provide researchers with a framework to further investigate return of serve anticipation in tennis and quantitatively identify the interaction of kinematic and contextual information sources. The current results generally support previous empirical work that has independently examined the various anticipatory information sources available to a performer. It also agrees with the small number of previous studies that have looked at the interaction of kinematic and contextual information sources (such as Runswick et al. (2018)), that athletes who are able to use both information sources during an anticipation task, are able to improve the outcome of their response to that task. It is envisaged that experimental designs can be developed to manipulate the salience of specific information sources and ascertain whether performers do indeed weight or prioritise particular information in specific circumstances. This will allow further insights into the contribution of subconscious processing relative to that information performers are consciously attuned to. In addition, the current research findings can be applied using a representative task design approach to develop a training protocol for players to develop their anticipation skills (Broadbent, Ford, O'Hara, Williams, & Causer, 2017). Similarly, the practical implications of the current study can be extended to interceptive tasks in sports such as baseball or cricket.

Chapter 4: Analysis of player movement during the return of serve in professional tennis match play

4.1 Abstract

The ability of expert tennis players to adjust their behaviour to the contextual and perceptual information available to them during the return of serve has not yet been established in match play investigations. While the vast majority of anticipation research in tennis returning has focused on movement accuracy and response time relative to these cues in laboratory-based studies, very little is known about how tennis players adjust their court position in response to this information. This study used spatiotemporal ball tracking data from Hawk-Eye to investigate the changes in court position of professional male tennis players returning serve in the 2018 Australian Open tennis tournament. Overall court position was measured at three individual time intervals during the return. The results show that the largest variation in overall court position occurs at return impact of the returner, compared to the earlier time intervals at 1 second before serve, and at serve impact. Individual analysis revealed that match and opponent factors altered the returner's position. However, the value and the direction of this change was influenced by which returner type the player was categorised as – a shifter, an adapter, or a consistent returner. Furthermore, the results found that on break point situations in a match, players are positioned significantly deeper in the court at all three time intervals compared to other points, and only changing lateral position significantly at return impact. These results appear to demonstrate that tennis players are willing to wait for ball flight information to be available to significantly change their lateral court position on all points, and when contextual information is available on break points. These findings are discussed with reference to information-movement coupling of the return, and how players are willing to wait until reliable information is available to commit to a change in court position.

4.2 Introduction

In interceptive sports such as tennis, skilled athletes must be able to use perceptual and contextual information available to them to respond accurately to the actions of their opponents. In tennis matches, many serves are recorded at over 200km/hr, meaning players have limited time to respond. Skilled players not only need to pick up anticipatory information and ball flight information, but also precisely coordinate the final stages of their movement response to respond accurately to the action outcome, meaning that every millisecond matters in these scenarios. Attunement to relevant perceptual and contextual cues in interceptive sports has long been the subject of research interest, and has variously shown to positively affect motor skill performance (Abernethy, Farrow, Gorman, & Mann, 2012). Furthermore, researchers have linked expertise to the extent to which performers can use these types of information to influence their behaviours (Van der Kamp & Renshaw, 2015). The anticipatory capabilities, used prior to ball flight information becoming available, of these skilled players are critical to the success of returning serve in tennis. Players must therefore be attuned to all available information sources prior to the moment of racquet-ball contact of the server. Contextual information, and in particular, situational probabilities (Cañal-Bruland & Mann, 2015) supply additional cues which may influence player behaviour prior to the perceptual information becoming available. The return of serve in tennis is a good example where skilled players are able to anticipate the serve direction in an attempt to more effectively return the serve. Perceptual skills were flagged in Study 1 (Chapter 3) as key characteristics that good tennis players possess. Despite the known superior anticipatory capabilities of expert tennis players, it remains unclear how these skills can affect behavioural changes associated with more successful returning.

Use of situational probabilities has long been associated with superior expert anticipatory skill, and it has been found that a number of athletes are attuned to this information in a number of studies of different interceptive sports including tennis (Farrow & Reid, 2012), baseball (Gray, 2002b), and cricket (Müller et al., 2006). These studies found that expert athletes are able to anticipate an action outcome above chance levels based on situational information. The probability of a specific action outcome of an opponent occurring on a particular score is important knowledge for tennis players, who are then able to use to inform their anticipation capabilities and respond appropriately. Due to the unique scoring system in tennis, it has been found that some points are weighted as more important than others. In professional grand slam match play, players who win a significantly greater proportion of break points than other points win the match (O'Donoghue, 2012). Therefore, servers are under increased pressure to deny their opponents the break of serve, and returners are under increased pressure to win to the point to gain a score advantage. In these scenarios, it has been found that servers tend to rely on their own strengths and specific patterns to give them the best chance of winning the point (see Chapter 3). Therefore, returners are able to enhance their anticipation of the serve outcome, and alter their return response based on their knowledge of this information.

The behaviour and movement of skilled tennis players, and how their return behaviour adjusts with the presence of difference sources of anticipatory information has not yet been established in the literature. While previous research demonstrates that tennis players are attuned to probability information, there is a lack of investigation to show how their returning behaviour may change during a match based on this information. The results from interviews with expert tennis players in Study 1 (Chapter 3) indicate that they are comfortable adjusting their return position to reflect their knowledge of this contextual information. However, there has been no research to demonstrate that this occurs during tennis matches using a quantitative approach. A systematic review from Avilés, Navia, Ruiz, and de Quel (2018) found that there is currently no evidence which suggests that tennis players demonstrate an observable change in anticipatory behaviour (i.e. from their response times and split step movement) prior to ball flight information becoming available when returning a first serve. However, this review failed to take into account the differences in overall starting returner position relative to the court dimensions, and how this may alter with the availability of situational information. Studies investigating other sports such as baseball, have looked at how changing situational probabilities based on ball count (Gray, 2002b; Paull & Glencross, 1997) or preference for a particular pitch type (Cañal-Bruland et al., 2015) have influenced batting response accuracy and timing. These studies have shown that baseball batters may not significantly change their response behaviour due to the possible negative outcomes associated with anticipating incorrectly (Alain & Proteau, 1980), instead preferring to wait until the early stages of available ball flight information so their response is correct. These results provide further evidence that experts prefer to wait until some ball flight information is available before they commit to a final movement to reduce possible deception from incorrect cues (Dicks, Button, & Davids, 2010a). While these studies are important for highlighting the responses of experts, it does not take into account the changes in starting position or technique. Baseball only allows so much variability in where the batter can stand relative to the homeplate, however in tennis, there is a much larger area on the court where the returner can position themselves, and therefore, gives them greater scope to change their position based on various information. Recent advances in spatiotemporal tracking may allow researchers to more accurately investigate changes in court position of expert tennis players when returning serve based on situational information of certain match play scenarios.

The use of Hawk-Eye (Hawk-Eye Innovations, Basingstoke, UK) technology in professional tennis matches has allowed accurate ball and player tracking during match play to become possible for the first time (International Tennis Federation, 2019). Research using Hawk-Eye data has predominantly centred around ball tracking, and determining tactical patterns in tennis match play based on this information (Wei, Lucey, Morgan, & Sridharan, 2013). To the author's knowledge, there is yet to be published research which uses player tracking data to assess changes to player movement and positioning based on tactical information, specifically on the return of serve. This study therefore aimed to use the player tracking data from professional tennis matches to determine the changes in court position based on situational information and address this current gap in the literature. In addition, the position of a tennis player on court prior to kinematic and ball flight information being available would also provide evidence that the use of contextual anticipatory cues alters overall return position, as was suggested by expert tennis players in Study 1. Finally, given the importance of break points in a tennis match (as discussed above), this data would also indicate that players are able to set up their initial return position on the expectation that the situational information on break points is different to other points.

The aim of this study was to investigate how the return position of professional players changes based on the availability of anticipatory information sources. The first aim of this study was to determine how individual players' return position changes over the duration of a match based on emerging situational information. Due to the increased availability of situational information which emerges as matches progress, it was hypothesised that the depth of a returner's position will become more aggressive (i.e. more forward in the court) over the duration of a match at three different time intervals (1s before serve, at serve impact, and at return impact) during the return of serve.

The second aim of this study was to statistically determine the changes in the court position of skilled players at the three time intervals based on the probability information on break points. Due to the importance of the returner needing to win the point to gain a score advantage in the match, it was hypothesised that the overall court position of the players returning serve at the three time intervals will be significantly more aggressive (i.e. more forward in the court) on break points compared to all other points. A number of individual male players and matches were analysed from the 2018 Australian Open tennis tournament to investigate these aims.

4.3 Method

4.3.1 Participants

Matches involving the top 20 male seeds from the 2018 Australian Open whom played at least three matches at the event were analysed. A total of 45 matches met this criterion involving 47 unique players (the 20 seeded players plus 27 opponents). The range in age among all players was 18-38 (M_{age} = 26.93 ± 4.79) and range in professional tennis rank was 1-224 (M_{rank} = 68.25 ± 58.30).

4.3.2 Data

The data for each match was collected from the Hawk-Eye camera tracking system that is used for line-calling reviews by most professional tennis events, including the Australian Open. The system uses ten, 50 Hz cameras, calibrated for the dimensions of a tennis court to provide three-dimensional (3D) trajectories of the ball position and two-dimensional (2D) trajectories of player position through the points. Player position is sampled at a rate of 25 Hz. In addition to the positional information, the Hawk-Eye system includes metadata about the serving player, the returning player, and the winner of the point.

The Hawk-Eye data from the Australian Open was accessed with consent from tournament organisers, and in turn the players. Institutional ethical approval was granted by the researcher's host University prior to the study commencing.

4.3.3 Pre-processing

Data collected by the Hawk-Eye system described the score and positional information of both players. This positional data was filtered using a low-pass Butterworth filter, after which the returner's position at the following three time intervals was identified: 1 second before serve impact (1s before serve), at the serve impact of the server's racquet-ball contact (at serve impact), and at the return impact of the returner's racquet-ball contact (at return impact). These three time intervals were selected as they reflect periods where contextual and/or perceptual information is likely to be available to the returner. For example, information from up to 1s before serve contains cues from contextual information sources only; between 1s before the serve to serve impact contains cues from kinematic information sources (server's action); and from serve impact to return impact contains cues from ball flight information. Given the variability in the number of second serves hit in each match and its potential effect on results, only first serves were included in the analysis.

4.3.4 Analysis

Given the hierarchical data structure, with observations for player position across multiple points within a match, a linear mixed-effects model was the basic framework used to describe changes in return position. To assess the changes in the depth and lateral position of the returner at the three time intervals, we used a random intercept and slope model to identify population and player-opponent specific adaptation trends. Population change in position over time was modelled by a fixed effect for the point number (the slope), while player-opponent specific trends were estimated with random effects for the point number for each player and match. Bootstrap resampling was used to derive 95% confidence intervals for the fixed and player-opponent random effects. The random effects of the depth position demonstrate how players adapted compared to the average player. In terms of depth, the direction of the changes was such that an increase in slope indicated more defensive positioning (i.e. standing further back from the baseline), while a decrease indicated more aggressive return position over the duration of the match (i.e. standing further up in the court). Although all players were included in these analyses, only the trends of players with multiple matches in the data sample are presented in detail.

To investigate the second aim of this study, a covariate for break points was added to the basic time trend mixed model as a main effect. This effect can reveal the changes in depth and lateral position in situations of greater pressure (a break point situation) compared to other points, controlling for player-opponent specific differences and adaptation trends. This method demonstrates the changes in returning behaviour on break points over the duration of a match due to the increase in situational information that emerges from a growing number of break points.

All data was analysed in R statistical analysis program (R Core Team, 2017) using mixed effects models with the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017).

4.4 Results

4.4.1 Changes to return position over the duration of a match

Table 4.1 shows the summary of the mixed model's fixed effects for lateral return position for the 1s before serve, at serve impact, and at return impact time intervals throughout the match (i.e. from the first return point to the final return point of the match). The lateral position of the players at -1s before serve (intercept = 3.619) and at serve impact (intercept = 3.600) was stable, but at return impact, a significant adaptation trend pointed to players contacting the return from wider in the court over the duration of matches (intercept = 3.365, point count number estimate = 0.0021, $Pr\ (>t)$ = 0.02).

There was no evidence of a statistically significant change in forward-backward displacement of the returner at any of the three time intervals but the negative estimates in the mixed model indicate that players tend to move forward from their average return depth as matches progress.

			Estimate	Std. error	df	T value	Pr (>t)	CI 2.5%	CI 97.5%
Lateral	1s Before serve	Intercept	3.619	0.0191	110.29	189.24	0.00		
		Point count number	0.0001	0.0004	104.44	-0.38	0.71	-0.0009	0.0005
	At serve impact	Intercept	3.600	0.0138	108.73	261.33	0.00		
		Point count number	0.0003	0.0002	85.54	1.24	0.22	-0.0001	0.0007
	At return impact	Intercept	3.365	0.0225	6901.19	149.27	0.00		
		Point count number	0.0021	0.0009	215.09	2.40	0.02*	-0.0004	0.0039
Depth	1s Before serve	Intercept	14.041	0.0680	109.02	206.58	0.00		
		Point count number	-0.0004	0.0008	90.88	-0.49	0.63	-0.0019	0.0009
	At serve impact	Intercept	13.855	0.0649	109.00	213.43	0.00		
		Point count number	-0.0005	0.0009	98.55	-0.58	0.56	-0.0023	0.0013
	At return impact	Intercept	13.403	0.0677	109.61	197.95	0.00		
		Point count number	-0.0006	0.0011	96.12	-0.53	0.60	-0.0029	0.0016

Table 4.1 Summary of fixed effects for player and match lateral and depth return position for three time intervals during the return of serve (NB * $p < 0.05$).

Table 4.2 contains estimates for the player-match variance components for the random effects of the lateral and depth of the return position. These variances account for the differences in return position (intercept) and adaptive behaviour (point count number), with larger magnitudes indicating more between-match heterogeneity. Small changes in lateral return position were observed between different players. At return impact, there were no changes in the average lateral return position between players (intercept = 0.000). The difference between lateral return position at return impact demonstrates that an average change in lateral return position of 0.5m (point count number = 0.0056) for every 100 points is a significant change. However, the largest variation among individual players was observed at the lateral return impact position (residual = 1.0063).

At return impact, the average difference in return depth position which is considered normal among two individual returners is 0.7m (as indicated by an intercept value of 0.6976). However, the significant differences in the average change in depth position of 1.1 metres (point count number = 0.0106) for every 100 points is in contrast with the player-to-player differences observed. Of the three time intervals, return impact showed the most variation among individual players (residual = 0.5169), as compared to 1s before serve (residual = 0.4397) or at serve impact (residual = 0.3871).

While the largest variation in both depth and lateral return positions occur at return impact among individual players, and also across the point count from the first point of the match to the last, the significant random effects at all three time intervals show player and match heterogeneity in depth and lateral return position could not be explained by chance.

		Groups	Name	Std. dev
Lateral	1s Before serve	Returner:match	Intercept	0.1832
			Point count number	0.0025**
		Residual		0.4687
	At serve impact	Returner:match	Intercept	0.1343
			Point count number	0.0014**
		Residual		0.3068
	At return impact	Returner:match	Intercept	0.0000
			Point count number	0.0056**
		Residual		1.0063
Depth	1s Before serve	Returner:match	Intercept	0.7084
			Point count number	0.0073**
		Residual		0.4397
	At serve impact	Returner:match	Intercept	0.6776
			Point count number	0.0086**
		Residual		0.3871
	At return impact	Returner:match	Intercept	0.6976
			Point count number	0.0106*
		Residual		0.5169

Table 4.2: Summary of random effects for player-match variances for all three time intervals for lateral and depth return position (NB * $p < 0.05$; ** $p < 0.01$).

Figures 4.1 a, b, c shows the match adaptation for each player per time interval. Highly negative or positive slope values are indicative of players that tend to become more aggressive or defensive over the duration of a match. Large variances in these slope values reveal players who assume varied return depth depending on the match and opponent. From these plots, and their associated random effects slope estimates, three different returner types can be determined – the shifters, the adapters, and the consistent returners. The shifters were categorised as players with either the same positive or negative slope value for all three time intervals, the same positive or negative slope minimum and maximum values, and a small range between minimum and maximum values (i.e. players who become consistently more aggressive or defensive over a match and across matches, see Tsonga as an example). The adapters were categorised as players with either a positive or negative slope at any time interval and who also had large range between their minimum and maximum values (i.e. players who change their return patterns depending on the match and opponent, see Nadal as an example). Consistent returners were those players with an average slope estimate close to 0 and a low range between their minimum and maximum values (i.e. players who tend to keep their return position consistent regardless of match or opponent, see Federer as an example). Individual player examples of these three different types of returners are discussed in the individual player analysis in section 4.4.3 below.

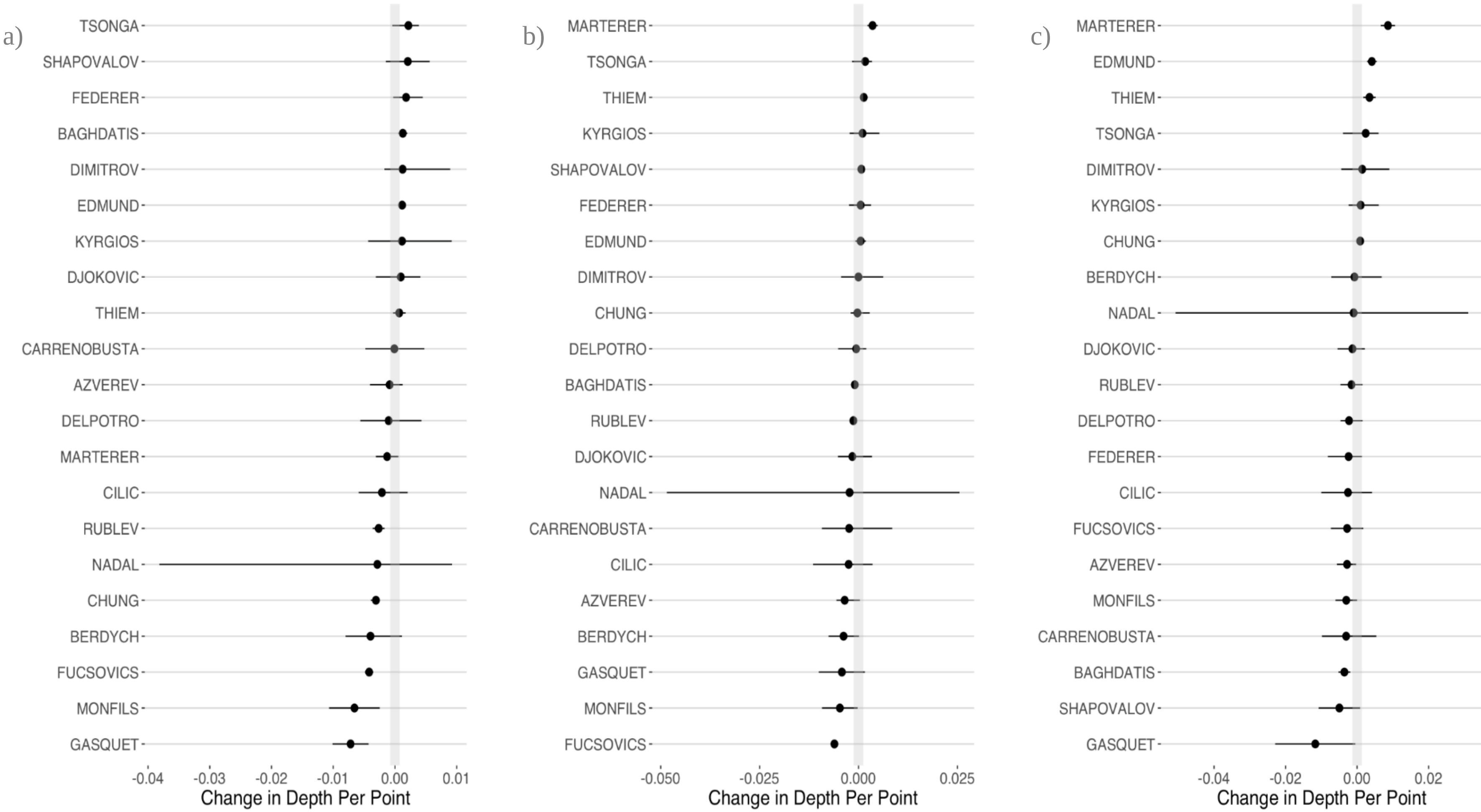


Figure 4.1: a) -1 before serve random effects slope values; b) At serve impact random effects slope values; c) At return impact random effects slope values

4.4.2 Changes to return position on break points

Compared to the depth of the returner on all points, players were found to adopt a more defensive position at all three time intervals of the return on break points. 1s before serve, players were significantly deeper in the court (0.079 metres). At return impact, they were set even further back in the court (0.123 metres) than usual. Difference in average serve speeds on either break point (192.07 km/hr) or all other points (191.13 km/hr) were minimal, and did not account for this increase in depth. No differences were observed in the lateral position of players 1s before serve or at serve impact, on break points compared to other points, however, keeping consistent with the results from above, significant changes in lateral return position was found at return impact.

			Estimate	Std. error	df	T value	Pr (>t)	CI 2.5%	CI 97.5%
Lateral	1s Before serve	Intercept	3.618	0.0192	111.2	188.86	0.00		
		Break point	0.012	0.0143	14784.9	0.85	0.40	-0.02	0.04
		Point count number	-0.0001	0.0004	104.3	-0.37	0.71		
	At serve impact	Intercept	3.600	0.0138	109.4	261.04	0.00		
		Break point	0.007	0.0094	14725.8	0.74	0.46	-0.01	0.03
		Point count number	0.0003	0.0002	85.5	1.24	0.22		
	At return impact	Intercept	3.368	0.0228	6949.4	147.83	0.00		
		Break point	-0.034	0.0420	7756.3	-0.81	0.42	-0.12	0.05
		Point count number	0.0022	0.0009	218.9	2.40	0.02*		
Depth	1s Before serve	Intercept	14.035	0.6793	109.1	206.60	0.00		
		Break point	0.079	0.0134	14677.1	5.87	0.00**	0.06	0.11
		Point count number	-0.0004	0.0008	90.9	-0.47	0.64		
	At serve impact	Intercept	13.847	0.0648	109.1	213.55	0.00		
		Break point	0.097	0.0118	14618.7	8.23	0.00**	0.07	0.12
		Point count number	-0.0005	0.0009	98.4	-0.56	0.58		
	At return impact	Intercept	13.393	0.0676	109.8	198.12	0.00		
		Break point	0.123	0.0218	7591.9	5.65	0.00**	0.08	0.17
		Point count number	-0.0006	0.0011	96.2	-0.54	0.59		

Table 4.3: Break point added as fixed effect in mixed model analysis for demonstrating change in return position depth over the duration of a match for each time interval (NB * p <0.05; ** p <0.01)

4.4.3 Individual player examples

One player from each of the three categories of returner type was chosen for further analysis. Players were categorised based on the slope average, minimum, and maximum, and only if they had two or more matches in the dataset. The players below are considered illustrative examples of each of the three returner types, and were selected as examples based on known anecdotal descriptions of their playing style.

Tsonga (Figure 4.2) was selected as the player who demonstrates consistent adaptation (the shifter) as he becomes consistently more defensive as his matches progress. This is especially evident in matches against Kyrgios and Shapovalov where these matches both went to five sets.

Figure 4.2: Tsonga depth returning position across cumulative point count for all three time intervals per opponent

Nadal is a player who is highly variable (the adapter) in his returning position and appears to change his patterns of returning positions based on his match or opponent. As evidenced in Figure 4.3, Nadal appears to have different, or emergent returning tendencies for each match. This is reinforced by inspecting Figure 4.1 a, b, c, where

Nadal's large range of minimum and maximum slope values (-0.0381 and 0.0311) is evidence of this large variety.

