# It's out of this world: Exploring the use of virtual reality technology for enhancing perceptual-cognitive skill in tennis

By

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# Student Declaration

I, Peter Le Noury, declare that the PhD thesis entitled ‘It’s out of this world: Exploring the use of virtual reality for enhancing the perceptual-cognitive skill of tennis players’ 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: Date: 14/01/2021

# Abstract

The aim of this thesis was to increase our understanding of how virtual reality (VR) can be applied to assess and train pattern recognition and decision-making skill in sport, specifically the sport of tennis. There has been a growing interest in using VR for training perceptual-cognitive skill in sport; however, for VR training to effectively simulate real-world performance, it must recreate the contextual information and movement behaviours present in the real-world environment. Although it is well established that skilled performers can effectively use prior sources of contextual information to enhance anticipation performance compared to lesser skilled performers, little is known about the relative difficulty of identifying different types of contextual information and the requisite regularity of patterns to influence anticipation. Moreover, there is a lack of research assessing the effect of using more representative experimental tasks on anticipation and decision-making behaviour. Therefore, study one of this thesis assessed the representativeness of VR for simulation of tennis performance. Participants included 28 skilled tennis players aged between 12 to 17 years (M = 14.4, SD = 1.6). Participants sense of presence was assessed VR, and participants movement behaviours were compared when playing tennis in VR and real-world environments. The results showed that when performing groundstrokes, participants frequently used the same stance in VR as they did in the real-world condition and experienced a high sense of presence. Study two of this thesis used VR to assess the ability of 28 skilled tennis players aged between 13 and 18 years (M = 15.7, SD = 1.4) to identify two specific serving patterns being used by opponents. These serving patterns related to the opponent's action tendencies, with a wide serve pattern connected to the side of the court the point started from (advantage side), and a tee serve pattern connected to the point score in the game (0-0). Participants were assessed on their ability to identify serving patterns by controlling how frequently patterns occurred during matches. Results revealed that patterns need to occur at high frequencies (100% of the time) during matches for skilled juniors to utilise this information to inform their anticipation responses. Study three of this thesis used VR to train 5 skilled tennis players aged between 14 and 18 years (M = 16, SD = 1.67) to utilise patterns of play when they occur at lower frequencies (80% of the time). Additionally, the influence of explicit instructions and no-instruction on learning and performance under pressure was assessed. It was found that exposure to patterns coupled with explicit instructions resulted in faster changes to response time and response accuracy performance, compared to no-instruction learning. Furthermore, instructions during training did not affect performance under pressure conditions. Overall, this thesis extends the perceptual-cognitive skill literature through its use of VR technology and methods of assessing task representativeness. Moreover, this thesis helps guide the design of future perceptual-cognitive skill research through the manipulation of contextual information in the VR environment and use of more implicit and explicit instructional methods to train decision-making performance.

# Acknowledgements

"The journey of 1000 miles begins with a single step".

Lao Tzu

This quote resonates with me as I think back to the humble beginnings of this long, exciting and challenging journey of completing a PhD. My first step as a PhD student was a tentative one. I feared the unknown and questioned whether I was capable of overcoming the many challenges I knew would be thrown my way. As I contemplate my first steps as a PhD student, I am humbled by how far I've come throughout this life changing experience. However, I certainly could not have done it alone. I owe many thanks to the people that have supported and guided me throughout this journey and made it such a memorable experience.

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## List of publications and presentations

Sections of this thesis have been published (or submitted for publication) and/or presented at relevant scientific and coaching conferences.

### Peer reviewed publications

Sections of Chapter 2**: Le Noury, P**., Farrow, D., Buszard, T., & Reid, M. (2019). Instructional approaches for developing anticipation and decision making in sport. In *Anticipation and decision making in sport*, Routledge, 306-326.

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Chapter 4: **Le Noury, P**., Buszard, T., Reid, M., & Farrow, D. (in review). Can skilled junior tennis players identify and utilise contextual information that occurs at different frequencies? Exploring anticipatory behaviour using a virtual reality tennis simulation. *Psychology of Sport and Exercise*.

### Conference presentations

**Le Noury, P.** (2018). “The use of virtuality technology for enhancing perceptual-cognitive skill in tennis”. Presented at the 2018 Tennis Australia National Coaching Workshop, Canberra, Australia.

**Le Noury, P.** (2018). “It’s out of this world: Assessing the representatives of VR tennis for assessing and training perceptual-cognitive skill”. Presented at the Australasian Skill Acquisition Network (ASAN) Conference, 2018.

**Le Noury, P.** (2018). “The use of virtuality technology for enhancing perceptual-cognitive skill in tennis”. Presented at the 2018 Grand slam Coaches Conference, 2018.

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# Chapter 1: Introduction and overview of thesis

## 1.1 Introduction

For three years running, American tennis player Andre Agassi (arguably the best returner the game of tennis has ever seen), agonised over how he could overcome the notoriously damaging serve of famous German tennis player Boris Becker to finally score victory over him. After countless hours of watching replays of Becker's serve in action, Agassi made a small, yet significant observation about Becker's serving action that would see him win eleven of the next twelve matches against him. Agassi realised that just before Becker performed his ball toss on serve he would stick his tongue out (that's right his tongue). If the serve was going out wide his tongue went to the left, and if the serve was being directed down the middle of the service box his tongue stayed central. Agassi's extremely subtle observation helps to describe the unique ability of expert athletes to identify and utilise contextual information from their opponent's behavioural tendencies to gain an advantage over them (in this case, successfully anticipate Becker's serve direction). This attribute of expert performers is part of an overarching term the sports literature refers to as perceptual-cognitive skill, or "the ability to identify and acquire environmental information for integration with existing knowledge such that appropriate responses can be selected and executed" (D. T. Y. Mann, Williams, Ward, & Janelle, 2007, p. 457). Perceptual-cognitive skill is considered a prerequisite for achieving expertise in a wide range of sports (Williams, 2000), but particularly those that require precise execution of motor skills under extreme time pressure (e.g. tennis) (Muller & Abernethy, 2012).

In past decades, research has established that skilled players in interceptive sports such as tennis, are