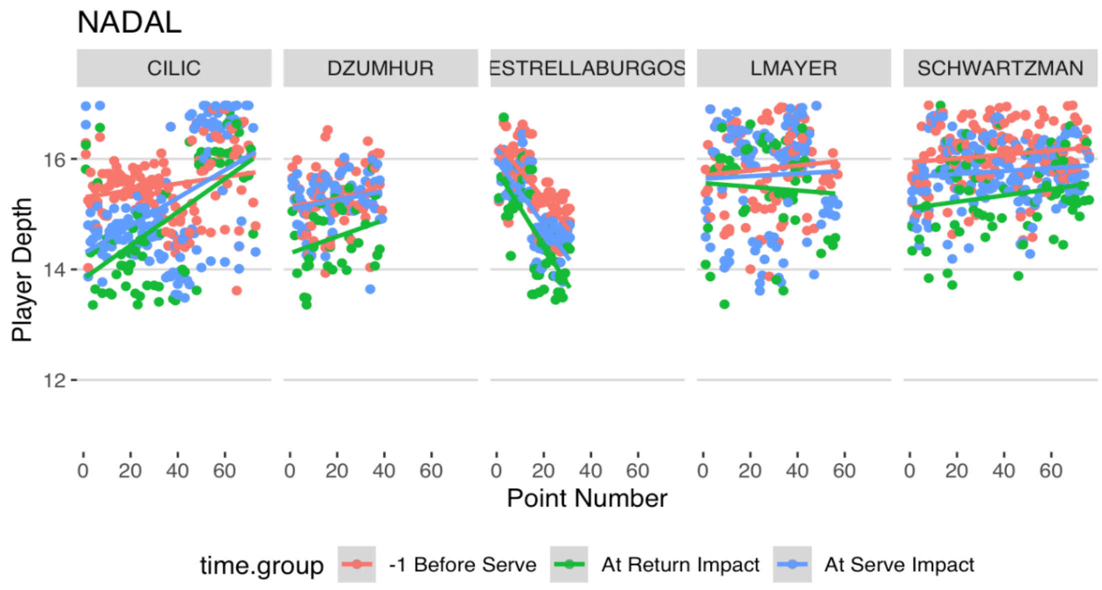


Figure 4.3: Nadal depth returning position across cumulative point count for all three time intervals per opponent

Finally, Federer in Figure 4.4 shows a consistent return position for all matches. His average slope estimate in Figure 4.1 for all time intervals is close to 0 (range between -0.0003 and 0.0045 slope values), which suggests that individual match factors do not alter his returning behaviour.

Figure 4.4: Federer depth return position across cumulative point count for all three time intervals per opponent

4.5 Discussion

The ability of tennis players to anticipate the direction of a first serve should theoretically allow them to hit a better quality return than those less-skilled tennis players who do not anticipate serve direction. However, despite considerable research investigating the return of serve, it remains unclear how the game's best players rely on the contextual and kinematic information to cause a change in their return of serve response during professional match play. This study therefore used player tracking data from 47 men's Australian Open main draw matches to determine the changes in return depth and lateral positions based on this contextual information. In the current study, different contextual information sources have been included under the singular umbrella of contextual information sources. The analysis of the first aim focused on the possible changes in return position when any contextual information sources are known to be available (at the 1s before serve time interval), rather than distinguishing between specific contextual information sources (with the exception of score, which was investigated as part of the second aim).

4.5.1 What general positioning strategies do players adopt when returning the first serve?

The 47 unique players in our analysis do not appear to display systematic adaptation in return position over the duration of matches. In particular, the stability in return position at 1s before serve, when only contextual information was present somewhat supports the conclusion of Avilés et al. (2018). From their systematic review of anticipatory research, Avilés et al. (2018) concluded that a number of studies had found no change in depth or lateral displacement during the anticipatory periods during the return of serve. Furthermore, the result that returners prefer a consistent returning style at the early time intervals of the return also supports the findings of Avilés et al. (2002), that anticipatory behaviours are not evident in the early stages during the return of serve.

The greatest variations in both the depth and lateral return position of players instead occurred at return impact. This is most stark for returner depth. The results show that the largest variation in returner depth occurs at return impact (residual = 0.5169), meaning the normal differences in return depth at return impact changes the most over 100 points at return impact. The usual differences in lateral return position between players again indicates that the largest variation (residual) occurs at return impact (residual = 1.0063).

This large variation of both lateral and depth return position at return impact (i.e. only after ball flight information becomes available) suggests that players are waiting for ball flight information before significantly altering their return position to match this information. At return impact, players have been exposed to all situational, kinematic, and ball flight information which confirms serve direction, and the direction the returners must move to match this. This finding supports the results of Triolet et al. (2013) who found that significant lateral displacement during the return of serve occurs only after the racquet-ball contact of the server. This suggests that there is the possibility of neutral return preparations prior to return impact (see Avilés et al. (2002)) and to eliminate any possible deception from the server's cues before ball flight is available (Dicks et al., 2010a). In other words, players are more in control over lateral displacement and depth at these earlier time intervals than they are at return impact, which will be directly influenced by the speed, spin, and placement of the serve. This result supports the findings of Cañal-Bruland et al. (2015) in baseball, where significant changes to a batter's swing initiation or batting action to account for different types of pitches, does not occur until after ball flight information is available. Furthermore, it may be possible that by waiting for ball flight information to confirm anticipatory cues, returners are eliminating possible negative consequences which may come from anticipating incorrectly (Alain & Proteau, 1980). This is an important finding as it indicates that ball flight information appears to be the most influential factor which contributes to the largest variation in return position. These results imply that the availability of known contextual (at 1s before serve) or kinematic (at serve impact) information may not be associated with a change in return position behaviour, which contradicts a number of studies which have investigated anticipatory sources in tennis (Singer et al., 1996).

A further explanation of this discrepancy in return behaviour is that during match play (as opposed to laboratory-based studies), correct anticipation and response accuracy to the serve is only one aspect of successful returning. It may be that because of the high stakes of professional tennis matches, and the possible negative consequences of anticipating incorrectly in match play, tennis players may tend to take a more conservative approach to their movement towards the serve. This would explain the small variations in return position at 1s before serve and at serve impact to reduce the possible negative consequences of anticipating too early, or incorrectly (Alain & Proteau, 1980). This is opposed to laboratory-based studies, where there is no disadvantage to anticipating incorrectly, or moving too early during these stages of the return. This is a risk-reward calculation that players must make before and during the return of serve during matches, and whether the possible benefits that come from moving to the anticipated serve early during the return, outweigh the possible disadvantages of losing the point if the player's anticipation of the serve is incorrect.

Furthermore, to return serve successfully, players must also time their movement to the ball and the action of the return shot. Moving or preparing too early or too late during the return may have a negative impact on the timing and momentum of the return, which may not align with the speed and direction of the serve (Van der Kamp & Renshaw, 2015). This may explain why the variations in depth and lateral return position at 1s before serve and at serve impact are smaller than the variation at return impact, where adjustments in return position to reflect the serve direction can be made based on ball flight information, as has been suggested by a number of previous studies (Singer et al., 1996; Triolet et al., 2013).

4.5.2 Do players adjust their return position according to the scoreboard, or more specifically, on break points?

The results from the current study have demonstrated that players significantly change their return depth at all three time intervals to a more defensive position on break points compared to their usual change in average return position on other points (1s before serve = 0.079 metres, *p* <0.01**, at serve impact = 0.097 metres, *p* <0.01**, at return impact = 0.123 metres, *p* <0.01**). This result signifies that situational information on break points contributes to a change in returning behaviour (i.e. their return position) compared to other points, albeit the opposite change in direction of what was hypothesised. This is an important finding as it somewhat supports the results of Study 1 that expert tennis players adjust their return position if they think they know where the serve is being directed. It also supports previous research that situational information is used to anticipate the outcome of a serve, and it is also the first study to quantitatively conclude that situational information on break points results in a change in return behaviour.

The largest change in both depth and lateral position occurs at return impact, which agrees with the conclusions of Avilés et al. (2018). This suggests that even though situational information is present and considered by the returner on break points, the largest change in return position, does not occur until ball flight information is available. This supports similar results in baseball about changes in batting technique based on probability information from Cañal-Bruland et al. (2015), and further supports the results from the first part of this study, that the ball flight information may be the most influential factor for altering position during the return of serve, despite the availability of situational or kinematic information. However, while these results suggest return position on break point is significantly different from their return position on other points, the absolute change in return depth when only situational information is available at 1s before serve is only 0.079 metres. Despite the significance, this difference may not be a noteworthy change that is visible to the naked eye of the server prior to the serve. This means that servers are unlikely to change their serve behaviour or tactics in response to these small changes from the returner, as they are unlikely to perceive them. A practical explanation of this small change is that the returner may not want to "give away" to the server that they have changed their returning position to accommodate for situational information on break points. However, the small change may be enough for the returner to give themselves the perception that they have changed their position in response to the availability of situational information. This explanation supports the discussions of the participants in study 1, where returning serve was referred to as a type of cat and mouse game between the returner and the server.

Although this change is relatively small compared to the dimensions of the court, there may still be a number of explanations as to why the return depth is significantly deeper on break points compared to other points. Firstly, it is important to note that there was no significant difference in serve speed on either of these points (192.07 km/hr on break points and 191.12 km/hr on all other points) which excludes this as an explanation as to why returners are deeper in the court. Given break points are high pressure points in the context of a match, by starting their return position further back in the court, the returner gives themselves more time to perceive and respond to the first serve successfully (Van der Kamp & Renshaw, 2015). This may also explain why the largest difference in return position on break points occurs at return impact, where skilled tennis players prefer to wait until ball flight information is available and they have more time to adjust their movement to give themselves more time to hit the return successfully (Alain & Proteau, 1980).

4.5.3 How generalisable or individual is movement behaviour on the return of serve?

These results, while accounting for individual variations, suggest that adaptation of return position is not the same for the entire group of players. This indicates that player and match heterogeneity must be due to some specific match or opponent factors which influences a change in returner position (as the results suggest this change cannot be explained by chance). Therefore, it is important to further investigate these results at the individual level to determine specific returning types, based on quantitative return position data. The average slope estimates that were calculated for each player and their specific matches indicated the direction of movement (either more aggressive or more defensive) over the duration of each match with larger ranges between minimum and maximum slope estimates indicating larger variation in return position adaptation. The significant random effects of both depth and lateral return positions supported the need for further investigation of the return position trends of individual players and matches. From this result, three categories of returner types were determined from this data – Shifter returner, adapter returner and consistent returner. Examples of individual players displaying these characteristics were added to demonstrate the differences in each category of returner.

Tsonga was the player who showed tendencies to be a shifter returner as he becomes more defensive over the duration of his matches. This is particularly evident in his matches against Kyrgios and Shapovalov where, at each of the three time intervals during the return, he became more defensive over the duration of the match. A possible explanation of this is that Tsonga is adapting to the higher first serve speeds of both of these opponents (206.0 km/hr and 198.7 km/hr for Kyrgios and Shapovalov respectively). As the match progresses, he is retreating deeper into the court to give himself more time to hit the return due to the higher than average serve speeds (Van der Kamp & Renshaw, 2015).

Nadal was the player who clearly displayed the tendencies of an adapter returner as his return position depth changed, not only over the duration of a match, but also across each of his matches based on his opponent or the situation of the match. Across all of his matches in this dataset, Nadal has varied his return depth by up to 4 metres. In the matches against both Cilic and Estrella Burgos, there appears to be a clear demarcation during these matches where his return position altered. A likely explanation of this clear change in return position is that Nadal either felt comfortable becoming more aggressive in his return position as he started winning the match, or he preferred to change to a significantly more defensive return position. It is known from the results of Study 1, that once returners begin to feel comfortable with their opponents serve, they may become more aggressive in their returning. Therefore, if players are not comfortable returning the serve of their opponent, they may also change their return position to be more defensive. Nadal clearly displays both of these tactics depending on the context of his match.

Finally, Federer was the player who demonstrated a consistent return position at all three time intervals across all of his matches. Despite playing different opponents and encountering different match circumstances, Federer does not appear to shift significantly from his average return position, which is consistently around 13m from the net (or just over 1m from the baseline). This pattern of returning indicates that Federer is able to return serve from a similar depth in the court (regardless of opponent or match situation). According to results from Study 1, these characteristics could indicate that Federer has clarity on his return of serve, and this does not require him to significantly change his returning position.

4.5.4 Conclusion

The current study used a mixed-methods analysis approach to investigate the changes in return position over the duration of a tennis match and on break points. The analysis found that individual changes in depth and lateral return position were present for all three time intervals, which indicates that specific match, individual, or opposition factors influence a change in returner position. In addition, the most variation in return position occurs at return impact, which indicates that ball flight information has the largest influence on both depth and lateral return position.

On break points, return position varies significantly from the average return position on other points during a match. The largest variation in return position depth on break points were found at return impact, suggesting that once again, return position is influenced the most by ball flight information.

The implications of this study are far-reaching to both future research and practical applications. Future research needs to determine the overall changes in lateral return position at various time intervals relative to serve direction. This would more accurately describe early knowledge of serve direction and whether players are influenced by this during anticipatory periods. The results of this study can be applied to practical tennis coaching scenarios including adjusting practice of the return of serve to be relevant for each returning style, as well as highlighting the importance that situational probabilities may alter return position when returning serve on break points.

Chapter 5: Understanding the interaction of anticipatory information sources during the return of serve in tennis

5.1 Abstract

Existing research that has investigated how tennis players anticipate the return of serve has predominantly been conducted in lab-based settings. This fails to capture how expert tennis players prioritise anticipatory information sources during the return of serve, and whether congruence or incongruence of contextual or kinematic information influences their behaviour in match play. The aim of this study was to investigate the priority of contextual and kinematic information sources by skilled tennis players during the return of serve, determine how congruence or incongruence of contextual information with kinematic information altered return outcomes, and how the gaze strategy of the participants changed with availability of this information. 10 elite tennis players (5 males, 5 females, M_{age} = 18.92 ± 2.54, $M_{playing}$ = 14.10 ± 2.77, M_{AR} = 64.42 ± 57.77) participated in this study. Participants were required to return 2 sets of serves under match-like conditions. Serve direction on break points was manipulated to answer the study's aims. A series of separate two-way ANOVA's 2 x 5 found that the different point types did not result in a difference in response time and return speed of the return. Two-proportion z-test determined there was no difference in the return outcome and location based on different point types. Two-way ANOVA with repeated measures showed that gaze duration and fixation location are significantly different when knowledge of contextual information is confirmed as congruent by fixation on the ball toss (break points set A), compared to other point types. The overall results suggest that tennis players are not completely susceptible to the congruence effect in match play as previous research has indicated. These results are important for coaches and tennis players who may benefit from knowledge of an opponent's serve tendencies prior to a

match to ensure gaze fixation on the ball toss can confirm congruent contextual information.

5.2 Introduction

Roger Federer has been hailed as one of, if not the greatest tennis player of all time. Among his key attributes is his superior ability to anticipate the intentions of his opponent, giving the appearance of him being unhurried. In time critical sports, such as tennis, superior anticipation skills allow players to manipulate time and space, essentially taking it away from their opponents and creating extra time to prepare for their own shot (Bartlett, 1947). This is evident with Federer, as he contacts rally balls up to 40 cm further forward in the court than other top 10 male players (Farrow, 2018). This ability to anticipate what's next can come from picking up on cues from an opponent's movement kinematics or situational probability information as described here by Federer: "When you play a player 10 or 20 times you also know the chances of where the balls are going to go" (Gatto, 2018). This example highlights how elite players use two forms of anticipatory information when preparing a movement response. The efficacy and temporal interaction of these information sources by a player is likely to be critical to successful anticipatory performance, and is the focus of this study.

In tennis, anticipation is used by players during rallies and, more particularly, when returning serve. In rallies, average groundstroke speeds are between 113-133 km/hr (Kovalchik & Spence, 2016), while average first serve speeds can often exceed 200 km/hr. Therefore, the ability to anticipate the direction and type of first serves, where players only have 500ms to respond, is critical for the success of the return (Triolet et al., 2013). The use of anticipation on the return of serve has been well documented (for examples, see Farrow and Reid (2012); Goulet et al. (1989); Murphy et al. (2016)), however investigations into how players prioritise the anticipatory information available during a return of serve has yet to be determined.

Anticipation is informed by both kinematic (i.e. cues from a server's service action) and contextual (i.e. situational probability) information sources. Investigations into the use of kinematic sources by expert tennis players often quantify gaze behaviour to understand a player's visual search strategies. This research has revealed that when attempting to return a tennis serve, experts often fixate on fewer, and more proximal areas of interest (Goulet et al., 1989), but for a longer duration of time (Mann et al., 2007). These interest areas are the kinematics of an opponent's serve and include a focus on the hip and trunk areas, the ball toss, and the head (Goulet et al., 1989) and are useful for indicating the direction or type of a serve. For example, the lateral displacement of the ball toss often indicates the direction of the serve i.e. when the ball toss is further to the left (in right-handed players), a wide serve is likely, compared to a tee serve, where the ball toss is further to the right (Reid et al., 2011). In addition to an attunement to kinematics, research has also demonstrated that tennis players have been shown to correctly anticipate a serve or shot direction based on contextual information sources, such as a player's relative court position, situational probabilities on specific scores (such as break points), and an opponent's strength or preferences (Farrow & Abernethy, 2015). More specifically in tennis, break points have been highlighted as an important point where specific serving patterns and situational probabilities are apparent for returners to attune themselves to this information (see O'Donoghue (2012), and also results from Chapter 3). A limitation of the extant literature is that these anticipatory information sources have often been examined independently of one another despite calls to examine their inter-connectivity in informing a players anticipatory response (Cañal-Bruland & Mann, 2015).

The limited research which has attempted to investigate the two sources of anticipatory information together, rather than independently, has concluded that the combination of kinematic and contextual information produces an additive effect on a player's anticipatory capabilities and a positive impact on football goalkeeping (Navia et al., 2013), baseball (Gray & Cañal-Bruland, 2018), cricket (Runswick et al., 2018), and tennis (Murphy et al., 2016). In each of these studies, results show that when both kinematic and contextual information sources were present, response times and accuracy were significantly improved compared to when only probability information was available. Furthermore, in the absence of kinematic information, participants had faster response times and better accuracy of the response task in high probability scenarios, compared to low probability scenarios. It therefore appears that expert athletes use these sources in a dynamic manner, and that contextual information influences the perceptual-cognitive processes which contribute to the pick-up and use of kinematic sources (Murphy et al., 2019) in the lead up to critical events (i.e. racquet-ball contact in the serve).

Experts may also alter their gaze patterns during a task if both sources of information are available to them (McRobert et al., 2011). These findings have corroborated that expert athletes use both kinematic and contextual information sources to anticipate opponent behaviour, however the temporal interaction and prioritisation of sources is still unclear. There is a logical belief among researchers that contextual information is attuned to prior to the kinematic information becoming available (Gredin et al., 2018), however there is limited research to show either when a switch between priority of contextual and kinematic information occurs, or how the information sources are used interactively during an anticipation task. Runswick et al. (2018) confirmed that a skilled group of cricket batters considered contextual information was used for anticipating throughout the bowling action, and kinematic information was found to be important for anticipation only in the final moments of the bowling sequence. While this study is important for confirming the priority of contextual and kinematic information sources throughout an anticipation task, there is still no specific investigation to determine this priority during the return of serve in tennis.

Current research indicates that expert athletes prioritise the most reliable source of anticipatory information during an anticipation task (Loffing & Hagemann, 2014). This raises the interesting prospect of what information source expert athletes prioritise when the information is unreliable or conflicting. For example, if a tennis player returning serve expects a wide serve on a specific point or score (based on past behaviour), yet the kinematic cues from the server suggest a different serve is likely, the player must make the decision to prioritise one source over the other, or to wait until ball flight information becomes available (Gredin et al., 2018), which essentially undermines the need or value of anticipation. The congruence effect refers to an expert athlete's ability to absorb contextual information to improve their anticipation capabilities, however when this information is incongruent with the actual outcome, the athlete may anticipate incorrectly, leading to impaired performance (Murphy et al., 2019). Runswick, Roca, Williams, McRobert, and North (2019) found that skilled cricket batters were more susceptible to incongruent information than less-skilled batters, signifying that there is a priority of contextual information during anticipation tasks leading to negative performance outcomes. This susceptibility of expert athletes to incongruent contextual information suggests that even when provided with situational information which appears to be correct, athletes must still use all available contextual and kinematic information sources to correctly anticipate within the given time constraints of the task. While the previous laboratory-based research about congruence and incongruence of contextual information has been informative, no empirical work has been conducted in situ.

Although in situ tasks are ideal for determining the ecological response of expert athletes, to date, there has yet to be a study in tennis which has replicated the match-like conditions necessary to investigate the interaction between the two sources of anticipatory information. Navia et al. (2013) examined a football goalkeeping task where situational information was manipulated, and mobile gaze tracking technology found that the goalkeepers who were more reliant on kinematic information were less likely to use situational information to guide their response. Research in tennis has tended to rely on video-based experimental designs that cut the video off at the moment of racquet-ball contact (Murphy et al., 2016). These types of methodologies fail to replicate the nuanced information-movement coupling of the response in tennis (Farrow & Abernethy, 2003), and neglects the importance of ball flight information, for finalising their motor response (Jackson & Mogan, 2007). It is expected that using an in situ methodology which replicates the conditions of a tennis match, that this experiment will be able to explain the priority of anticipatory and ball flight information sources used by expert tennis players during the return of serve.

The aim of this experiment was to investigate how expert tennis players use and combine contextual and kinematic information sources during a return of serve, both when there is congruence of information provided to the participants about serve direction on break points, and when there is incongruence of serve direction on break points. The presentation of specific contextual information, such as serve location was controlled on specific points, i.e., hitting to the same, and then different, locations on break points. Gaze tracking technology monitored the attention of players to server's kinematics to determine whether there were changes in the player's allocation of attention to specific kinematic information when the contextual information varied. This allowed investigation of how the addition of both contextual information and kinematic information influenced return quality compared to the influence of only available kinematic information. Consequently, the following hypotheses were formulated:

1. Where contextual and kinematic information was congruent (break points in Set A) compared to points where there was incongruence between the contextual and kinematic information provided (break points in Set B):
    a) Response time would be significantly shorter
    b) Response quality (response time, return outcome, return speed, and return location) would be significantly greater
    c) Gaze fixations would be of a longer duration and directed to less kinematic areas of interest
2. Where congruent contextual and kinematic information was present (break points in set A) compared to points where only reliable kinematic information was present (all other points):
    a) Response time would be significantly shorter
    b) Response quality (response time, return outcome, return speed, and return location) would be significantly greater
    c) Gaze fixations would be of longer duration, and directed to less kinematic areas of interest

5.3 Method

5.3.1 Participants

Ten highly skilled tennis players (5 males and 5 females; M_{age} 18.92 ± 2.54) with over 10 years of playing experience ($M_{playing}$ = 14.10 ± 2.77) and an open Australian tennis ranking within the top 200 (M_{AR} = 64.42 ± 57.77) participated in this study. Participants were free from any injury and used their own tennis equipment (i.e. racquet). Prior to the experiment commencing, each participant had reviewed an information sheet concerning the purpose of the research and signed a consent form. Institutional ethical approval was granted prior to the study commencing.

5.3.2 Materials, Apparatus and Set Up

The experiment was conducted on an outdoor clay tennis court of standard dimensions using new Dunlop Forte tennis balls (international standard) in each experimental match. The court was equipped with the Playsight (Tel Aviv, Israel) ball tracking and video system which uses four analytical cameras (recording at 100 frames per second), at each corner of the court, 5 metres above the ground to locate the ball landing location, capture ball speed for both the serve and return, determine the type of shot played (forehand or backhand based on participants handedness and position in the court), and determine the landing location of the return shot. The Playsight system also used two high-definition video cameras (recording at 25 frames per second), 3 metres above the ground in the centre of the back of each end of the court (Figure 5.1).

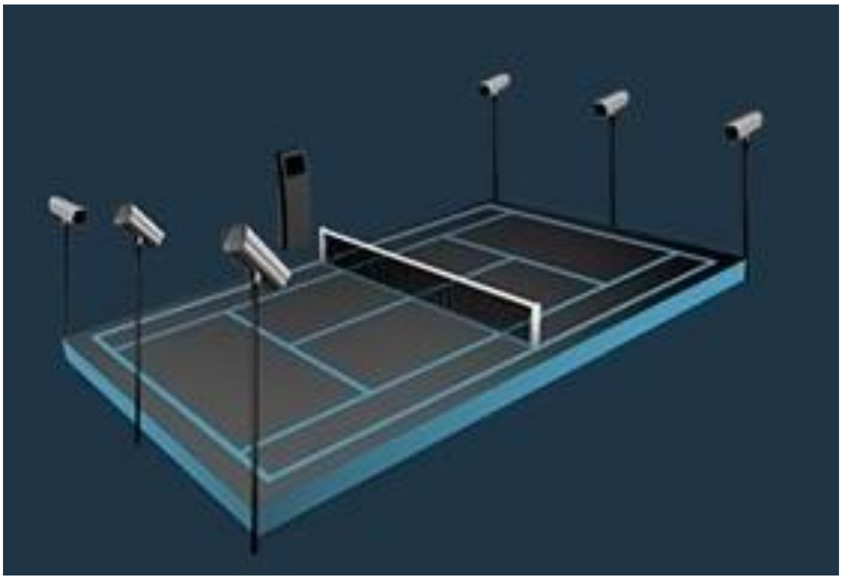


Figure 5.1: Tennis court equipped with Playsight system with 2 HD cameras and 4 analytical cameras

Participants were also required to wear mobile eye-tracking glasses (SMI Vision, Teltow, Germany) which recorded pupil movements and gaze fixations at 60Hz. The mobile eye-tracking glasses were worn like normal glasses, with a drawstring attached to reduce movement during the trials. The glasses were attached to a battery and recording device which was kept in a waist pack worn by the participant. The cord connecting the glasses to the battery and recording pack was tucked underneath the shirt of the participant to reduce any possible interference during the experimental task. A 3-point calibration was undertaken in accordance with the manufacturer’s instructions prior to the task commencing. Participants were then given a 10-minute familiarisation period during their tennis warm-up. A second calibration was conducted prior to the first serve trial to ensure the familiarisation period had not affected the calibration in any way. Participants did not remove the glasses until the end of the experiment. Only one participant out of 10 reported feeling any interference from the glasses after the trials had commenced.

Figure 5.2: One of the participants during the task equipped with the eye-tracking glasses

5.3.3 Procedure

The experiment required participants to return 80 serve trials. A recently retired, male, professional tennis player acted as the server for all trials (aged 28, peak professional ranking of 241). The server needed to hit a valid first serve for each trial to be counted. If an ineligible serve occurred (i.e. outside the confines of the service box, served into the net, or a let serve where the ball touched the net before landing in the service box), the serve was repeated until a valid serve was registered. The average serve speed of all trials was 159 km/hr and the total percentage of serves in on the first attempt across all trials was 63.3% (52% of trials on break points in set A and 64% of trials on break points in set B were served in on the first attempt and return outcomes did not significantly differ to break point trials that took multiple attempts).

The experiment was broken down into two sets of five games, with eight serve trials per game for a total of 80 serve trials, with a score provided after each serve-return (see Table 5.1). Participants were given a five-minute break in between the two sets, in addition to 90 seconds rest between each game to reduce both server and participant fatigue. Prior to each serve, the researcher would call out the score (as if it were during a match), and the participant had up to 30 seconds to move to the corresponding side of the court which related to that score and prepare to return the serve (i.e. scoring scenarios were randomly generated, but was designed to ensure there were break points in each game – see Table 5.1). Throughout the trials, two break point scores occurred per game. Prior to the experiment, participants were told that there was an 80% probability that a tee serve would occur on these break point scenarios. In set A, the tee serve was hit in 8 out of 10 break points presented, mirroring the contextual information provided to the participants prior to the experiment (replicating pre-match coach instruction). However, in set B, a wide serve was served in 8 out of 10 break points, without the knowledge of the participants that the serve direction had changed. The contextual information on break points in set B that was given to the participants was incongruent with what the server actually did. It should be noted that all break points in set A were considered as congruent, and all break points in set B were considered incongruent, as the information given to the participants (80% of tee serves on break points) mirrored the actual serves that occurred (i.e. 8 out of 10 break point serves). This is in contrast to other studies investigating congruence in which all individual trials were considered as congruent (e.g. Mann et al. (2014); Murphy et al. (2019); Runswick et al. (2019)). This manipulation allowed determination of how strong the priming effect of contextual information was on subsequent response accuracy, that is, were participants conditioned to become reliant on contextual information or did the kinematic information and subsequent ball flight information override the priming effects.

All other serves on non-break point trials were of the server's choice and did not follow a pattern, and therefore, only the kinematic information available was reliable. The two sets were counterbalanced, with half of the participants commencing the experiment with set A, and the other half with set B. The participants did not know which set they were starting with. The only other information the participants were provided was that they were to return each serve as they would during a normal match situation. The outcome of each return was captured using the Playsight system including whether the return was a forehand or backhand, the return speed, the direction of the return (cross court, middle, or down the line), whether the return went in or out, and the ball landing location. This information was verified post-hoc via the video data captured.

Set A			Set B		
Score	**Court side**	**Serve direction**	**Score**	**Court side**	**Serve direction**
			Game 1		
30-30	Deuce	Server's choice	**30-30**	Deuce	Server's choice
30-15	Ad	Server's choice	**30-40 (break point)**	Ad	Wide
0-30	Deuce	Server's choice	**0-30**	Deuce	Server's choice
15-15	Deuce	Server's choice	**15-15**	Deuce	Server's choice
30-40 (break point)	Ad	Tee	**30-15**	Ad	Server's choice
Deuce	Deuce	Server's choice	**Deuce**	Deuce	Server's choice
0-40 (break point)	Ad	Tee	**0-40 (break point)**	Ad	Wide
0-0	Deuce	Server's choice	**0-0**	Deuce	Server's choice
			Game 2		
30-30	Deuce	Server's choice	**30-30**	Deuce	Server's choice
15-30	Ad	Server's choice	**15-30**	Ad	Server's choice
40-Ad (break point)	Ad	Tee	**0-15**	Ad	Server's choice
40-15	Deuce	Server's choice	**40-15**	Deuce	Server's choice
40-0	Ad	Server's choice	**15-0**	Ad	Server's choice
Ad-40	Ad	Server's choice	**40-Ad (break point)**	Ad	Wide
Deuce	Deuce	Server's choice	**Deuce**	Deuce	Server's choice
30-40 (break point)	Ad	Wide	**30-40 (break point)**	Ad	Wide
			Game 3		
30-30	Deuce	Server's choice	**30-30**	Deuce	Server's choice
0-40 (break point)	Ad	Tee	**0-40 (break point)**	Ad	Wide
Deuce	Deuce	Server's choice	**Deuce**	Deuce	Server's choice
0-30	Deuce	Server's choice	**0-30**	Deuce	Server's choice
15-30	Ad	Server's choice	**40-Ad (break point)**	Ad	Tee
40-Ad (break point)	Ad	Tee	**15-30**	Ad	Server's choice
0-0	Deuce	Server's choice	**0-0**	Deuce	Server's choice
0-15	Ad	Server's choice	**0-15**	Ad	Server's choice
			Game 4		
15-15	Deuce	Server's choice	**15-15**	Deuce	Server's choice
15-30	Ad	Server's choice	**0-40 (break point)**	Ad	Wide
Ad-40	Ad	Server's choice	**Ad-40**	Ad	Server's choice
0-40 (break point)	Ad	Tee	**30-0**	Deuce	Server's choice
30-0	Deuce	Server's choice	**15-30**	Ad	Server's choice
40-30	Ad	Server's choice	**40-30**	Ad	Server's choice
Deuce	Deuce	Server's choice	**Deuce**	Deuce	Server's choice
30-40 (break point)	Ad	Wide	**30-40 (break point)**	Ad	Wide
			Game 5		
15-15	Deuce	Server's choice	**30-0**	Deuce	Server's choice
40-0	Ad	Server's choice	**15-15**	Deuce	Server's choice
40-15	Deuce	Server's choice	**40-Ad (break point)**	Ad	Tee
30-30	Deuce	Server's choice	**40-0**	Ad	Server's choice
40-Ad (break point)	Ad	Tee	**40-15**	Deuce	Server's choice
0-40 (break point)	Ad	Tee	**0-40 (break point)**	Ad	Wide
30-0	Deuce	Server's choice	**30-30**	Deuce	Server's choice
Deuce	Deuce	Server's choice	**Deuce**	Deuce	Server's choice

Table 5.1: Serving pattern for Set A and Set B

5.3.4 Dependent Measures

Return quality consisted of four separate measures– response time, return speed, return outcome, and return location. Response time was measured based on the initial moment that the returner's foot left the ground (irrespective of the direction of that movement i.e. forward, side or back) relative to the server's racquet-ball contact (negative values indicate movement initiated prior to the server's racquet-ball contact). In most cases, the response time represents the initial movement from a participant's ready position, into a split-step. Return speed was defined as the speed of the ball as it crossed over the net. Return outcome was defined as the ball landing in the singles court (in), or an error, where the ball was hit into the net, or landed outside the dimensions of the singles court. Return locations were defined as the ball landing location of the return where the locations were classified as good, neutral, or poor returns (classifications are based on information gathered from three individual high-performance tennis coaches). These locations are shown in Figure 5.3 below.

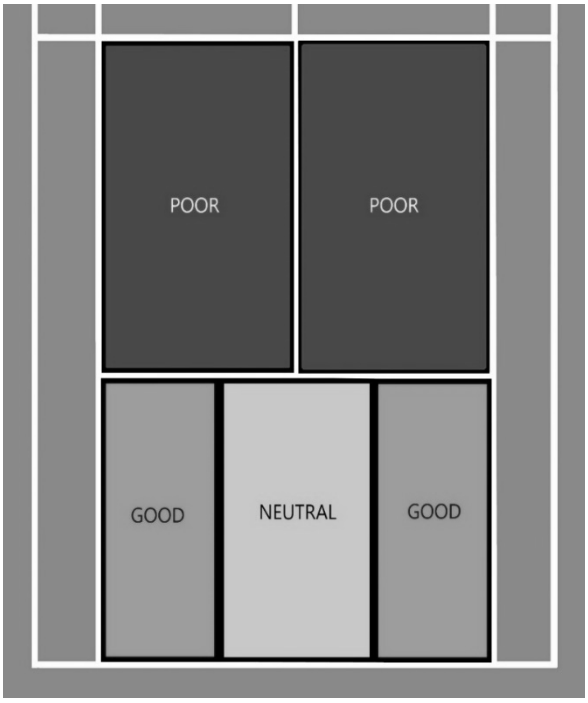


Figure 5.3: Classification of three return locations based on information from high-performance tennis coaches

The gaze data was coded to include the number of fixations per point type, the duration of each fixation, and fixation location per service phase. The five service phases were adapted from Kovacs and Ellenbecker (2011), and can be seen in Figure 5.4. The data gathered from the mobile eye-tracking glasses included only fixations over 100ms of a steady gaze, on a single point of fixation (Vickers, 2007). These fixations were coded per fixation location on each trial. Given the increased distance between the returner and the server compared to a gaze tracking task on a computer, the fixation locations were categorised as larger parts of the server. These categories grouped smaller areas of interest that were previously reported as areas of fixation when viewing the serve (i.e. upper body was categorised to include arms, shoulders, and head) (Goulet et al., 1989). This ensured that fixation data captured as much accurate information as possible from the increased distance, and reducing the potential error for miscategorising the fixation locations. Fixation length was reported as a percentage of total point time, which was measured from the time the server placed the front foot behind the baseline, through to the racquet-ball contact of the returner (thereby taking into account ball flight information).

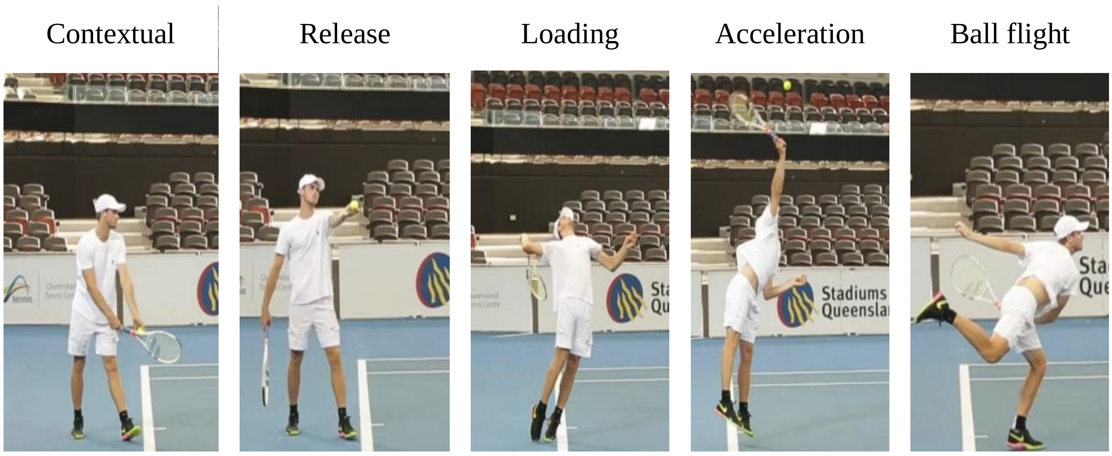


Figure 5.4: Five serving phases adapted from Kovacs and Ellenbecker (2011)

Post-experiment qualitative surveys were also administered to participants and analysed to understand the awareness the returners had of the available information sources (contextual and kinematic) and whether this had a conscious influence on their decision-making and returning behaviour.

5.3.5 Data Analysis

The first comparison of interest addressed the first hypothesis and compared the break point performance of the participants in set A (congruent) with set B (incongruent). The second comparison addressed the second hypothesis and compared the performance of the participants on points with only reliable kinematic information (all other points) to points with congruent contextual and kinematic information (break points set A). A series of separate two-way ANOVA's 2 x 5 (point type x game) was used to examine the differences in response time and return speed, while two-proportion z-test was used to examine differences in the proportion of the return outcomes and locations. Two-way ANOVA with repeated measures was used to assess the gaze duration and fixation location per service phase, and to assess the influence the number of games had on return quality measures and fixation data. The alpha level was set at .05. Effect sizes were set at 0.01 (small), 0.06 (medium), and 0.14 (large). All analyses were conducted in R studio (R Core Team, 2017) using the ggplot2 (Wickham, 2016) and dplyr packages (Wickham, Francois, Henry, & Muller, 2016).

5.4 Results

5.4.1 Congruent points (break points set A) compared to incongruent points (break points set B)

5.4.1.1 Response time

The response times of break points in set A (M_{rt} = -480.8ms, *SD* = 225.77) and set B (M_{rt} = -483.6ms, *SD* = 279.17) were examined using two-way ANOVA. The results revealed no significant differences for the main effects of congruence (F = 0.03, η^2_p <0.01, p = 0.86) or game (F = 0.52, η^2_p = 0.01, p = 0.72). Furthermore, there was no significant congruence x game interaction (Figure 5.5) (F = 0.45, η^2_p = 0.01, p = 0.77).

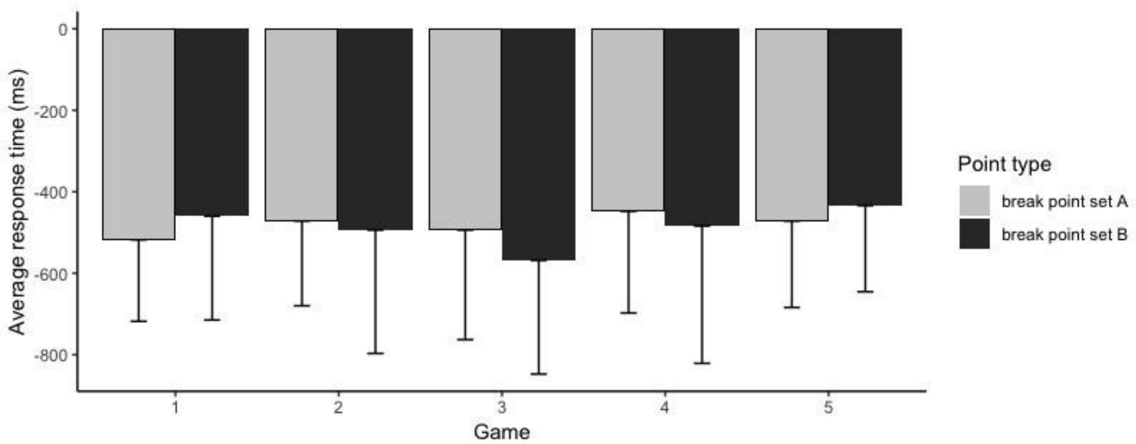


Figure 5.5: Response time (ms) break points set A and break points set B per game. *N.B. Error bars represent mean error.*

5.4.1.2 Return speed

The two-way ANOVA examining return speeds and congruence revealed no significant difference for the main effects of congruence (F = 2.42, η^2_p = 0.03, p = 0.12) or game (F = 2.09, η^2_p = 0.03, p = 0.15). Furthermore, the congruence x game interaction was also not significant (Figure 5.6) (F = 0.01, η^2_p <0.01, p = 0.93).

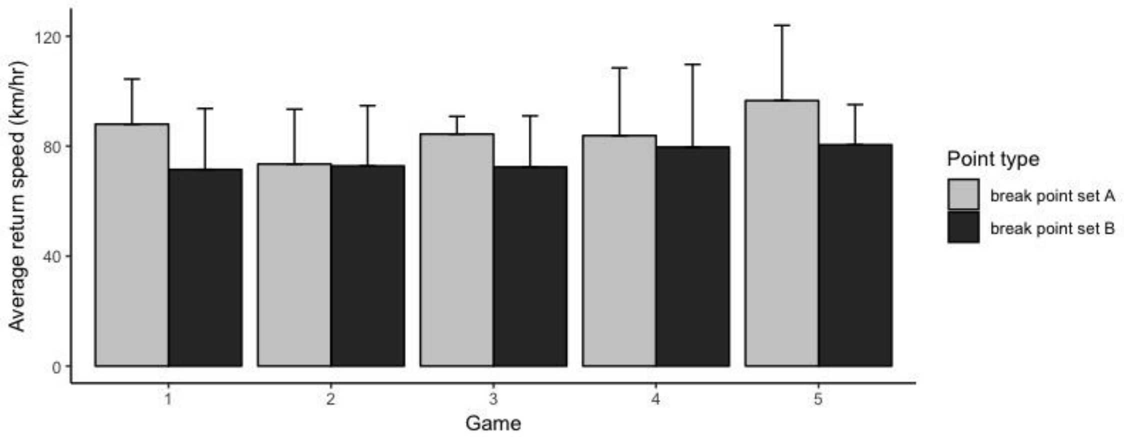


Figure 5.6: Average return speed (km/hr) break points set A and break points set B per game. *N.B Error bars represent mean error.*

5.4.1.3 Return outcome

The proportion of returns in for break points in each set were also examined (Set A = 55%; Set B = 65%). Two-proportion z-test results for return outcomes showed no significant differences between break points in set A and break points in set B, and the proportion of in returns (z = 1.44, p = 0.15).

5.4.1.4 Return locations

Point type	Good returns (% total in serves)	Neutral returns (% total in serves)	Poor returns (% total in serves)
Break point – set A	65.45%	25.45%	9.09%
Break point – set B	53.85%	33.85%	12.31%

Table 5.2: Proportion of returns by location on break points set A and break points set B

The proportion of returns to the three categorised locations for sets A and B can be found in Table 5.2 and visually presented in Figure 5.7. Two-proportion z-test results show the difference of return locations by congruence. A larger proportion of returns in set A compared to set B occured to a good location (z = 1.29, p = 0.20), however, this was not a significant difference. A larger proportion returns in set B compared to set A occurred to neutral (z = 1.00, p = 0.32) and poor (z = 0.56, p = 0.57) locations, although these were again, not significantly different.

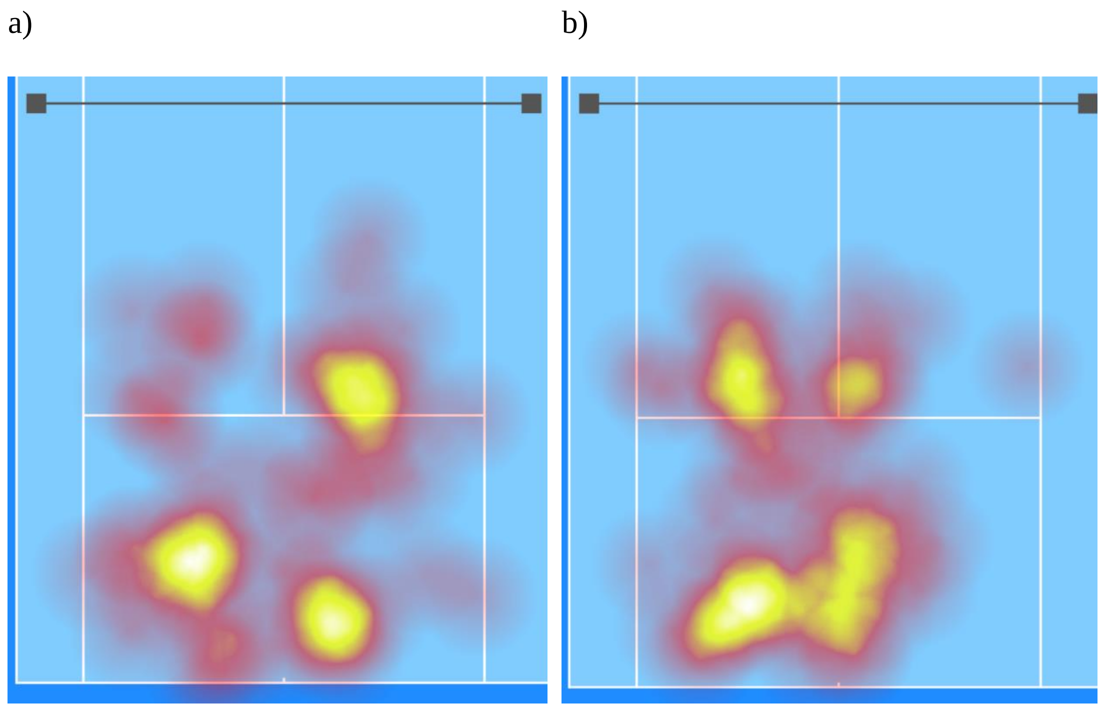


Figure 5.7: Heatmap of return locations in a) break points in Set A and b) break points in Set B

5.4.1.5 Gaze fixations

5.4.1.5.1 Number of fixations

The two-way ANOVA revealed there was a significant main effect for congruence with set B having a significantly high number of fixations compared to set A (F = 3.85, η^2_p = 0.06, p = 0.05). The average number of fixations per point type is presented in the box plot in Figure 5.8. There was also a significant main effect of service phase (F = 2.56, η^2_p = 0.14, p = 0.05), however, the number of fixations with congruence x service phase interaction was not significant (F = 0.32, η^2_p = 0.02, p = 0.86).

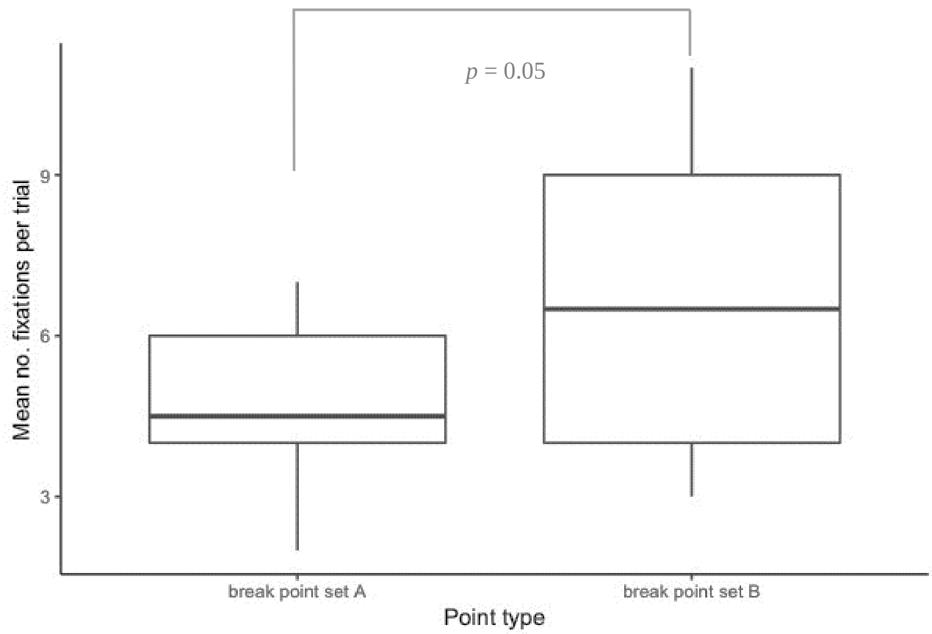


Figure 5.8: Number of fixations break points set A and break points set B

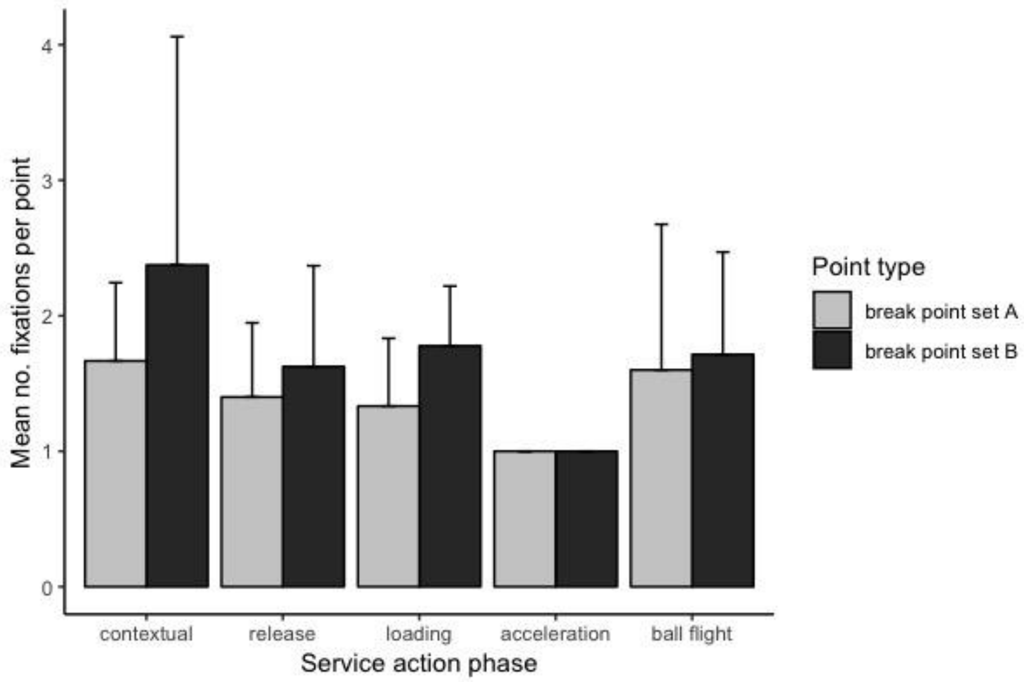


Figure 5.9: Mean number of fixations per service phase break points set A and break points set B. *N.B. Error bars represent mean error.*

5.4.1.5.2 Fixation Length

The two-way ANOVA for fixation length revealed a significant main effect for congruence, with fixation length in set A significantly longer compared to fixation length in set B (F = 4.95, η^2_p = 0.05, p = 0.03) (Figure 5.10), however, there was no significant effect with games (F = 1.06, η^2_p = 0.05, p = 0.38) or a significant interaction (F = 0.99, η^2_p = 0.04, p = 0.42).

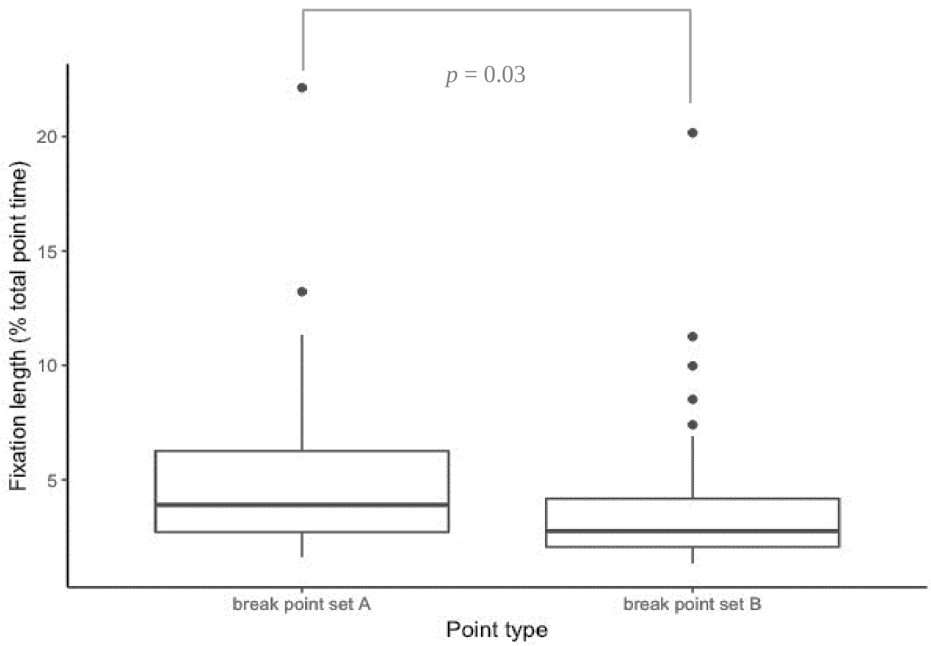


Figure 5.10: Mean fixation length (% of total point time) break points set A and break points set B

5.4.1.5.3 Fixation locations during the service phases

Five fixation locations were determined in the analysis of the fixations - upper body (from head to hip, including arms and shoulders), lower body (from hip to feet), ball toss (any fixation on the ball from the time leaving the server's ball toss hand to server's racquet-ball contact), serve contact point (predicted server's racquet-ball contact and actual racquet-ball contact), and ball flight (tracking the ball from the server's racquet-ball contact). Fixation locations which were outside of these categories were categorised as other locations, and were excluded from the results as they did not involve participants viewing any kinematic information of the server. This included areas away from the server's body, such as looking down at the participant's own feet or racquet. Additionally, areas which were unable to be distinguished due to the length of the eye movement being below the fixation threshold (100ms) were also excluded. Separate two-way ANOVAs were conducted for each service phase to determine the difference in fixation length point type and their interaction. Figure 5.11 visually highlights the different lengths of fixations per location for each serve phase and point type of each experimental condition (set) from the perspective of the returner.

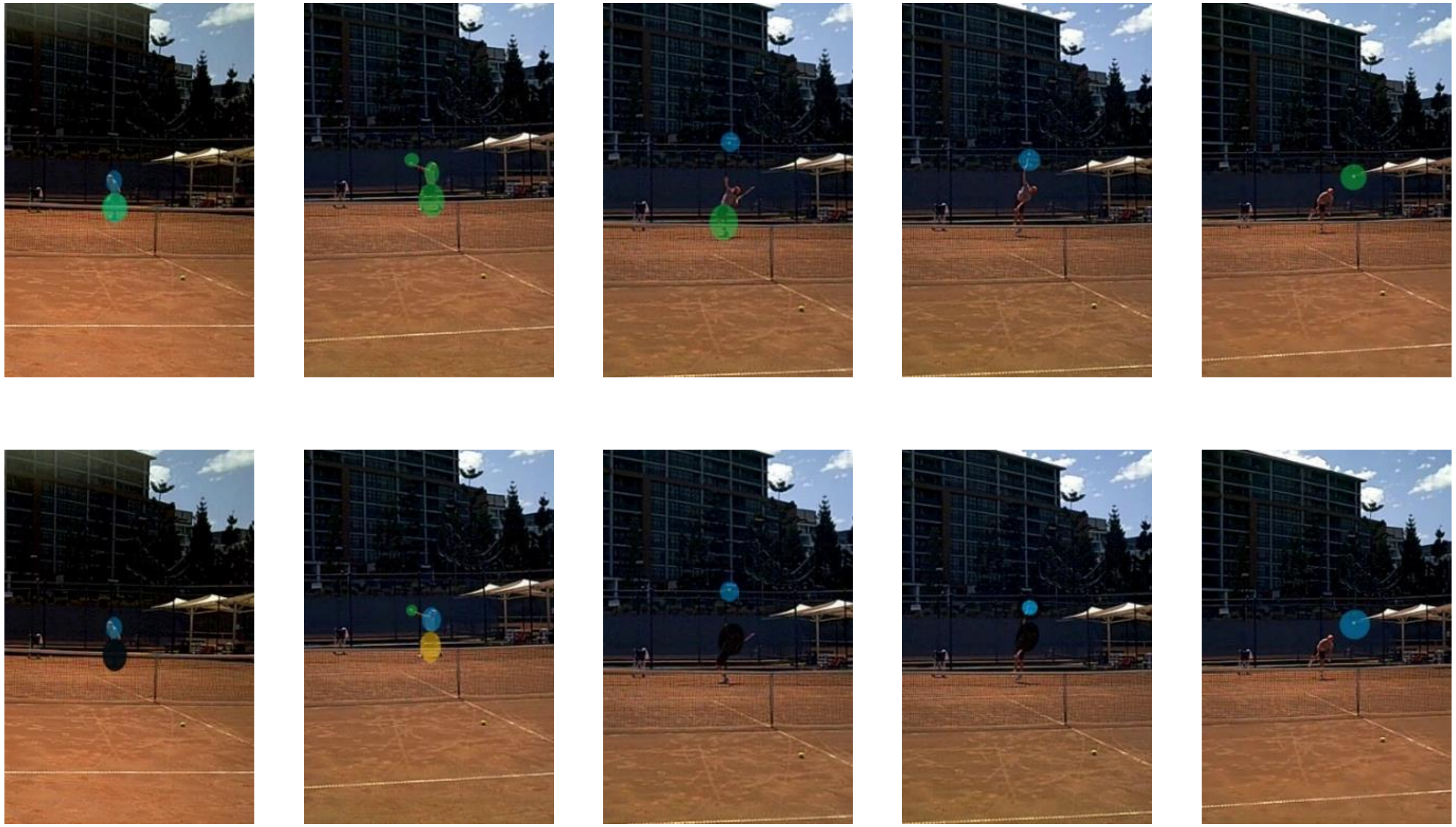


Figure 5.11: Fixation locations per serve phase break points set A and break points set B

5.4.1.5.4 Contextual phase

In the contextual phase, no significant main effects indicated similar fixation lengths on break points in set A and set B (F <0.01, η^2_p <0.01, p = 0.95). Although there was a large effect size for the main effect of games (F = 0.78, η^2_p = 0.22, p = 0.56), as well as the congruence x game interaction (F = 0.44, η^2_p = 0.08, p = 0.65). In both point types, the upper body was a consistent fixation location in this phase (F = 0.70, η^2_p = 0.08, p = 0.43), and games (F = 0.44, η^2_p = 0.18, p = 0.78), however there was not enough fixation data across both point types and games to determine an interaction.

5.4.1.5.5 Release phase

In the release phase, fixation length on both point types was consistent (F = 0.01, η^2_p <0.01, p = 0.93) and games (F = 0.23, η^2_p = 0.10, p = 0.92). However, a large effect size suggests there may be a difference in fixation length of the congruence x game interaction (F = 0.91, η^2_p = 0.19, p = 0.44), as can been seen in figures 5.11 and 5.12. Furthermore, there were no significant differences between congruence and fixation length on upper body (F = 2.10, η^2_p = 0.34, p = 0.22), and games (F = 1.82, η^2_p = 0.58, p = 0.28), or the congruence x game interaction (F = 0.48, η^2_p = 0.11, p = 0.53), however, the large effect sizes of these results suggest this may be the dominant fixation area across the majority of games.

5.4.1.5.6 Loading phase

In the loading phase, there was significant differences and a large effect size between point type and fixation length (F = 7.40, η^2_p = 0.32, p = 0.02), but only a large effect size for games (F = 0.57, η^2_p = 0.12, p = 0.69). There was also a significant interaction of congruence and games (F = 6.73, η^2_p = 0.63, p <0.01). As confirmed in Figure 5.12, this difference is predominantly driven by the large fixation on the lower body in these games. Otherwise, for the main effect (with large effect sizes) of congruence across all games, key fixation is on the ball toss, (F = 1.12, η^2_p = 0.08, p = 0.31), as well as games (F = 0.71, η^2_p = 0.18, p = 0.60), in addition to the congruence x game interaction (F = 1.72, η^2_p = 0.28, p = 0.21). Planned T-test comparisons with Bonferroni correction reveal that in set A, there are significantly longer fixations on all locations compared to set B in game 1 (t = 12.28, p <0.01), and game 2 (t = 3.27, p = 0.05).

5.4.1.5.7 Acceleration phase

The large effect sizes suggest that in set A, there are longer fixations than in set B (F = 1.47, η^2_p = 0.27, p = 0.29), and across games (F = 3.82, η^2_p = 0.79, p = 0.11), but no significant interaction (F = 0.15, η^2_p = 0.04, p = 0.72). Figure 5.11 shows the serve contact point is the predominant fixation area for both sets, however, there is no statistical significance between fixation length on serve contact point on break points in set A compared to break points in set B (F = 0.46, η^2_p = 0.13, p = 0.54).

5.4.1.5.8 Ball flight phase

Finally, fixation length on the ball flight in set A was significantly longer than in set B (F = 4.60, η^2_p = 0.21, p = 0.05), as well as a large effect size across games (F = 0.79, η^2_p = 0.16, p = 0.55). The interaction effect suggests that the break points in set A have longer fixations on the ball flight across the games, compared to set B, due to the large effect size (F = 0.82, η^2_p = 0.13, p = 0.50).

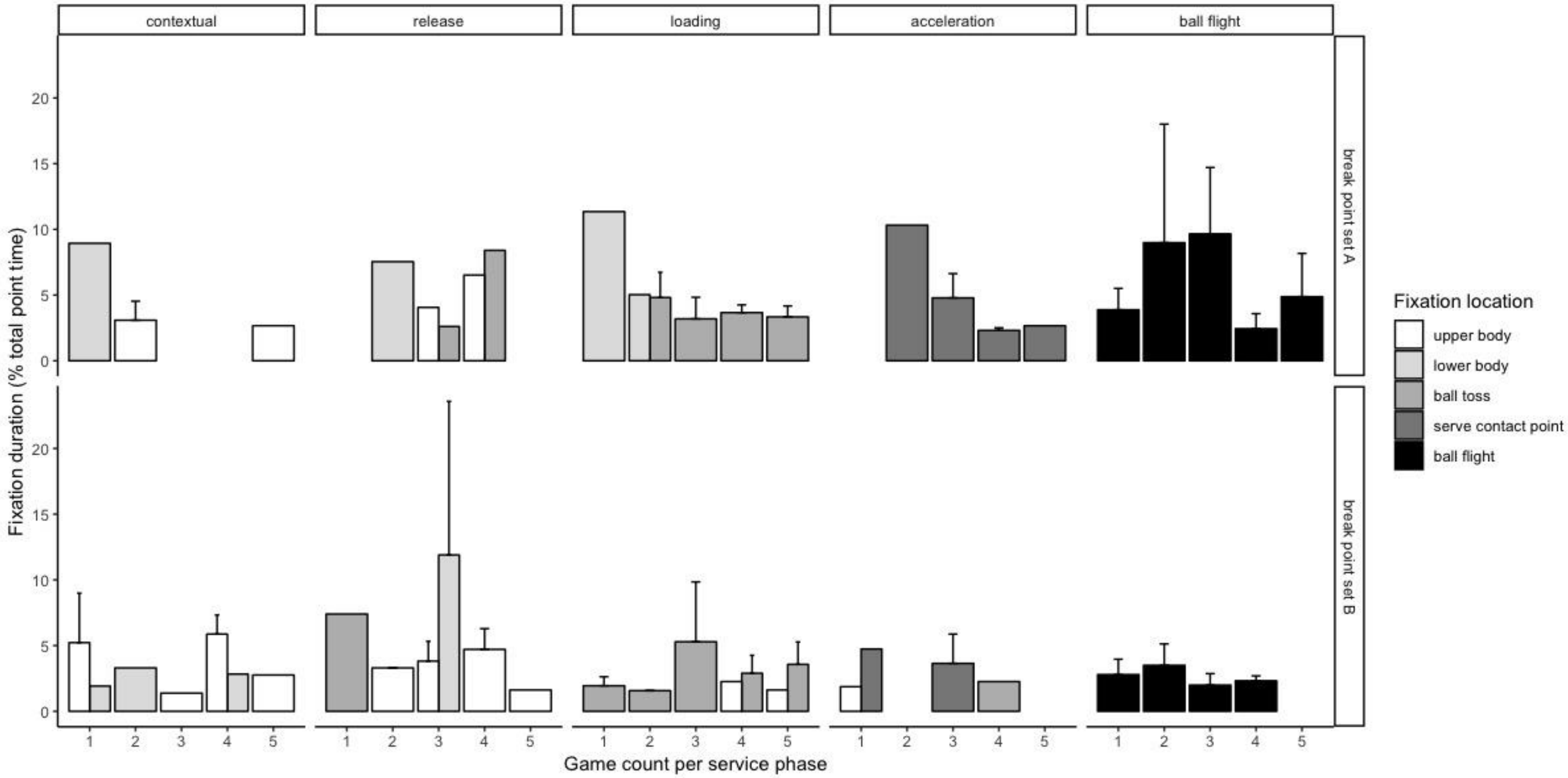


Figure 5.12: Fixation length over the trial games for each serve phase break points set A and break points set B. *N.B. Error bars represent mean error.*

5.4.2 Congruent points (break points set A) compared to other points

5.4.2.1 Response time

The response times of other points (M_{rt} = -480.94ms, *SD* = 228.45) and break points in set A (M_{rt} = -480.80ms, *SD* = 225.77) were examined using two-way ANOVA. The results revealed no significant differences for the main effects of point type (F <0.01, η^2_p <0.01, p = 0.99) or game (F = 0.43, η^2_p <0.01, p = 0.79). Furthermore, there were no significant differences of point type x game interaction (F = 0.43, η^2_p <0.01, p = 0.79).

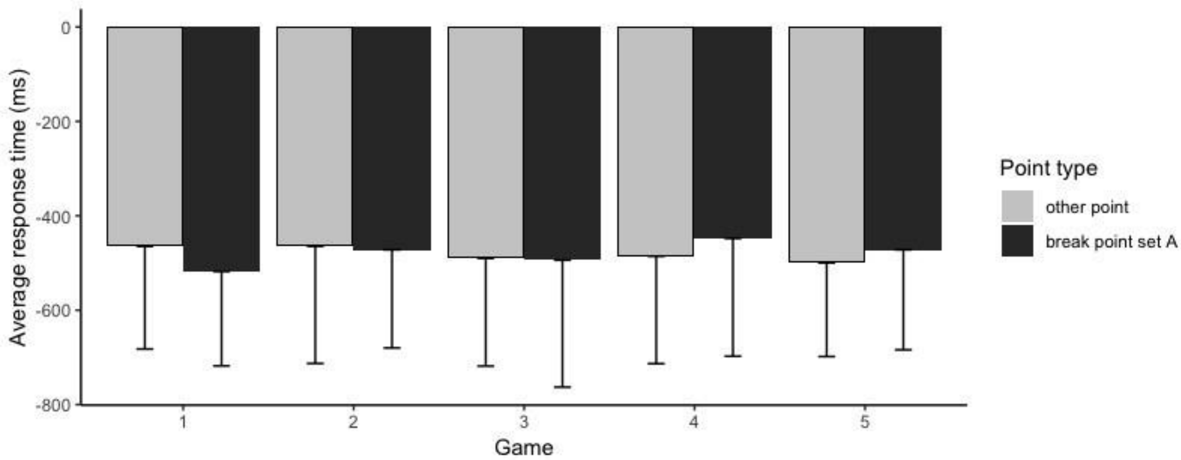


Figure 5.13: Response time (ms) other points and break points set A per game. *N.B. Error bars represent mean error.*

5.4.2.2 Return speed

A two-way ANOVA was conducted to compare return speed and point type with an interaction of games. This revealed that on other points, return speed was not significantly higher compared to break points set A (F = 0.22, η^2_p <0.01, p = 0.64), however only a small effect size was determined between games (F = 1.27, η^2_p = 0.02, p

= 0.28). No significant differences were found in the point type x game interaction (F = 0.78, η^2_p = 0.01, p = 0.54).

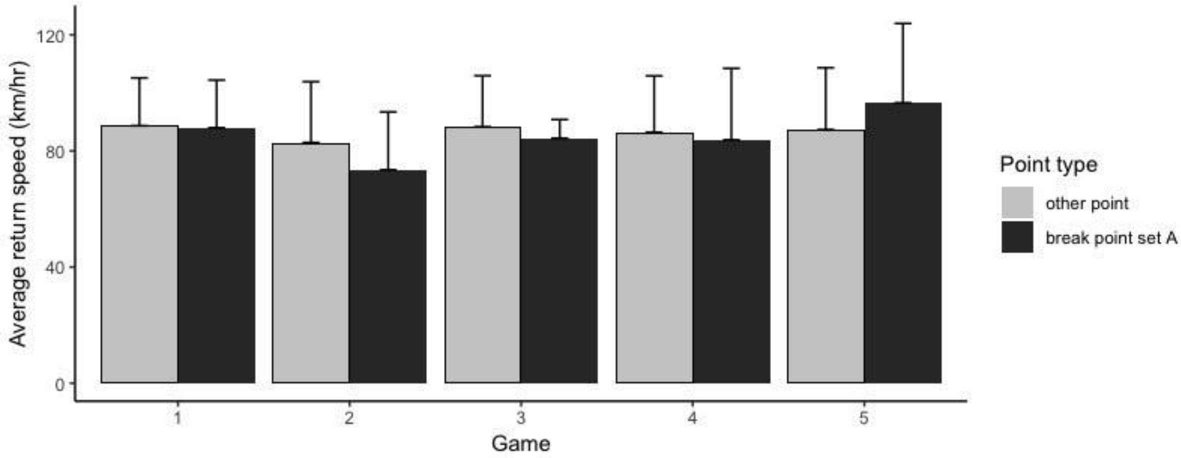


Figure 5.14: Average return speed (km/hr) other points and break points set A per game. *N.B. Error bars represent mean error.*

5.4.2.3 Return outcome

The proportion of in returns on other points (63%) and break points in set A (55%) were compared using z-test. No significant differences were found between other points and break points in set A, and the proportion of in returns (z = 1.52, p = 0.13).

5.4.2.4 Return locations

Two-proportion z-test results show the difference in the proportion of return locations by point type. On break points in set A, a larger proportion of returns to a good location occur compared to other points (z = 1.41, p = 0.16), however this was not significant. There were a similar proportion of returns to neutral locations on both point types (z = 0.06, p = 0.95). On other points, a larger proportion of returns to a poor location (z =

1.78, $p = 0.08$) occur compared to break points in set A, although again, this was not significantly different.

Point type	Good returns (% total in serves)	Neutral returns (% total in serves)	Poor returns (% total in serves)
Other points	55.25%	25.83%	18.92%
Break point – set A	65.45%	25.45%	9.09%

Table 5.3: Proportion of returns by location on other points and break points set A

a) b)

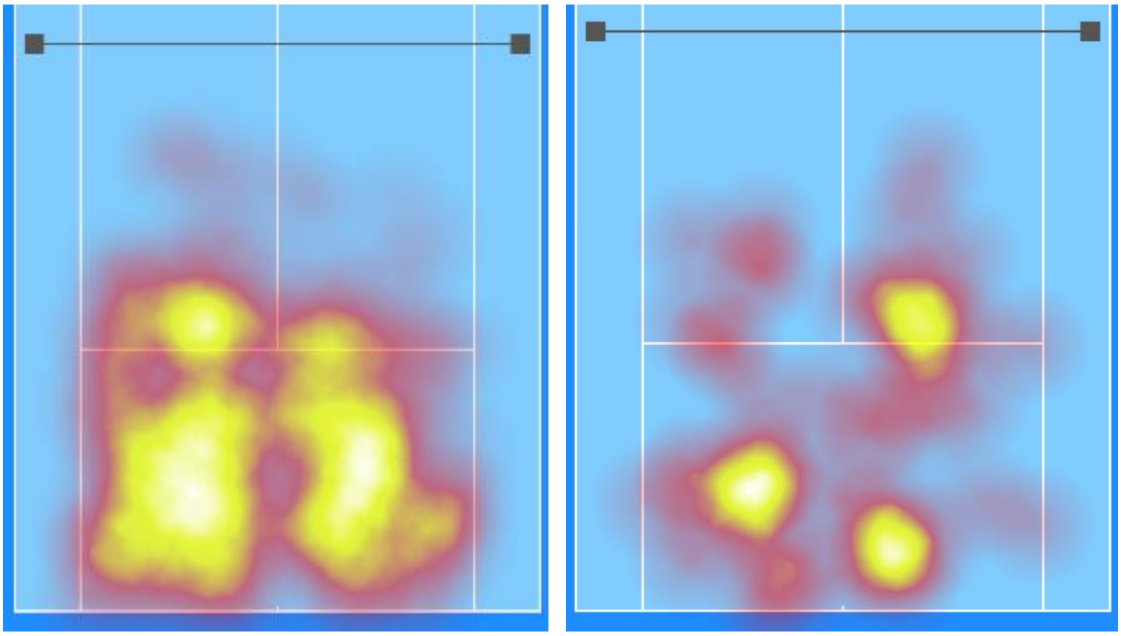


Figure 5.15: Heatmap of return locations in a) other points b) break points in Set A

5.4.2.5 Gaze fixations

5.4.2.5.1 Number and length of fixations

A two-way ANOVA with point type and service phase as the main effects was conducted and showed that on other points, there was a significantly larger number of fixations compared to break points in set A ($F = 7.66$, $\eta^2_p = 0.03$, $p < 0.01$). The number of fixations per point type is presented in the box plot in Figure 5.16. The main effect of service phase revealed significant differences in the number of fixations between the service phases (F = 5.23, η^2_p = 0.09, p <0.01). However, there was not significance between the point type and service phase interaction (F = 0.28, η^2_p = 0.01, p = 0.89) (Figure 5.17).

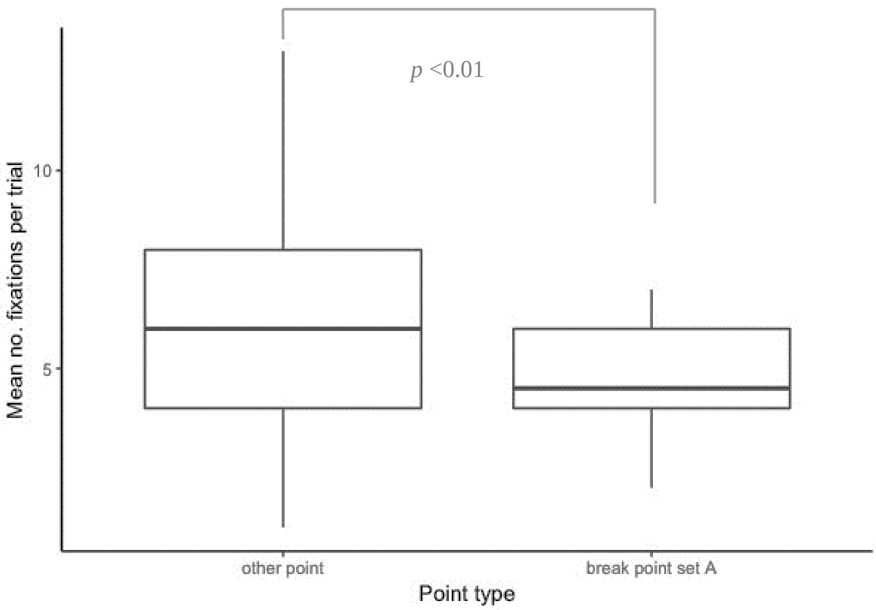


Figure 5.16: Number of fixations other points and break points set A

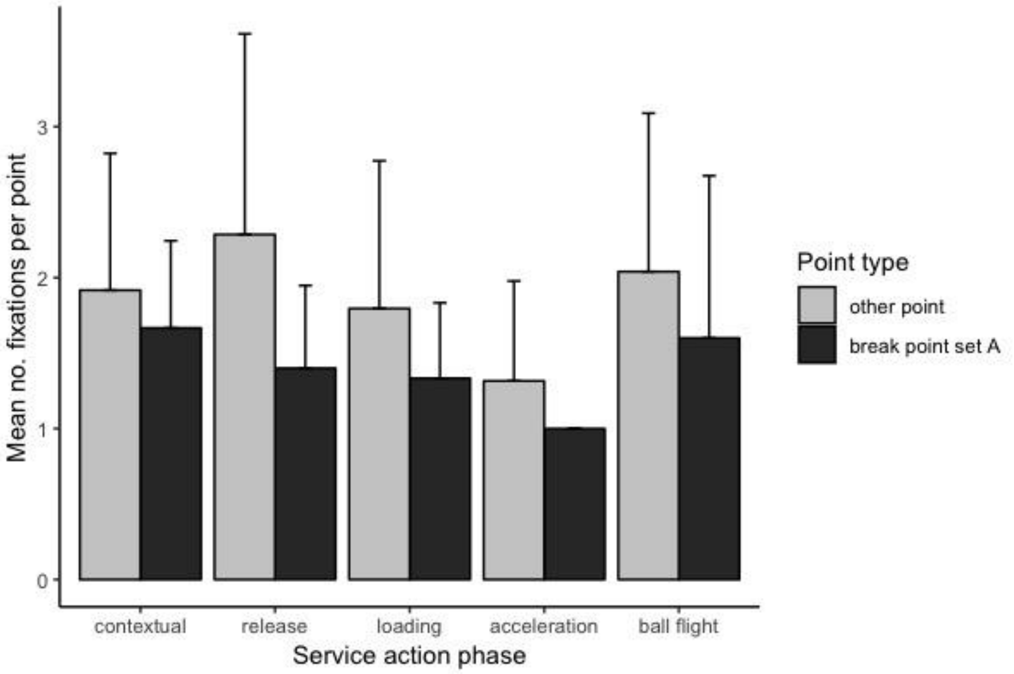


Figure 5.17: Mean number of fixations per service phase other points and break points set A. *N.B. Error bars represent mean error.*

5.4.2.5.2 Fixation Length

The mean fixation length for point type can be found in Figure 5.18. A two-way ANOVA showed a large variation in the fixation length on other points, however, the main effect between mean fixation length on other points compared to break points in set A showed no significant change ($F = 1.34$, $\eta^2_p < 0.01$, $p = 0.25$), and this was also not significant when accounting for games ($F = 0.82$, $\eta^2_p = 0.01$, $p = 0.51$), or point type x game interaction ($F = 0.99$, $\eta^2_p = 0.01$, $p = 0.41$).

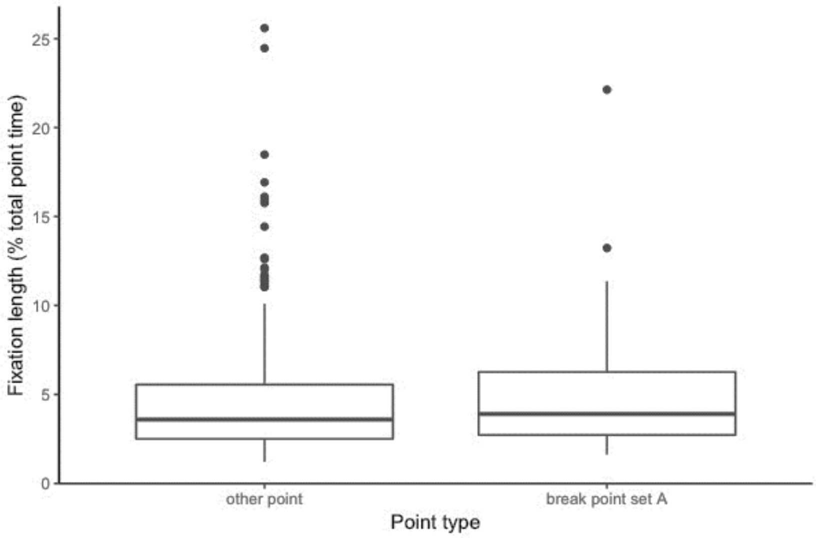


Figure 5.18: Mean fixation length (% of total point time) other points and break points set A

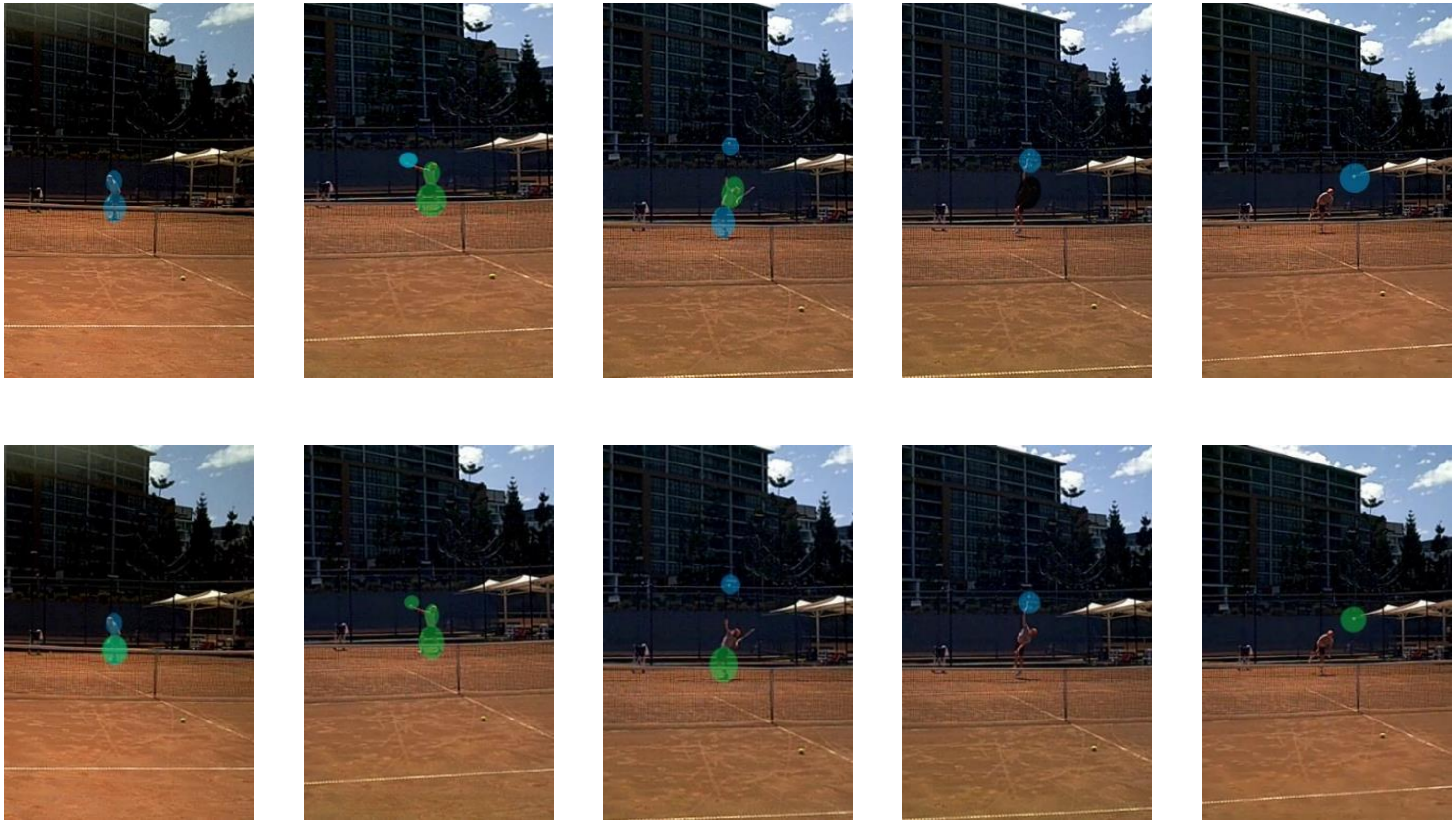
5.4.2.5.3 Fixation locations during the service phases

Figure 5.19 shows the fixation locations and lengths per service phase for each point type from the perspective of the returner. Separate two-way ANOVAs were conducted for each service phase to determine the difference in fixation length and point type, and the interaction effect of the location of the fixation. In each service phase, individual two-way ANOVAs were also conducted for fixation location between point type and games as an interaction effect. Figure 5.20 shows the different fixation locations per serve phase for each of the point types across the five games of each experimental condition.

Contextual Release Loading Acceleration Ball flight

Other points

Break point Set A



fixation length
2.1-5% fixation length
5.1-10% fixation length
11-15% fixation length

Figure 5.19: Fixation locations per serve phase other points and break points set A

5.4.2.5.4 Contextual phase

In the contextual phase, there were no significant effects which indicated that on other points, there were longer fixations compared to break points in set A (F = 0.03, η^2_p <0.01, p = 0.86), across games (F = 0.26, η^2_p = 0.02, p = 0.90), or with the point type x game interaction (F = 1.72, η^2_p = 0.07, p = 0.19). There were also no significant differences between point types and fixation lengths on the upper body (F = 0.40, η^2_p = 0.01, p = 0.53), games (F = 0.97, η^2_p = 0.11, p = 0.44), or the point type x game interaction (F = 0.26, η^2_p = 0.01, p = 0.62). There was no significance between point types and fixations on the lower body (F = 2.62, η^2_p = 0.16, p = 0.13), or games (F = 2.69, η^2_p = 0.43, p = 0.07), however there was insufficient fixation data across both point types and games on the lower body to determine an interaction.

5.4.2.5.5 Release phase

In the release phase, fixation lengths were consistent between the point types (F <0.01, η^2_p = <0.01, p = 0.96), with a significant difference between games (F = 3.30, η^2_p = 0.20, p = 0.02), however, not point type x game interaction (F = 1.42, η^2_p = 0.05, p = 0.25). There were no significant differences between point types and fixation length on the upper body (F <0.01, η^2_p <0.01, p = 0.94), however, there was a significant difference for games (F = 2.74, η^2_p = 0.20, p = 0.04), but not point type x game interaction (F = 0.61, η^2_p = 0.01, p = 0.44). There were no differences between point type and fixation length on the ball toss (F = 0.03, η^2_p = 0.01, p = 0.88), however, large effect sizes for interaction of the fixation length on the ball toss between games were found (F = 0.43, η^2_p = 0.39, p = 0.76). This indicates the ball toss may be the dominate fixation area in the point type x game interaction (F = 1.90, η^2_p = 0.49, p = 0.30).

5.4.2.5.6 Loading phase

There were no significant main effects determined between point types and the duration of fixations in the loading phase (F <0.01, η^2_p <0.01, p = 0.97), nor across games (F = 0.75, η^2_p = 0.04, p = 0.56), or the point type x game interaction (F = 0.96, η^2_p = 0.05, p = 0.44). The fixation length on the ball toss on both point types (F = 0.34, η^2_p <0.01, p = 0.56) and across all games (F = 0.60, η^2_p = 0.03, p = 0.66), was consistent with the point type x game interaction (F = 0.04, η^2_p <0.01, p = 0.99), as the most consistent area of fixation in this phase.

5.4.2.5.7 Acceleration phase

In the acceleration phase, there are no differences between the point types and fixation length (F = 0.46, η^2_p = 0.01, p = 0.50), across games (F = 1.34, η^2_p = 0.10, p = 0.27), or with the point type x game interaction (F = 2.23, η^2_p = 0.12, p = 0.10). Figure 5.19 shows the serve contact point is the predominant fixation area for both point types (F = 3.71, η^2_p = 0.12, p = 0.06), and across games (F = 1.37, η^2_p = 0.17, p = 0.27). The point type x game interaction of the serve contact point shows that these fixations significantly decreased over the trial games (F = 7.67, η^2_p = 0.47, p <0.01). Post-hoc results with Bonferroni correction of p = 0.01 indicate that in game 2 there are significantly longer fixations on the serve contact point on break points in set A compared to other points (t = 9.27, p <0.01).

5.4.2.5.8 Ball flight phase

Finally, there were no differences between point types and fixation length during the ball flight phase (F = 3.03, η^2_p = 0.03, p = 0.08), or across games (F = 1.44, η^2_p = 0.06, p = 0.23). However, this was overshadowed by a significant interaction between game and point type (F = 2.89, η^2_p = 0.11, p = 0.03). Post-hoc testing with Bonferroni correction indicated that in game 3 there are significantly longer fixations on the ball flight on break points in set A than other points (t = 2.74, p = 0.01).

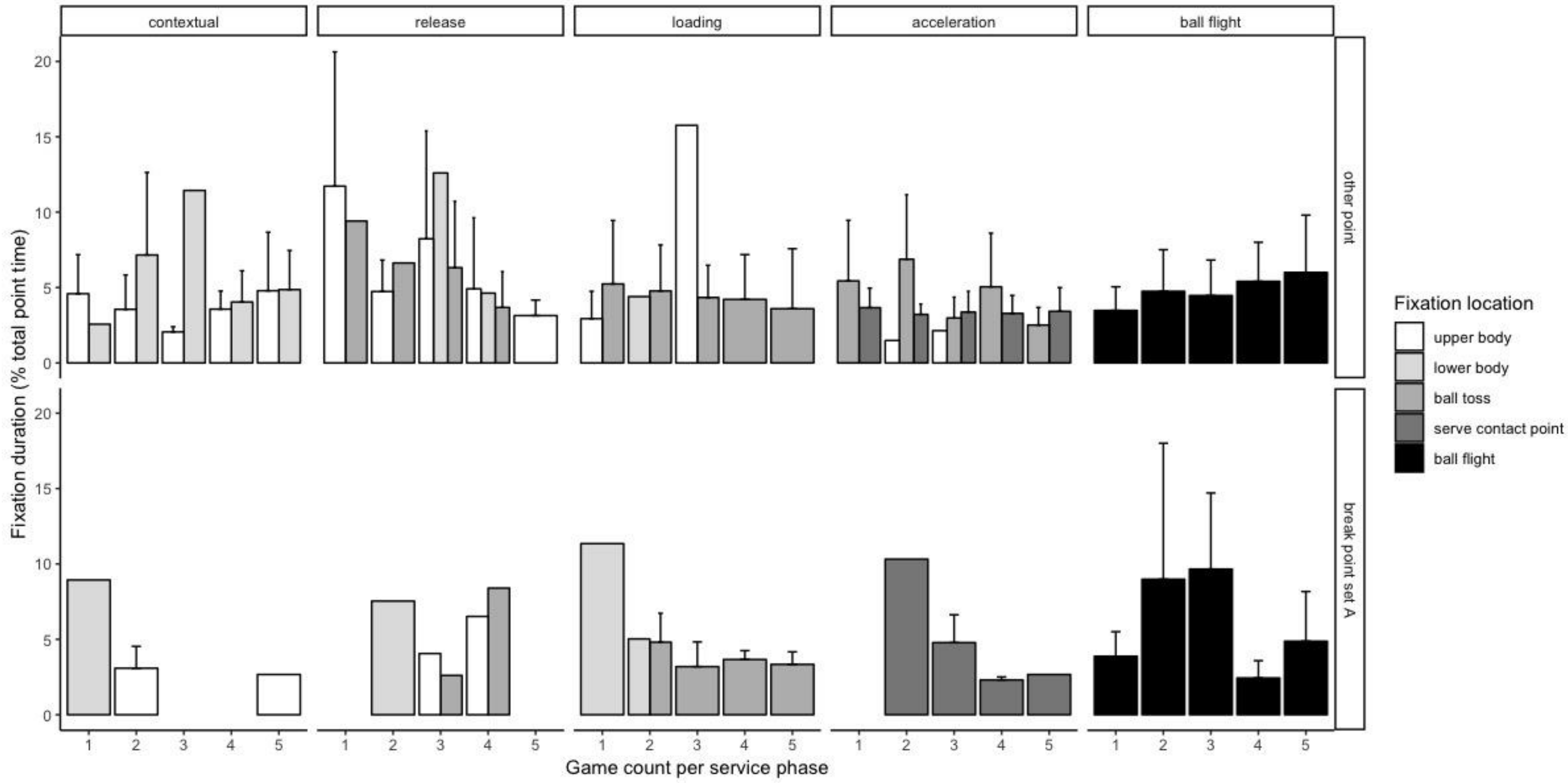


Figure 5.20: Fixation length over the trial games for each serve phase other points and break points set A. *N.B. Error bars represent mean error.*

5.4.3 Post-experiment qualitative reports

At the completion of the experiment, each participant verbally responded to three short questions about the returning task. When asked about whether they noticed any particular serving patterns during the task, 8 out of 10 participants indicated they were aware of the serving patterns on break points. They also elaborated and said they noticed how the server was serving tee in set A, and then started serving wide in set B. This was true also for participants who started the experiment with set B, with one participant stating that "I thought he was supposed to be going tee, but went wide most of the time. He then started going tee more in the second set".

When the returners were asked if they changed any part of their returning routine to enhance their return once they became aware of the serving patterns, 4 of the 10 participants discussed changing their return position, while the remainder preferred a neutral or consistent return position, regardless of the knowledge of the contextual information. For example, one participant stated that they "still wanted to cover the other serve, just in case", while another participant was saying that they tried "covering tee (serve), but then he started going wide, so I went back to my original returning position".

Finally, when asked about any kinematic cues the participants focused on during the serve to predict the return, 5 out of 10 participants cited ball toss as an important cue, while another 3 out of 10 said they were waiting for the ball flight or they were reading the ball off the racquet.

These qualitative results largely correspond with the fixation results from above, that demonstrate fixations on the ball toss and the serve contact point were considered important for attempting to predict the direction of the serve on all point types.

5.5 Discussion

The current study investigated how skilled tennis players alter their behaviour during the return of serve based on the availability of contextual and kinematic information sources. By manipulating the situational context provided by the score and providing kinematic information through an in situ experimental design, fixation patterns, response time, and return outcomes were examined to determine if contextual or kinematic information is prioritised during a return of serve task in tennis.

5.5.1 Return quality

Previous research has established that an expert's superior anticipation skill is useful in time-stressed scenarios such as returning serve during a tennis match, when the player often has less than 1 second to respond (Triolet et al., 2013). Tennis players must therefore make their initial responsive movements prior to ball flight information becoming available to execute a successful return of the serve within the time constraints. The results of the current experiment found that returners were making their initial movement, on average, between 480.80ms and 483.60ms prior to the server's racquet-ball contact on the differing point types. This initial movement before the ball flight information is available demonstrates that the participants were displaying anticipatory behaviours prior to the racquet-ball contact of the server, however, it also shows that the availability or congruence of situational information on break points did not influence any improvements in response time. It appears that these initial movements were merely used to initiate momentum of the player into the court, rather than responding based on the early pick-up of anticipatory information. Response time did not significantly change between games suggesting the absence of a proactive strategy to enhance anticipation as the information became more reliable. These results reject hypotheses 1a and 2a of this study.

The return speeds did not differ between the point types, nor did they change over the games, indicating a consistent return speed throughout the duration of the trials, despite the availability of congruent situational information. This is a consistent result with response time, and suggests that players were not taking advantage of the available contextual information on break points to hit a faster return.

Return outcomes were classified as either in or an error. It was found that a similar proportion of in returns occurred on break points in Set A and Set B, and also on other points when only kinematic information was available. The results suggest that even when contextual information is incongruent with kinematic information, expert tennis players are not susceptible to this information and this does not negatively influence the outcome of a return, as has been previously reported (e.g. as Murphy et al. (2019) reported).

The proportion of returns to poor, neutral, or good locations did not significantly differ between the point types. However, when only kinematic information was available (other points) there were more returns hit to poor locations than on break points in set A, suggesting that both contextual and kinematic information may need to be available for an improvement in return outcome. Although this result was not statistically significant, it may be that if a larger number of participants were examined, a more conclusive result regarding higher proportion of returns to a poor location on other points may be made.

The lack of significant results regarding the measures of return quality (return speed, return outcome, and return location) and congruence of contextual information, means that the null hypothesis regarding return quality on break points in set A and other points is maintained. However, this also means that the alternative hypothesis that return quality on break points in set A would be significantly better than the other point types cannot be rejected outright. Further investigation is needed with a larger sample group to determine if the hypothesis can be statistically rejected.

5.5.2 Gaze fixations

The results show that when contextual information is congruent (break points in set A), there were significantly less fixations, but of longer duration, than there were on points where there is no contextual information available (other points), or it is incongruent with the emerging kinematic information (break points in set B). This suggests that kinematic information may be the priority anticipatory source of information on other points and break points in set B given the lack of contextual congruence. This data indicated that there may be different gaze patterns employed during the return when contextual information is available and congruent. McRobert et al. (2011) found similar changes to gaze fixation strategies with available contextual information during batting in cricket, and indicated that experts are able to increase their attention to kinematic information when contextual information is unreliable or unavailable. However, while McRobert and colleagues (2011) found that these changes in gaze strategies also change after repeated exposure to the same information, this was not the case in the current experiment given the lack of significance in point type x game interactions in the various serve phases.

It was found that there were consistent fixations on the ball toss in the loading phase on all point types, as well as significantly longer fixations on break points in set A compared to set B. This indicated that the ball toss was an important kinematic cue for returners to attune to regardless of the availability of information sources. This is supported by the reported strategies used by the participants in the post experiment survey and is consistent with Goulet et al. (1989), who also found that fixations on the ball toss are a key feature of return of serve performance.

In the acceleration phase there were consistent fixations across the trial games on the serve contact point on break points in set A, as well as a number of fixation areas on other points (Figure 5.20). It may be that by this phase of the return on break points in set A, the returners have been exposed to enough kinematic information from the ball toss to confirm that contextual information is congruent. The returners then switch their gaze to extract kinematic information from the server’s contact point so they can prepare to steady their fixation on the ball flight from the time the ball meets the racquet. This is in contrast to break points in set B and other points where the number of different fixation areas indicated that the participants may still be trying to extract kinematic information from a number of other sources. These results are consistent with previous investigations in tennis (Murphy et al., 2019), football (Gredin et al., 2018), and baseball (Gray & Cañal-Bruland, 2018), which demonstrated that experts prioritise the most reliable source of information at different times prior to executing a response to an anticipatory task..

There were significantly longer fixations on the ball flight on break points in set A compared to break points in set B. This suggests that the participants were more attuned to the ball flight when contextual information was congruent, as they were confident in the serve direction, compared to when it was incongruent. This result is similar to findings from McRobert et al. (2011), who found that experts are able to more efficiently extract relevant kinematic information as a result of confirming contextual information. It may be that the incongruence of the contextual information on break points in set B, in addition to the increased number of fixation areas in the acceleration phase, has resulted in shorter fixations on the ball flight on these points throughout the games and has negatively impacted the participant's ability to extract relevant kinematic information (as indicated by a large effect size for the congruence x game interaction for all point types).

5.5.3 Combining contextual and kinematic information to improve return outcomes

It appears that when information from the ball toss in the loading phase is congruent with contextual information, a change of fixation areas in the acceleration and ball flight phases occurs. This is a significant finding that indicates that the most reliable source of information is prioritised by expert tennis players during the return task and agrees with previous research (Jackson & Mogan, 2007; Murphy et al., 2019). This also suggests that a change in gaze strategy is triggered when contextual information has been confirmed as congruent with the kinematic information.

The subsequent change in gaze strategy may explain why the number of successful in returns was similar to the number of return errors on points when contextual information was congruent with kinematic information. It may also explain the similarities between the number of successful in returns and the number of return errors when action outcome is incongruent to the contextual information. It appears that extracting relevant kinematic information from fixation on the ball toss, regardless of availability of information, means that tennis players are able to distinguish between different serves, and adjust their gaze strategy and subsequent return response to minimise the chances of a return error. These results suggests that expert tennis players are not completely susceptible to the congruence effect when returning serve in match play scenarios as suggested in previous research (Murphy et al., 2019). This is further in contrast to previous studies that have shown that when the action outcome is congruent with the expected situational and/or kinematic information, the response outcome improves (Mann et al., 2014). This finding partially supports hypotheses 1b and 2b of the current study, however given the lack of statistical significance throughout these results, further investigations with additional gaze data and a larger sample of congruent points are needed to confirm this.

The availability of ball flight information during the experiment, as well as the lower average serve speed compared to professional matches (Cross & Pollard, 2009) may account for why the current results are inconsistent with those of Farrow and Reid (2012), who found that response times improve significantly over the duration of a returning task when contextual information is present. However, the use of a video-based response task in the study from Farrow and Reid (2012) may also exaggerate the response times seen in congruent information conditions, as no physical return was required. In the match play task of the current experiment, participants were still required to execute the return of serve successfully, so incorrect spatial awareness and timing of movement (i.e. too early or too late) of the return may be detrimental to performance. Additionally, decision making regarding the type of shot when hitting the return (i.e. forehand or backhand, chip, slice, or drive) was still needed to be considered and executed by the participants, all of which must occur under the time constraints of returning the serve (around 0.5 seconds).

It is also possible that participants were able to extract enough kinematic information from the ball flight, so that they were not deceived by incongruent contextual information and were able to adjust their return response accordingly. This is in contrast to previous studies which have investigated responses based on anticipatory information only, and did not include ball flight (such as Murphy et al. (2019). It is likely that the video-based methodologies, such as those used in studies of skilled handball goalkeepers (Mann et al., 2014) and volleyball players (Loffing et al., 2015), which showed that experts were susceptible to incongruent action preferences that decreased their performance, could potentially explain this difference in performance outcomes. Furthermore, the current experiment required participants to execute a physical return response to the serve, which allowed for perception-action coupling to be present (Farrow & Abernethy, 2003), and while return quality may be susceptible to the incongruent contextual information in laboratory-based tasks, participants in the current experiment were able to use the available ball flight information to make adjustments to their response and reduce the difference in return outcomes. To further support this, when the participants were asked if they changed their behaviour based on contextual information to improve their return, some participants said they adapted their position and movement accordingly, while other participants said they still wanted to cover the other side of the service box “just in case”. This suggests the participants may have had a conservative returning mindset during the experiment, which may account for the return outcome results observed and suggests that returners were not deceived by the incongruent trials. It is also important to note that in these previous studies investigating congruence, individual congruent trials were considered in their results, whereas in the current study, the congruent trials were considered as all break points in set A, and incongruent trials were all break points in set B (where 80% of these points mirrored the information given to the participants prior to the experiment). This method was deliberately chosen to replicate the scenarios which would occur in an actual tennis match, where it is unlikely that 100% of points are served in the same direction. While there is no reason to believe this has affected the results of the current experiment, this methodological difference must be considered when comparing to previous research of congruence (for example Mann et al. (2014); Murphy et al. (2019); Runswick et al. (2019)).

5.5.4 Limitations

While the current study was conducted in situ and played like a tennis match it was still not completely representative of a real tennis match. Although the participants were instructed to return as they would normally during a match, the lack of subsequent point play may have led to some returners to alter their usual returning style by returning more conservatively or aggressively which may have influenced the results of the return outcome measures.

It was important to counterbalance sets A and B across the participants to reduce possible ordering effects of the experiment, however it is possible that the participants who started with set B (without their knowledge) may have reduced the potential congruence effect of the results as the participants ignored the contextual information in set A. When asked about the serving patterns, one participant noted about the server that "I thought he was supposed to be going tee but went wide most of the time at the start. He then started going tee more in the 2nd set". This suggests that on at least one trial that started with set B, the participant was still able to consider the congruent contextual information when the second set was set A, however there is not enough information to conclude that the absence of the congruence effect resulting from the experiment can be ruled in or out due to the counterbalancing of the sets.

It must also be noted that average serve speeds during the trials was below the average serve speeds that would require players to rely completely on anticipatory information. This may explain why there was a reliance on ball flight information and, a lack of significant differences on return outcomes based on congruent or incongruent contextual information. Due to the design of the study, where the server must serve a valid in serve for each trial, it is possible that a speed-accuracy trade-off may have occurred. The server may have decreased their serve speed (despite encouragement to continue to hit hard) to ensure they served in the direction they were supposed to according to the serve script, or that they served a valid serve in as few attempts as possible. That being considered however, the difference in time between the average serve speed of the current study and the average serve speed of a professional men's match may be as little as 100ms. This may not be a large enough difference in time to cause the participants to change their behaviour is response to this. Additionally, players may start their return position further up in the court, negating this difference in time by reducing the distance the serve must travel. As return position was not captured in the experiment, this is not possible to conclude.

Finally, the current study did not measure response movement accuracy or changes in return position on different point types. This is important for future studies to address as response times and outcomes may provide the complete story when it comes to determining if anticipatory behaviour is altered based on the priority of information sources during the return.

5.5.5 Conclusion

The current study investigated the temporal interaction of contextual and kinematic information during the return of serve in tennis match play scenarios. The results suggested that when contextual information is present and congruent with kinematic information and the action outcome, that response time and return outcomes do not change significantly compared to when only kinematic information is available. However, attention to kinematic information changes in the later stages of the service phase if there is incongruent contextual information or only kinematic information available. It was found that ball flight information continues to be the most important reliable kinematic source, which allowed participants to adjust their return response, and time the execution of their return. The results of the current experiment highlight the need for future studies to continue to examine anticipatory performance in real world contexts to truly understand how skilled performers use contextual and kinematic information sources to inform their movements.

Chapter 6: General discussion

The overall aim of this thesis was to determine the priority of anticipatory information sources used during the return of serve by expert tennis players. The first aim was to determine the specific contextual and kinematic information sources used by expert tennis players when returning serve through qualitative interviews with professional tennis players. The second aim was to determine how contextual information sources (specifically, situational probabilities on certain scores) influenced the court position of a tennis player when returning. The final aim was to investigate the temporal interaction of contextual and kinematic information sources to determine when during the return of serve the use of such information is prioritised. This chapter will provide a thorough discussion regarding the main points of each of the three experiments, and how the results tie together to address the overall aims of the thesis. Methodological considerations will also be discussed, as well as the implications of these results for coaches and tennis players. Finally, the limitations of the work, and future research applications will also be discussed.

6.1 The experimental series

6.1.1 Qualitative exploration of tennis specific contextual information sources

Previous research has already indicated that some contextual information sources such as the opponent's location in the court (Murphy et al., 2016), or certain scores (Farrow & Reid, 2012) are used to anticipate groundstroke or serve direction. A qualitative methodology was used to interview former and current professional tennis players about specific information sources used when anticipating the serve, which of these sources are prioritised during the return, and how this influenced their decision-making about the return.

Nine themes representing important factors for anticipating the return of serve were determined from the responses of the interviews. These themes were consciousness, tactical awareness, contextual information sources, kinematic information sources, mentality/confidence, build pressure on the server, returner technique/strategy, returning characteristics, and practice. These themes revealed important tactical strategies which contribute to the success of the return. Firstly, the contextual and kinematic information sources which were discussed in the interviews confirmed that expert tennis players are not only picking up these important factors, but are also highly aware of the implications these sources have on the outcome of the serve, and how this influences their subsequent return behaviour. The interviews confirmed that there is a conscious awareness on the ball toss by players to help anticipate the direction or type of serve. This confirms the results of previous research about the importance of fixating on the ball toss (Ward et al., 2002). The conscious awareness of contextual information sources, such as serving preferences of the opponent on certain scores, or serving patterns were also found to be important sources discussed by the participants, again confirming previous research in this area (Farrow & Reid, 2012; Stern et al., 2016). Participants discussed how they altered their return position to reflect knowledge of contextual information (such as situational probabilities on break points) in an attempt to show the server that they know where to the serve is going.

A temporal model that identified when the information sources potentially influenced behaviour during the return of serve was developed from these interviews (see Figure 3.1 in Chapter 3). The key aspects to come from this model was the confirmation of theories presented in previous research (Müller & Abernethy, 2012), that contextual information sources, such as a server's preferences on certain scores, or patterns of serving, are considered the priority source up to the point in time when enough kinematic information from the ball toss becomes available and either confirms or rejects the contextual information.

6.1.2 Quantitative explanation of returner behaviour based on contextual information sources

Study 2 (Chapter 4) of this thesis expanded on the results of previous research about the anticipatory behaviours of expert tennis players in match play (Triolet et al., 2013), to investigate the changes in return behaviour based on availability of anticipatory information sources. The purpose of this study was to use spatiotemporal player tracking data from Hawk-Eye to determine how a returner's court position changes (i) over the duration of a match, and (ii) on break points compared to all other points.

The results of Study 2 indicate that a tennis player's change in court position during the return of serve may not be consistent with previous findings about expert's behaviour during anticipatory periods (i.e. Cañal-Bruland et al. (2015) in baseball or Farrow and Reid (2012) in tennis). Firstly, the results suggest that at the time intervals that relate to the anticipatory periods (1s before serve and at serve impact), players are not altering their return position significantly from the average position, either laterally, or forwards or backwards. It is not until ball flight information becomes available that lateral position at return impact was found to be significantly different from the average return position. This is consistent with findings from Avilés et al. (2018), who concluded that expert tennis players do not display observable anticipation towards serve direction, and instead prefer to use ball flight to guide their return actions, rather than relying solely on anticipatory information.

Finally, the data from this study confirms return position at all three time intervals (1s before serve, at serve impact, and at return impact) was significantly deeper in the court on break points, compared to other points, however there was no significant change in lateral position until return impact. These results suggest that players are not significantly altering their return position to reflect serve direction based on anticipatory information available at 1s before serve or at serve impact. Instead, players are preferring to wait until ball flight confirms serve direction, before they move their lateral position based on that information. This finding contradicts a number of results from previous studies which have investigated anticipatory sources in tennis (Farrow & Reid, 2012; Singer et al., 1996). It is likely that this discrepancy in return behaviour during match play (compared to laboratory-based studies), may be explained by the fact that correct anticipation and response accuracy to the serve is only one aspect of successful returning, and players still need ball flight information to guide their movements during the return (Van der Kamp & Renshaw, 2015). In addition to this, in a real match, if players were to move too early to the serve, the timing of their movement to the return may not match the timing of the serve, and could be a possible disadvantage to the outcome of the execution of their return shot. In contrast, this may not be the case in laboratory-based studies where there is no disadvantage for moving towards the serve earlier.

6.1.3 Exploring the temporal interaction of kinematic and contextual information sources during the return of serve task

Experiment 3 (Chapter 5) of this thesis attempted to capture the interaction of kinematic information sources and contextual information sources during the return, determine when these sources are prioritised by expert players during the return, and how congruence or incongruence of this information influences return outcomes. The purpose of this experiment was to assess changes in return quality and gaze patterns on points where contextual information was congruent (break points set A), contextual information was incongruent (break points set B), and when only kinematic information was available (other points). This experimental design was the first time kinematic and contextual information sources had been manipulated in a match play scenario, and determine how this information influences return outcomes and the temporal priority of each anticipatory source, in an in situ task compared to a laboratory-based study (e.g. Gredin et al. (2018) or Murphy et al. (2016)).

The results from this experiment revealed that players do display an element of anticipatory behaviour during the return as movement initiation typically occurred some 480ms before racquet-ball contact. This is similar to a number of findings about the anticipatory response of tennis players in match play scenarios, where it was also found that response time and split step occur prior to racquet-ball contact of the server (Avilés et al., 2018; Triolet et al., 2013). However, this initial anticipatory behaviour did not manifest into a specific pattern as it related to the nature of the information sources available for the player to use (i.e., congruent or incongruent).

The results revealed there was no significant difference in return speed, number of in returns, or returns to good locations on break points in set A compared to break points in set B or other points, nor did the results indicate that there was a significantly higher proportion of returns to poor locations on other points. While this lack of result reveals that tennis players are not completely susceptible to incongruent contextual information (Murphy et al., 2019), it also reveals that they are also unable to take advantage of congruent information to improve their return quality (Mann et al., 2014). It is likely that due to this experiment being a match play based experiment, the lower than average serve speeds of the trials, and that experts still need to respond to the serve outcome, they not only have access to contextual and kinematic information sources, but are also able to adjust their response to the incongruent information, based on ball flight information and maintain the quality of their return response.

The results of the fixation data revealed there were a significantly larger number of fixations on other points and break points in set B compared to set A. In addition, fixation length was significantly longer in set A than set B. These results indicate a change in gaze strategy when contextual information is congruent compared to when it is incongruent or unavailable. McRobert et al. (2011) found a similar result in cricket batters who also changed their gaze strategies when contextual information was available. This indicates that during an anticipatory task, depending on the availability or reliability of contextual information, experts are able to alter their attunement to kinematic information.

Further breakdown of the fixations in each of the service phases revealed that in the loading phase, the ball toss was the consistent fixation area for all point types. This indicates that the ball toss is a key kinematic cue for tennis players to be attuned to, regardless of other available sources of information. In the acceleration phase, there is consistent fixation on the serve contact point on break points in set A compared to other points and break points in set B, where there are still a number of fixation areas. Finally, there was a significantly increased fixation length on the ball flight in the final phase of the serve on break points in set A. Players may be more attuned to the ball flight information on these points as the congruent contextual and kinematic information has confirmed serve direction, and the participants are using the ball flight information to make final adjustments to their return. However, given that the ball flight is the only area of fixation for all point types in this phase, it is therefore the most reliable source of information regardless of previous anticipatory information. This change in gaze strategy when contextual information is congruent indicates that returners have different priorities for fixating on the ball flight in this phase. This is consistent with the overall fixation results above, and how participants are likely to attune to the most reliable source of information. This is also supported by results from (McRobert et al., 2011). However, further investigation from a larger sample of congruent points is required to conclusively determine if this change in gaze strategy is as a result of availability and/or congruence of contextual information, and how returner prioritise this information.

Although there is a change in gaze strategy during the different serve phases based on congruence of information, this change and subsequent reliance on ball flight information does not result in better quality returns when information is congruent, nor does it negatively influence return quality when it is incongruent. These results conclude that ball flight information is the most critical factor for guiding return behaviour, regardless of whether information is congruent or incongruent. However, as the response of the returners starts prior to ball flight information becoming available, it appears that neutral return preparations are used by the returners as suggested by Alain and Proteau (1980) and Avilés et al. (2002), then reliable ball flight information is able to direct return behaviour towards the correct serve direction.

6.2 Conclusions from the results of the experimental series

6.2.1 Do returners behave the way they say they do during the return?

The combined results of Studies 1 and 2 demonstrate that while expert tennis players are attuned to the contextual information sources (specifically, knowledge of server preferences on score), this may only influence returner position after ball flight information becomes available. Results from the interviews in Study 1 confirmed the findings of previous studies (Murphy et al., 2016) that expert tennis players are able to use both kinematic and contextual information sources to influence their anticipatory capabilities. However, this influence was not evident during the anticipatory periods in Study 2, either over the duration of the match, or on lateral court position on break points. Study 2 found that significant changes only occur for lateral return position at return impact, therefore these results may not indicate that knowledge of server's preferences causes a change in returner behaviour towards serve direction during anticipatory periods (as suggested by the professional players interviewed in Study 1). While significant changes to returner depth on break points was found, the difference was only a matter of mere centimetres when compared with other points. This demonstrates that contextual information does influence returner behaviour in anticipatory periods (i.e. 1s before serve, and at serve impact), however, these changes may not be large enough for the server to perceive and that it would force the server to change their behaviour, as was suggested by the interviews in Study 1. Previous research in laboratory settings has indicated that contextual information sources do have an influence on improved anticipatory capabilities of experts (Abernethy et al., 2001; Alain et al., 1986; Farrow & Reid, 2012; Mann et al., 2014; Murphy et al., 2016), however, it appears that in a match play setting, this may not be the case, and players prefer to wait for ball flight information to become available before changing their lateral return position to reflect the serve direction.

The discrepancy between lateral position changes in Study 2 and the results of Study 1 can be explained by a number of factors. This includes the information-movement coupling of needing to time the movement of the response correctly (i.e. moving too early or too late towards the serve that may negatively affect the return outcome), the possible negative consequences of responding incorrectly to contextual information (therefore players waiting for ball flight information before committing one way or the other), or the neutral preparatory movements of the players in these anticipatory periods. This discrepancy also does not rule out the possibility that just because there is no significant physical difference of return position or movement, that returners do not undertake some sort of cognitive anticipation (i.e. mentally preparing for a serve in a specific direction, without physically indicating that knowledge of serve direction). Unfortunately, it is not possible from the results of the current study to conclude whether this is the cause of this discrepancy. Further investigation of this phenomenon may be more conclusive at indicating that returners are mentally preparing for a specific serve direction based on their attention to anticipatory information, but prefer to avoid moving too early to the serve to reduce the possible negative consequences of mis-timing their return response.

Information-movement coupling is an important factor to consider in match play studies as participants are required to time the movement of the response correctly (i.e. not moving too early or too late). Returners must couple the available anticipatory information with the timing of their movement in order for the return to be successful or else incorrect timing of the return may not align with the speed and direction of the serve, resulting in a negative return outcome (Van der Kamp & Renshaw, 2015). The players in a real match situation must decide whether the possible benefits that come from moving to the anticipated serve early during the return, outweigh the possible disadvantages of losing the point if the player's anticipation of the serve is incorrect. The risk-reward trade off of moving too early towards the anticipated serve direction may not be enough to warrant players moving to the serve in the early stages of the return sequence as this may put them at a disadvantage on an important point. The coupling of movement and information demonstrates this difference between the laboratory-based studies (Farrow & Reid, 2012) (where accurate information-movement coupling is not the priority, but rather the fastest or most accurate possible response) and match play data. By waiting until ball flight information is available in the early stages after racquet-ball contact of the server, returners are able to make the necessary adjustments to their return position based on correct serve direction. This aligns with the findings of Triolet et al. (2013), who found that significant movement does not occur until after ball flight information is available in match play data.

It is known that break points are an important point for both the server and the returner to try and win, given the context in the match (Knight & O'Donoghue, 2012). Therefore, it may be possible that with the added pressure on break points, returners prefer to maintain their neutral preparatory movements, rather than committing to one serve direction which may be incorrect. As discussed by Alain and Proteau (1980), experts do prefer to maintain neutral preparatory movements in these scenarios (unless it is the highest possible probability of a certain serve), rather than anticipating incorrectly, or moving too early towards the serve, which may have negative consequences. It appears that the data from this analysis confirms that this is also the case with expert tennis players in lateral return position in match play. This may be a further explanation as to why there is no difference in lateral return position until ball flight information has been viewed at return impact.

6.2.2 Returning behaviours and outcomes based on contextual and kinematic changes in match play

While the results of Study 2 revealed a lack of changes in a returner's position on break points, it did not take into account the actual situational probability information of each match and opponent. Experiment 3 overcame this by controlling the situational probabilities on break points and measuring how returner behaviour changes with congruent or incongruent information. Experiment 3 also allowed the capture and usage of kinematic information of the participants, which was not available in Study 2.

Firstly, the average response times of the participants were negative, indicating that the participants were making their initial movements prior to ball flight information being available. However, response times did not differ between point types and were relatively consistent despite the availability of anticipatory information. Furthermore, Study 2 revealed that significant changes to return position on break points, as well as the largest variation in return position (both depth and lateral), occurred at return impact. The combination of consistent negative response times plus a lack of significant position changes until ball flight information is available, are good indicators that players prefer to make some neutral preparatory movements prior to racquet-ball contact of the server, and then move towards the direction of the serve once ball flight is available, rather than base their initial movement on anticipatory sources (Alain & Proteau, 1980; Avilés et al., 2002). By not moving too early towards the serve, returners also reduce the chances of a negative return outcome resulting from incorrect timing of their movement towards the serve. It appears that contextual information may not be a prioritised source of anticipatory information to influence these return behaviours prior to ball flight information.

However, while it appears from the results of studies 2 and 3 that contextual information is not prioritised to influence returner behaviour, the results in Experiment 3 which also considered return quality (i.e. return speed, return outcomes, and return location), reveals that there is a trend that experts may have a decreased return quality on other points when contextual information isn’t available. This confirms that the additive effect of contextual and kinematic information may help improve return outcomes in these tasks (Cañal-Bruland & Mann, 2015). However, given the lack of significance between return quality and availability of anticipatory sources, further investigation is required to determine if this is true across a larger sample group. In addition to this, experts may also not be completely susceptible to incongruent information to the extent that has been previously reported (Loffing et al., 2015; Mann et al., 2014). As a player’s return position does not vary significantly until the later stages of the return (based on data from Study 2), this suggests there is a reliance on the ball flight information. This is consistent with the results of Experiment 3, as players are able to make adjustments to their return based on ball flight information, given they were not susceptible to incongruent situational information. However, given the change in gaze strategy that is seen on points where contextual information is congruent compared to points where contextual information is incongruent, there is still an argument to be made that kinematic information is somehow potentially influencing return behaviour.

This change in gaze strategy on the different point types is consistent with results from McRobert et al. (2011) who found expert cricket batters were able to extract more relevant kinematic information when contextual information was unavailable. Being attuned to the ball toss in the loading phase is important for determining serve direction (as per previous research from Goulet et al. (1989)), regardless of congruence or incongruence of ball toss information with contextual information. Following the emergence of ball toss information, the participant's gaze strategy changes based on whether the ball toss was congruent or incongruent with the contextual information. In the following acceleration phase, visual attention either then switches to the serve contact point for reliable cues (if information is congruent), or reverts back to a searching strategy (if information is incongruent, or only kinematic information is available). This confirms that experts are able to prioritise searching for the most reliable source of kinematic information during the service action (as Gredin et al. (2018) found in football).

The results from these two studies, when considered together, suggest that reliable anticipatory information is the prioritised information source during the return. For example, up until ball toss information becomes available, contextual information is the prioritised source for returners. Once ball toss information becomes available, it then becomes the prioritised source. However, neither of these information sources appear to physically influence returner behaviour towards a particular serve direction until ball flight information becomes available. The results of studies 2 and 3 show that ball flight information is the source of information which is the most influential to return behaviour, and while contextual and kinematic information sources may be prioritised at different times during the return, this information is negated once ball flight information becomes available, as it is the most reliable source which indicates serve direction.

6.2.3 Overall outcomes from the experimental series

When the results of the three studies are considered collectively, a number of key conclusions can be made regarding the temporal priority of kinematic and contextual information sources by expert tennis players during the return of serve. These key findings are:

- Specific contextual information sources considered by expert tennis players during the return of serve include probability information on break points and other "high pressure" points
- While expert tennis players are attuned to these contextual information sources, especially on break points, it appears that it does not significantly alter a returner's lateral return position in the court until after ball flight information is available.
- If available, expert tennis players prioritise contextual information, such as situational probabilities, up to the early stages of the service action, when kinematic information takes over. Once ball toss information becomes available, tennis players use this cue to confirm or reject the contextual information. Tennis players continue to prioritise kinematic information, until the server's racquet-ball contact and ball flight information becomes available.
- As the most reliable source of information that indicates serve direction, ball flight is the most influential factor which affects return behaviour. Therefore, the findings from all three studies demonstrate that expert tennis players prioritise the most reliable source of information at any given time during the return.
- The lack of significant differences in return outcomes (i.e. in and error returns) in Experiment 3 indicates that even though expert tennis players are attuned to

anticipatory information sources, they still have enough time on the first serve to couple anticipatory and ball flight information with their movements, and make adjustments to their return using this late information to ensure a positive return outcome, rather than being susceptible to incongruent information.

6.3 Methodological considerations

A number of different methods were used in the experimental series of this thesis in order to better understand the different aspects anticipatory information players may have selectively used during the return of serve. These methods are discussed below to better describe their advantages and limitations in the context of the overall thesis.

6.3.1 Qualitative interviews

Qualitative interview methodologies have not been commonly used in skill acquisition research until recently. As discussed in Chapter 2, qualitative approaches are advantageous when wanting to consider the psychological factors that may influence anticipatory performance, especially during high pressure scenarios. The use of qualitative interviews to investigate the temporal interaction of kinematic and contextual information sources in Study 1 allowed participants to describe the order they consider these sources during the return of serve, which provided a richer amount of detail than can be determined from other methods (Pitney & Parker, 2001). This method was also used in Experiment 3 and asked participants about their awareness of the kinematic and contextual information sources during the returning task. Qualitative methods provide strong evidence that expert tennis players are cognitively aware of this information and whether it influences their overall behaviour or not. Given this consideration, the results of Study 1 therefore allowed the participants to focus on only the critical anticipatory sources they considered during the return of serve when giving their responses to the interview questions, while also considering the psychological considerations of the increased pressure on these points (albeit ad-hoc reflections).

While using an interview methodology was advantageous for the reasons above, it is important to note that this method only captures the conscious priority of these information sources. It is known from previous research that experts possess an element of automaticity during tasks that they have completed thousands of times over (Gray, 2015), therefore it is possible that the participants under reported kinematic or contextual information sources they may consider when actually returning serve. While this is an important consideration, participants were still able to provide a rich amount of detail about their use of anticipatory information sources and how perception of these cues influence their return behaviour. However, the acknowledgement of specific conscious information sources will be useful in future quantitative research which investigates these specific influences.

6.3.2 Spatiotemporal player tracking

Spatiotemporal data was used in Study 2 to track changes in returner position at three time intervals during the return. Previous studies have tended to use this data from tennis matches to track ball landing locations and determine patterns of rally play (Wei et al., 2013), describe the average ball strike location, or the physical requirements of a tennis match (Reid, Morgan, & Whiteside, 2016). Therefore, the analysis of the player tracking data in this way in Study 2 was a unique way of using the spatiotemporal data. This data enabled us to determine whether return position is influenced before, or during the service action, based on the availability of the anticipatory information sources from the timeline of the model in Study 1 (i.e. contextual information sources were available at 1s before serve, kinematic information sources were available at serve impact, and ball flight information was available at return impact).

While these time intervals are a consistent reference point to the service action, it does restrict the position of the player to only these static intervals and does not account for movement or changes in position between the time intervals, nor does it account for response time or movement accuracy. Given that Hawk-Eye tracks player position at 25 Hz, it is possible to account for these movements using all available points of player tracking data to more accurately describe changes in returner position. Furthermore, it would allow researchers to describe exact court position movement based on the availability of anticipatory information sources (keeping in mind the typical cognitive processing and response time of around 200ms) (Le Runigo, Benguigui, & Bardy, 2010).

The use of the Hawk-Eye data in Study 2 is a positive indication that the player tracking data can be used as a valid measure of player movement, not just during the return of serve, but also within match play. This has positive implications for future research which may investigate how players move around the court during a match, including their movement patterns in response to time-stressed events on court. The ability of technology such as Hawk-Eye to track player movements to 95% accuracy will allow researchers to conduct experiments in match play scenarios, which will greatly maintain the ecological application of the results of these studies (Farrow, Reid, Buszard, & Kovalchik, 2018), more so than research that has been conducted in the past.

6.3.3 Manipulation of in situ anticipatory information sources

Manipulating anticipatory information sources is not a new method of investigating changes in anticipatory response behaviour. Previous research has used deception-type methods to determine that expert athletes are deceived by the congruence effect (Murphy et al., 2019). However, Experiment 3 was the first study in tennis to use an in situ experimental method to manipulate contextual information sources (in this case, situational information based on specific scores), and then determine how attunement to kinematic information sources also changes (by tracking gaze fixations). This has obvious advantages over laboratory-based experiments as it replicates the conditions of a tennis match as closely as possible (Dicks et al., 2010b) and allows the scores to be manipulated in a way which was controllable to ensure two break points per game occurred. This ensured that researchers were able to investigate the influence that the contextual information (given prior to the task) had on their returning behaviour, rather than (i) relying on break points to occur organically if the participant and the volunteer server played out a full match or (ii) manipulating the first and/or last serve of a game (which has been done in previous research e.g. (Cañal-Bruland et al., 2015; Farrow & Reid, 2012; Gredin et al., 2018). The manipulation of contextual information sources is also a valid template for future research in other in situ sports scenarios (i.e. baseball or cricket batting, or returning serve in volleyball).

6.4 Practical implications

The findings from the experimental series have important implications for coaches, players, and tennis analysts, about using anticipatory sources during the return of serve to prepare for matches based on the availability of this information.

Experiment 3 found that expert tennis players do not appear to be susceptible to incongruent contextual information, and given that performance analysis is now common place in elite tennis player's preparation for matches, players are accessing and using more contextual information (such as serving patterns) than ever before. It may be that players who collect this information about their opponents, could possibly gain an advantage without being susceptible to the congruence effect. However, as has been previously established (Alain & Proteau, 1977), the probability of these serving patterns must be at least 80% before players will commit to changing their return behaviour based on this information.

As was suggested by a number of participants in Study 1, by adding variety of serving types, and exposure to different serving actions and outcomes in practice allows players to become more aware of these cues, and how these result in a change of serve outcome. Studies 2 and 3 found that ball flight is the most reliable source of information that influences returner behaviour. Therefore, it would also be important for players to be able to train to recognise ball flight early in order to move correctly to the direction of the serve.

Studies have found that training to respond to specific action preferences also improves anticipation accuracy (Mann et al., 2014). It is therefore important that coaches not only present this information to their players prior to a match, but that players also practice returning against their opponent's likely serving patterns. This allows players to couple their returning responses and movement to the available information and their anticipatory capabilities. Williams, Ward, Knowles, and Smeeton (2002) demonstrated that this strategy of training significantly improved decision time of expert tennis players, who had undergone anticipation training, in both laboratory and field-testing.

The combination of being presented with the kinematic and contextual information sources, and practicing to respond to these cues prior to a match, therefore appears to be advantageous for players preparing for a match, and may allow them to adjust their returning behaviours earlier in a match than if they did not prepare in this way. However, further research is required to determine if this type of training improves match performance, not just experimental performance.

6.5 Limitations and future research

6.5.1 Limitations

There are some limitations regarding the overall experimental results of this thesis which must also be addressed. One of the limitations of the results of this thesis is the individual preferences of each participants in the experimental series. Specific returning styles and serving strategies are used by different players depending on their own individual strengths and weaknesses, therefore the results of the group data, particularly in studies 2 and 3, must be interpreted with this in mind. This extends to a player's lateral movement in response to the serve direction, as the response to each serve will be based on this information.

Studies 2 and 3 used return position, return outcomes and return speed as measures of return quality based on correct anticipation. However, these measurements do not take into account the movement accuracy relative to the serve direction, nor does it capture changes to other movements which may have been influenced by anticipatory information. By using more advanced technology to record changes in return swing path kinematics (as Gray and Cañal-Bruland (2018) did with baseball batting), initial anticipation movements and accuracy can be more effectively measured as they were highlighted in Study 1 as measures that the participants said they altered when anticipating the serve. It is also recommended that measuring returner position data in response to anticipatory information sources must be investigated in future studies. Farrow et al. (2018) highlighted that accurate in situ measurements of this type of data is now accessible for researchers and therefore future studies are able to use available spatiotemporal data to more accurately track player movements.

Experiment 3 considered the initial movement of the front foot leaving the ground was the time of response relative to the racquet-ball contact of the server from the video replays of the returning task. However, the frame rate of the cameras was limited to 25 frames per second, and therefore this movement is only accurate to 40ms increments. Experiment 3 also did not measure response movement accuracy or changes in return position. By not including these measures, there is no way to determine if players are initially moving in the correct direction towards the serve based on anticipatory sources (as all players demonstrated anticipatory capabilities by initiating their response prior to the critical event of the server's racquet-ball contact), or waiting until ball flight information is available, as was found in Study 2.

Although the mobile gaze tracking equipment was the best available technology used for Experiment 3, the glasses only captured four complete trials out of the possible ten participants from the experiment. The increased distance between the returner's position at one end of the court to the server down the other end was much greater than the normal use of gaze tracking glasses and may explain this decrease in the amount of data. Fixations may not have been able to be captured due to this distance, as the glasses may have been able to capture these as fixations and instead categorised them as other eye movements (such as saccades or blinks which are not relevant in the current research).

This is a limitation of the technology, and the automatic coding of the eye events from the software used.

Experiment 3 also presented some issues about the need for anticipation in these trials. While the trials attempted to replicate match play conditions as closely as possible, the average serve speed of the trials (159 km/hr) was well below the average speed of professional male players (Cross & Pollard, 2009). This is an important limitation to acknowledge, as the lower serve speeds means that participants were unlikely to need to anticipate the serve, as they had enough time to respond to ball flight information and make adjustments where necessary to return the serve successfully. This is the most likely explanation for why there were no significant differences in response times or return quality between point types.

6.5.2 Future research considerations

Given the new knowledge determined from the results of the experimental series, it is recommended that future research addresses the limitations as discussed above. It is also important to investigate the impact this information may have on other measures of return behaviour and decision-making, such as the returner's preparation prior to the point, their swing path kinematics, the type of shot they choose to hit, or their lateral movement accuracy. Alain et al. (1983) explored the idea of total, partial, or equal preparation movements during anticipation of squash shots, which may help explain the behaviours of tennis returners as above. The results from this thesis show that expert tennis players may exhibit some of these anticipation movements as either cognitive anticipation or physical anticipation. Cognitive anticipation may include players mentally preparing for an expected serve outcome, but also preferring to wait until reliable ball flight information is available to make any significant physical changes which reflects this knowledge. This is highlighted by the fact that the results of the experimental series (in particular, Study 1, and the verbal reports from Experiment 3), and previous research from Avilés et al. (2002) demonstrate that neutral return preparatory movements are preferred by expert tennis players in match play. There is also the possibility of a physical anticipation response which was not explored in this experimental series. Physical changes to their grip on the racquet, swing path, or lateral movement response times could be explored further. These behaviours which occur in the anticipatory periods prior to the server's racquet-ball contact may be influenced by anticipatory sources rather than ball flight information and demonstrate physical anticipation in tennis returning. However, these ideas have not been explored in detail in tennis returning. Further investigations are required to demonstrate if return behaviour is altered in these scenarios using other measures such as movement accuracy from the split-step, the grip on the racquet which covers either a forehand or backhand, or the swing path kinematics of the returner.

6.6 Conclusion

The primary aim of this thesis was to determine the temporal priority of the contextual and kinematic information sources used in anticipation of expert tennis players during the return of serve to enhance our understanding of how these sources interact to influence decision-making and return behaviour. The results of the experimental series demonstrate that contextual information sources are the prioritised source up until the kinematic information from the ball toss becomes available. From this moment, kinematic information is the priority source until ball flight information becomes available after the server's racquet-ball contact. However, when these information sources are congruent with each other, the results show that return quality does not significantly improve. The results of this thesis have concluded that ball flight information is the most reliable source to influence movement and timing of the return, which may explain why return quality does not improve. This is an important application for future research in this field, as it provides evidence that early perception of ball flight information may be just as critical for successful returning as anticipatory information sources.

The results of this thesis can be applied in a practical coaching environment to ensure expert tennis players are able to train to recognise the specific contextual and kinematic information sources of an opponent. Knowledge of the priority of information can help expert tennis players to determine the outcome of a serve based on the most reliable source of available information at any given time during the return. By presenting contextual and kinematic information of an opponent's serve and combining this with training for the specific serving patterns, expert tennis players may be able to enhance their return capabilities based on this priority of reliable information. Considering the results of the experimental series together reinforces previous research that both contextual and kinematic information sources are important for anticipating the return of serve, but also that ball flight information is the most reliable source of information to influence return behaviours. The ability to prepare for each of these sources prior to a match, will have a large influence on the successful returning ability of expert tennis players.

References

Abernethy, B. (1988). *Expertise, visual search and information pick-up in squash*. Belconnen, ACT: National Sports Research Centre.

Abernethy, B., Farrow, D., Gorman, A. D., & Mann, D. L. (2012). Anticipatory behavior and expert performance *Skill acquisition in sport: Research, theory and practice* (pp. 287). Abingdon, Oxon: Routledge.

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception, 30*(2), 233-252. doi:10.1068/p2872

Abernethy, B., & Wollstein, J. (1989). *Improving anticipation in racquet sports*. Belconnen, ACT: Australian Sports Commission.

Abernethy, B., & Zawi, K. (2007). Pickup of Essential Kinematics Underpins Expert Perception of Movement Patterns. *Journal of Motor Behavior, 39*(5), 353-367.

Afonso, J., Garganta, J., & Mesquita, I. (2012). Decision-making in sports: the role of attention, anticipation and memory. / A tomada de decisão no desporto: o papel da atenção, da antecipação e da memória. *Brazilian Journal of Kineanthropometry & Human Performance, 14*(5), 592-601.

Alain, C., & Girardin, Y. (1978). The use of uncertainty in racquetball competition. *Canadian Journal of Applied Sport Sciences, 3*, 240-243.

Alain, C., Lalonde, C., & Sarrazin, C. (1983). Decision-making and Information Processing in Squash Competition. In H. Reider, K. Bos, H. Mechling, & K. E. Reischle (Eds.), *Motorik und Bewegungsforschung* (pp. 196-202). Heidelberg Verlag Karl Hofmann Schorndorf.

Alain, C., & Proteau, L. (1977). Perception of objective probabilities in motor performance. In B. Kerr (Ed.), *Human Performance and Behaviour*. Banff, Alberta.

Alain, C., & Proteau, L. (1980). Decision making in sport. *Psychology of motor behavior and sport*, 465-477.

Alain, C., Sarrazin, C., & Lacombe, D. (1986). The use of subjective expected values in decision making in sport. In D. M. Landers (Ed.), *Sport and elite performers.* Champaign, IL: Human Kinetics.

Avilés, C., Benguigui, N., Beaudoin, E., & Godart, F. (2002). Developing early perception and getting ready for action on the return of serve. *ITF Coaching & Sport Science Review, 28*(6), 8.

Avilés, C., Navia, J. A., Ruiz, L. M., & de Quel, Ó. M. (2018). Do expert tennis players actually demonstrate anticipatory behavior when returning a first serve under representative conditions? A systematic review including quality assessment and methodological recommendations. *Psychology of Sport and Exercise, 43,* 16-26. doi:10.1016/j.psychsport.2018.12.015

Baker, J., Farrow, D., Elliott, B., & Anderson, J. (2009). The influence of processing time on expert anticipation. *International Journal of Sport Psychology, 40*(4), 476-488.

Bartlett, F. C. (1947). The Measurement Of Human Skill. *British Medical Journal, 1*(4510), 835-838. doi:10.1136/bmj.1.4510.835

BBC Sport. (2008). Tennis skills: Player tactics. Retrieved from news.bbc.co.uk/sport2/hi/tennis/skills/5337508.stm

Bennie, A., & O'Connor, D. (2012). Coach-athlete relationships: A qualitative study of professional sport teams in Australia. *International Journal of sport and health Science, 10*, 58-64.

Broadbent, D. P., Ford, P. R., O'Hara, D. A., Williams, A. M., & Causer, J. (2017). The effect of a sequential structure of practice for the training of perceptual-cognitive skills in tennis. *PloS one, 12*(3), e0174311.

Cañal-Bruland, R., Filius, M. A., & Oudejans, R. R. D. (2015). Sitting on a Fastball. *Journal of Motor Behavior, 47*(4), 267-270. doi:10.1080/00222895.2014.976167

Cañal-Bruland, R., & Mann, D. L. (2015). Time to broaden the scope of research on anticipatory behavior: A case for the role of probabilistic information. *Frontiers in Psychology, 6*(OCT). doi:10.3389/fpsyg.2015.01518

Carpenter, R. H. (1988). *Movements of the Eyes, 2nd Rev*: Pion Limited.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive psychology, 4*(1), 55-81.

Cotterill, S., Breslin, G., & Weston, N. (2016). *Sport and exercise psychology: practitioner case studies*: John Wiley & Sons.

Crespo, M., & Miley, D. (1998). *ITF advanced coaches manual*: International Tennis Federation.

Crognier, L., & Féry, Y.-A. (2005). Effect of tactical initiative on predicting passing shots in tennis. *Applied Cognitive Psychology, 19*(5), 637-649. doi:10.1002/acp.1100

Cross, R., & Pollard, G. (2009). Grand Slam men's singles tennis 1991-2009 Serve speeds and other related data. *Coaching & Sport Science Review, 49*, 8-10.

De Groot, A. D. (1965). *Thought and choice in chess*. The Hague, NL: Mouton.

Dicks, M., Button, C., & Davids, K. (2010a). Availability of advance visual information constrains association-football goalkeeping performance during penalty kicks. *Perception, 39*(8), 1111-1124.

Dicks, M., Button, C., & Davids, K. (2010b). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics, 72*(3), 706-720.

Endsley, M. R., & Smith, R. P. (1996). Attention distribution and decision making in tactical air combat. *Human Factors, 38*(2), 232-249.

Farrow, D. (2018, 23/1/2018). Workrate, clutch and serve - how Federer and Nadal win Australian Opens.   Retrieved from https://theconversation.com/workrate-clutch-and-serve-how-federer-and-nadal-win-australian-opens-90523

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception-action coupling affect natural anticipatory performance? *Perception, 32*(9), 1127-1139.

Farrow, D., & Abernethy, B. (2015). Expert anticipation and pattern perception *Routledge handbook of sport expertise* (pp. 35-47). New York, NY, US: Routledge/Taylor & Francis Group.

Farrow, D., Abernethy, B., & Jackson, R. (2005). Probing expert anticipation with the temporal occlusion paradigm: experimental investigations of some methodological issues. *Motor Control, 9*(3), 330-349.

Farrow, D., & Reid, M. (2012). The contribution of situational probability information to anticipatory skill. *Journal of Science and Medicine in Sport, 15*, 368-373. doi:10.1016/j.jsams.2011.12.007

Farrow, D., Reid, M., Buszard, T., & Kovalchik, S. (2018). Charting the development of sport expertise: challenges and opportunities. *International Review of Sport and Exercise Psychology*, *11*(1), 238-257.

Filipcic, A., Leskosek, B., & Filipcic, T. (2017). Split-Step Timing of Professional and Junior Tennis Players. *Journal of Human Kinetics, 55*(1), 97-105.

Gatto, L. (2018). Roger Federer explains why he, Rafael Nadal, Djokovic are so good. Retrieved from https://www.tennisworldusa.org/tennis/news/Roger_Federer/60768/roger-federer-explains-why-he-rafael-nadal-djokovic-are-so-good/

Giampaolo, F., & Levey, J. (2013). *Championship tennis*. Champaign, IL: Human Kinetics.

Gibson, J. J. (2014). *The ecological approach to visual perception: classic edition*: Psychology Press.

Goulet, C., Bard, C., & Fleury, M. (1989). Expertise differences in preparing to return a tennis serve: A visual information processing approach. *Journal of sport and Exercise Psychology, 11*(4), 382-398.

Gray, R. (2002a). Behavior of College Baseball Players in a Virtual Batting Task. *Journal of Experimental Psychology. Human Perception & Performance, 28*(5), 1131. doi:10.1037/0096-1523.28.5.1131

Gray, R. (2002b). “Markov at the Bat”: A model of cognitive processing in baseball batters. *Psychological Science, 13*(6), 542-547.

Gray, R. (2015). Movement automaticity in sport *Routledge handbook of sport expertise* (pp. 100-109). New York, NY, US: Routledge/Taylor & Francis Group.

Gray, R., & Cañal-Bruland, R. (2018). Integrating visual trajectory and probabilistic information in baseball batting. *Psychology of Sport and Exercise, 36*, 123-131. doi:10.1016/j.psychsport.2018.02.009

Gredin, N. V., Bishop, D. T., Broadbent, D. P., Tucker, A., & Williams, A. M. (2018). Experts integrate explicit contextual priors and environmental information to improve anticipation efficiency. *Journal of Experimental Psychology: Applied*. doi:10.1037/xap0000174

Hagemann, N., & Memmert, D. (2006). Coaching anticipatory skill in badminton: Laboratory versus field-based perceptual training. *Journal of Human Movement Studies, 50*(6), 381-398.

Hagemann, N., Strauss, B., & Cañal-Bruland, R. (2006). Training perceptual skill by orienting visual attention. *Journal of sport and Exercise Psychology, 28*(2), 143-158.

Hardy, L., Barlow, M., Evans, L., Rees, T., Woodman, T., & Warr, C. (2017). Great British medalists: Psychosocial biographies of Super-Elite and Elite athletes from Olympic sports. *Progress in Brain Research*.

Huys, R., Cañal-Bruland, R., Hagemann, N., Beek, P. J., Smeeton, N. J., & Williams, A. M. (2009). Global information pickup underpins anticipation of tennis shot direction. *Journal of Motor Behavior, 41*(2), 158-171.

International Tennis Federation. (2019). Technical centre - Line Calling. Retrieved from https://www.itftennis.com/technical/technical-centre/line-calling.aspx

Jackson, R. C., & Mogan, P. (2007). Advance Visual Information, Awareness, and Anticipation Skill. *Journal of Motor Behavior, 39*(5), 341-351.

Knight, G., & O'Donoghue, P. (2012). The probability of winning break points in Grand Slam men's singles tennis. *European Journal of Sport Science, 12*(6), 462-468.

Kovacs, M., & Ellenbecker, T. (2011). An 8-stage model for evaluating the tennis serve: implications for performance enhancement and injury prevention. *Sports Health, 3*(6), 504-513.

Kovalchik, S., & Spence, G. (2016). AO Leaderboard - Forehand speeds. Retrieved from on-the-t.com/2016/11/26/aoleaderboard-forehand-speed/

Kredel, R., Vater, C., Klostermann, A., & Hossner, E.-J. (2017). Eye-Tracking Technology and the Dynamics of Natural Gaze Behavior in Sports: A Systematic Review of 40 Years of Research. *Frontiers in Psychology, 8*, 1845.

Kuznetsova, A., Brockhoff, P., & Christensen, R. (2017). lmerTest Package: Tests in Linear Mixed Effects Models (Version 13): Journal of Statistical Software. Retrieved from http://doi.org/10.18637/jss.v082.i13

Le Runigo, C., Benguigui, N., & Bardy, B. G. (2010). Visuo-motor delay, information–movement coupling, and expertise in ball sports. *Journal of Sports Sciences, 28*(3), 327-337.

Loffing, F., & Cañal-Bruland, R. (2017). Anticipation in sport. *Current opinion in psychology, 16*, 6-11.

Loffing, F., & Hagemann, N. (2014). On-Court Position Influences Skilled Tennis Players' Anticipation of Shot Outcome. *Journal of Sport & Exercise Psychology, 36*(1), 14-26. doi:10.1123/jsep.2013-0082

Loffing, F., Stern, R., & Hagemann, N. (2015). Pattern-induced expectation bias in visual anticipation of action outcomes. *Acta Psychologica, 161*, 45-53. doi:10.1016/j.actpsy.2015.08.007

Mann, D., Williams, M., Ward, P., & Janelle, C. M. (2007). Perceptual-Cognitive Expertise in Sport: A Meta-Analysis. *Journal of Sport & Exercise Psychology, 29*(4), 457-478.

Mann, D. L., Schaefers, T., & Canal-Bruland, R. (2014). Action preferences and the anticipation of action outcomes. *Acta Psychologica, 152*, 1-9. doi:10.1016/j.actpsy.2014.07.004

McPherson, S. L. (1993). The influence of player experience in problem solving during batting preparation in baseball. *Journal of Sport & Exercise Psychology, 15*(3), 304-325. doi:10.1123/jsep.15.3.304

McPherson, S. L., & Vickers, J. N. (2004). Cognitive control in motor expertise. *International Journal of Sport and Exercise Psychology, 2*(3), 274-300.

McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual–cognitive processes during a simulated anticipation task. *British Journal of Psychology, 102*(3), 519-534.

Mishler, E. G. (1986). The analysis of interview-narratives *Narrative psychology: The storied nature of human conduct.* (pp. 233-255). Westport, CT, US: Praeger Publishers/Greenwood Publishing Group.

Müller, S., & Abernethy, B. (2012). Expert Anticipatory Skill in Striking Sports: A Review and a Model. *Research Quarterly for Exercise and Sport, 83*(2), 175-187.

Müller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *The Quarterly journal of experimental psychology, 59*(12), 2162-2186. doi:10.1080/0264290600576595

Murphy, C. P., Jackson, R. C., Cooke, K., Roca, A., Benguigui, N., & Williams, A. M. (2016). Contextual information and perceptual-cognitive expertise in a dynamic, temporally-constrained task. *Journal of Experimental Psychology: Applied, 22*(4), 455.

Murphy, C. P., Jackson, R. C., & Williams, A. M. (2019). Contextual information and its role in expert anticipation *Anticipation and Decision Making in Sport*. London, UK: Routledge.

Navia, J. A., Van Der Kamp, J., & Ruiz, L. M. (2013). On the use of situation and body information in goalkeeper actions during a soccer penalty kick. *International Journal of Sport Psychology, 44*(3), 234-251.

O'Donoghue, P. (2012). Break points in Grand Slam men's singles tennis. *International Journal of Performance Analysis in Sport, 12*(1), 156-165. doi:10.1080/24748668.2012.11868591

Panchuk, D., & Vickers, J. N. (2009). Using spatial occlusion to explore the control strategies used in rapid interceptive actions: Predictive or prospective control? *Journal of Sports Sciences, 27*(12), 1249-1260.

Panchuk, D., Vine, S., & Vickers, J. N. (2015). Eye tracking methods in sport expertise *Routledge handbook of sport expertise* (pp. 202-213). New York, NY, US: Routledge/Taylor & Francis Group.

Paull, G., & Glencross, D. (1997). Expert perception and decision making in baseball. *International Journal of Sport Psychology, 28*(1), 35-56.

Phillips, E., Davids, K., Renshaw, I., & Portus, M. (2010). Expert performance in sport and the dynamics of talent development. *Sports medicine, 40*(4), 271-283.

Pitney, W. A., & Parker, J. (2001). Qualitative inquiry in athletic training: principles, possibilities, and promises. *Journal of Athletic Training, 36*(2), 185.

R Core Team. (2017). R: A language and environment for statistical computing: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

Reid, M., Morgan, S., & Whiteside, D. (2016). Matchplay characteristics of Grand Slam tennis: implications for training and conditioning. *Journal of Sports Sciences*, 1-8.

Reid, M., Whiteside, D., & Elliott, B. (2011). Serving to different locations: set-up, toss, and racket kinematics of the professional tennis serve. *Sports Biomechanics, 10*(4), 407-414.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of sport and Exercise Psychology, 35*(2), 144-155.

Runswick, O. R., Roca, A., Williams, A. M., McRobert, A. P., & North, J. S. (2018). The temporal integration of information during anticipation. *Psychology of Sport and Exercise, 37*, 100-108.

Runswick, O. R., Roca, A., Williams, A. M., McRobert, A. P., & North, J. S. (2019). Why do bad balls get wickets? The role of congruent and incongruent information in anticipation. *Journal of Sports Sciences, 37*(5), 537-543.

Schläppi-Lienhard, O., & Hossner, E. J. (2015). Decision making in beach volleyball defense: Crucial factors derived from interviews with top-level experts. *Psychology of Sport and Exercise, 16*(P1), 60-73. doi:10.1016/j.psychsport.2014.07.005

Schlink, L. (2017, June 21 2017). Kokkinakis and Thompson defeat Milos Raonic and Andy Murray at Queen's. *Herald Sun*. Retrieved from http://www.heraldsun.com.au/sport/tennis/thanasi-kokkinakis-defeats-milos-raonic-76-75-76-108-in-aegon-championships/news-story/08190944a6d49bc53a0ae668ed97045f

Singer, R. N., Cauraugh, J. H., Chen, D., Steinberg, G. M., & Frehlich, S. G. (1996). Visual search, anticipation, and reactive comparisons between highly-skilled and beginning tennis players. *Journal of Applied Sport Psychology, 8*(1), 9-26.

Sparrow, W., & Sherman, C. (2001). Visual expertise in the perception of action. *Exercise and sport sciences reviews, 29*(3), 124-128.

Stern, R. (2018). *Contextual cues and anticipation.* University of Kassel.

Stern, R., Loffing, F., & Hagemann, N. (2016). *Patterns in previous event sequences influence anticipation of serves in tennis*. Paper presented at the NASPSPA 2016

Conference, Montreal, Quebec, Canada. http://naspspa.com/wp-content/uploads/2016/06/2016-NASPSPA-Abstract-Supplement-6-16-16.pdf

Straus, A., & Corbin, J. (1998). Basics of qualitative research: Techniques and procedures for developing grounded theory: Thousand Oaks, CA: Sage.

Takeuchi, T., & Inomata, K. (2009). Visual search strategies and decision making in baseball batting. *Perceptual & Motor Skills*, *108*(3), 971-980.

Triolet, C., Benguigui, N., Le Runigo, C., & Williams, A. M. (2013). Quantifying the nature of anticipation in professional tennis. *Journal of Sports Sciences*, *31*(8), 820-830.

Van der Kamp, J., & Renshaw, I. (2015). Information-movement coupling as a hallmark of sport expertise *Routledge handbook of sport expertise* (pp. 50-63). New York, NY, US: Routledge/Taylor & Francis Group.

Van der Kamp, J., Rivas, F., Van Doorn, H., & Savelsbergh, G. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology*, *39*(2), 100.

Vickers, J. N. (2007). *Perception, cognition, and decision training: The quiet eye in action*: Human Kinetics.

Ward, P., & Williams, A. M. (2003). Perceptual and cognitive skill development in soccer: The multidimensional nature of expert performance. *Journal of sport and Exercise Psychology*, *25*(1), 93-111.

Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion perception in tennis. *Research Quarterly for Exercise & Sport*, *73*(1), 107-112.

Wei, X., Lucey, P., Morgan, S., & Sridharan, S. (2013). *Sweet-spot: Using spatiotemporal data to discover and predict shots in tennis.* Paper presented at the 7th Annual MIT Sloan Sports Analytics Conference, Boston, MA.

Weissensteiner, J., Abernethy, B., & Farrow, D. (2009). Towards the development of a conceptual model of expertise in cricket batting: A grounded theory approach. *Journal of Applied Sport Psychology, 21*(3), 276-292.

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. New York, NY, USA: Springer-Verlag.

Wickham, H., Francois, R., Henry, L., & Muller, K. (2016). dplyr: A grammar of data manipulation. R package version 0.5.0. Retrieved from https://CRAN.R-projecy.org/package=readr

Williams, A., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport, 69*(2), 111-128.

Williams, A. M. (2009). Perceiving the intentions of others: how do skilled performers make anticipation judgments? *Progress in Brain Research, 174*, 73-83.

Williams, A. M., Huys, R., Cañal-Bruland, R., & Hagemann, N. (2009). The dynamical information underpinning anticipation skill. *Human Movement Science, 28*(3), 362-370.

Williams, A. M., Janelle, C. M., & Davids, K. (2004). Constraints on the search for visual information in sport. *International Journal of Sport and Exercise Psychology, 2*(3), 301-318.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Anticipation skill in a real-world task: measurement, training, and transfer in tennis. *Journal of Experimental Psychology: Applied, 8*(4), 259.

Williams, M., & Davids, K. (1995). Declarative Knowledge in Sport: A By-Product of Experience or a Characteristic of Expertise? *Journal of Sport & Exercise Psychology*, *17*(3), 259-275.

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Appendix A: Information to participants (Chapter 3)

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled "A qualitative examination of the interaction of anticipatory information sources used by professional tennis players".

This project is being conducted by a student researcher, Georgina Vernon as part of a larger PhD study at Victoria University under the supervision of Damian Farrow from The Institute of Health and Sport.

Project explanation

The aim of this project is to interview past professional tennis players about their return of serve behaviours and decision-making. The rationale behind this study is to determine the real-world factors that contribute to tennis players decision-making abilities when returning serve. This study is part of a larger PhD study which aims to investigate the influence of contextual and perceptual information in return of serve decision-making in tennis.

What will I be asked to do?

- Participants will be asked to conduct a one-on-one interview with the student researcher about their return of serve abilities during their professional playing career.
- There will be a set of questions which the interview will follow, however, by nature, the interviews will aim to be semi-structured to allow for free-flowing conversation and discussion of ideas.
- The interviews should take no longer than 60 minutes.
- The interviews will be conducted in a private room to avoid disruption, and to provide privacy to the participant and their responses.
- The student researcher will audio record the interview, which will be digitally stored, and password protected.

What will I gain from participating?

- There will be no financial reimbursement or incentive to persuade potential participants to participate in the interviews.
- You may find the project interesting, and be happy to answer interview questions to contribute your knowledge and beliefs about return of serve decision-making to research.
- You may benefit from the results of the interviews once they are complete, and will provide helpful information to tennis players and coaches.

How will the information I give be used?

- The information will be used as part of Georgina Vernon’s larger PhD study.
- The information will also be used to contribute to research into decision-making in tennis in peer-reviewed published journals.
- The information given to us by you, will not be used in any way other than the ways outlined in this information sheet.

What are the potential risks of participating in this project?

- There are no physical or social risk involved in this study
- There is a small psychological risk involved in this study which may be attributed to you not being comfortable to discuss the questions posed to you, or that the questions may address shortcomings of your playing career. In this instance, we are able to direct you to VU research psychologist, Dr. Harriet Speed, for any consultations if needed.

How will this project be conducted?

- The project will be conducted as a one-on-one 60-minute interview with the student researcher.
- The interview will comprise of a set of questions which will provide the outline for a semi-structured discussion about your opinions and beliefs about decision-making in tennis return of serves.
- The interviews will be voice recorded, and answers and participant information will be kept anonymous.
- The interviews will be arranged to be conducted at a time and place to suit each individual participant to ensure privacy, and that there is enough time to address all issues raised during the interview.

Who is conducting the study?

Victoria University and Tennis Australia are joint collaborators on this project.

The Chief Investigator is Damian Farrow who may be contacted on 0408 445 701 or by email at Damian.Farrow@vu.edu.au.

The student researcher is Georgina Vernon and may also be contacted on 0427 683 347 or by email at georgina.vernon@live.vu.edu.au.

Any queries about your participation in this project may be directed to the Chief Investigator listed above. If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Appendix B: Consent form (Chapter 3)

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study into decision-making in tennis. This project aims to investigate the extent of the influence of contextual information on player return of serve behaviour and decision-making in a naturalistic setting. To achieve this, we wish to conduct questionnaire interviews with current or former professional tennis players to gain insight about their behaviours and decision-making ability when returning serve during matches of their professional career. There are minimal risks associated with this study, however, there is a low psychological risk involved. If you experience any difficulty during or after the interview with the researchers, you are able to contact the Victoria University psychologist, Dr. Harriet Speed.

CERTIFICATION BY PARTICIPANT

I, ____

of ____

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study: "A qualitative examination of the interaction of anticipatory information sources used by professional tennis players" being conducted at Victoria University by Damian Farrow

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Georgina Vernon

and that I freely consent to participation involving the below mentioned procedures:

- Conduct an interview with the researchers about my professional tennis playing career,
- Answer all questions posed to me by the interviewers to the best of my ability,
- Am able to end the interview at any time without providing a reason to the researchers,
- Agree that the interviews will take around 60 minutes to complete.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher
Damian Farrow
0408 445 701

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Appendix C: Information to participants (Chapter 5)

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled 'Determining the interaction of anticipation sources during the return of serve in tennis'.

This project is being conducted by a student researcher, Georgina Vernon as part of a larger PhD study at Victoria University under the supervision of Professor Damian Farrow from The Institute of Health and Sport.

Project explanation

The aim of this project is to investigate how professional tennis players use anticipatory information sources when returning serve. The rationale behind this study is to determine the priority of these information sources and how this contributes to tennis players' decision-making processes when returning serve. This study is part of a larger PhD study which aims to investigate the influence of situational and biomechanical information in return of serve decision-making in tennis.

What will I be asked to do?

- Participants will be asked to complete a number of return of serve trials from both sides of a tennis court.
- There will be 2 sets of serve trials to return. These sets will consist of 5 trial games of 8 serves each for a total of 40 trials per set and 80 trials in total. You will have 30 seconds rest in between each serve trial and 90 seconds rest between each trial game.
- You will be required to wear a set of mobile gaze glasses that will track your eye movements. The student researcher will demonstrate how these are to be worn. They should not impede on your ability to complete the trials. A familiarisation period will occur prior to the start of the experiment for you to become used to the glasses.
- Ball and participant tracking will be recorded using the Playsight camera system.
- The experiment should take no longer than 90 minutes to complete, including the set up of your equipment, a self-directed warm-up (which should replicate what you would typically complete prior to a training session or match), and rest periods in between points and games.
- The experiment will be conducted on an outdoor tennis court at the Queensland Tennis Centre, 190 King Arthur Terrace, Tennyson, QLD, 4105.
- Data will be collected using the Playsight system, and from the mobile gaze glasses you will be asked to wear. All data will be de-identified and stored in a password protected database.

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

- If at any time, you wish to end the experiment, you are free to do so without any explanation or reasoning. Any data collected to that point will be destroyed and not used in the final results of the study.

What will I gain from participating?

- There will be no financial reimbursement or incentive to persuade participants to participate in the study.
- You may find the project interesting, and be happy to contribute your specific skill set about return of serve decision-making to research.
- You may benefit from the results of the project once they are complete, and it will provide helpful information to tennis players and coaches.

How will the information I give be used?

- The information will be used as part of Georgina Vernon's larger PhD study.
- The information will also be used to contribute to research into decision-making in tennis in peer-reviewed published journals.
- The information given to us, by you will not be used in any way other than the ways outlined in this information sheet.

What are the potential risks of participating in this project?

- There are no psychological or social risks involved in this study.
- As participants will be required to undertake a tennis-specific task, there is a small chance of an acute musculoskeletal injury to the participant during the task. Therefore, all participants are required to submit a medical clearance, which states they are free from injury before the start of the experiment. In addition to this, participants will complete a 10-minute, self-directed warm-up, which should include both physical and technical warm-up and replicate what they would do before a training session or a match. Participants will also use their own tennis equipment during the experiment.
- All researchers conducting the experiment are trained in emergency first aid, and are able to provide first aid assistance the participants should they sustain an acute injury during the experiment. In the event of any injury during the task, the trials will immediately end and the participants will be referred to their General Practitioner or Sports Medicine Doctor for further assistance.

How will this project be conducted?

- Participants will return 2 sets of 40 serve trials for a total of 80 trials.
- The 2 sets will be grouped into 5 games of 8 serve trials per game.
- 30 seconds rest will be given in between each return of serve trial, 90 seconds rest period will be given after each game, and 5 minutes rest will be given between the sets.
- Participants will complete their own self-directed warm-up prior to the start of the trials
- Participants will be required to use their own tennis equipment to complete the trials
- Participants will be provided with mobile eye tracking glasses, which must be worn, along with the battery pack for the glasses. This should not interfere with the participant's ability to complete the trials.
- Prior to the start of each serve scenario, participants will be shown an example game score, which will indicate which side of the court to return serve.

- Prior to starting each set of trials, you will be given the probability of the direction of serve occurring at certain scenarios.
- Data will be collected using the Playsight enabled tennis court to track ball and participant movement behaviour, as well as eye-gaze movements. All data will be de-identified and stored in a password-protected database to protect participant's anonymity.
- The experiment should take no longer than 90 minutes to complete.
- The experiment will be arranged for a time to suit each individual participant without interfering with his or her personal schedules.

Who is conducting the study?

Victoria University and Tennis Australia are joint collaborators on this project.

The Chief Investigator is Professor Damian Farrow who may be contacted on 0408 445 701 or by email at Damian.Farrow@vu.edu.au.

The student researcher is Georgina Vernon and may also be contacted on 0427 683 347 or by email at georgina.vernon@live.vu.edu.au.

Associate investigators are: Dr Stephanie Kovalchik (SKovalchik@Tennis.com.au) and Dr Machar Reid (MReid@tennis.com.au).

Any queries about your participation in this project may be directed to the Chief Investigator listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Appendix D: Consent form (Chapter 5)

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study investigating decision-making in tennis. This project aims to investigate what types of information professional tennis players use when anticipating a serve. To achieve this, we wish to conduct a series of return of serve trials with you to assess the priority of information. There are minimal risks associated with this study; however, there is a low physical risk involved in the experimental trials whereby there is a small possibility of sustaining an acute musculoskeletal injury. To lower the risk of this, we ask you to provide us with medical clearance from a Sports Doctor clearing you of any underlying injury prior to the start of the experiment. Medical assistance will be provided should any such type of injury occur.

CERTIFICATION BY PARTICIPANT

I, ____

of ____

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:

"Determining the interaction of anticipation sources during the return of serve in tennis" being conducted at Victoria University by: Professor Damian Farrow, Dr Machar Reid, Dr Stephanie Kovalchik and student researcher Georgina Vernon.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Georgina Vernon

and that I freely consent to participation involving the below mentioned procedures:

- Conduct 80 return of serve trials as outlined in the provided information sheet,
- Complete all tasks given to me to the best of my ability,
- Am able to end the task at any time without providing a reason to the researchers,
- Agree that the task will take around 90 minutes to complete.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the Chief Investigator Professor Damian Farrow:

Ph: 0408 445 701

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.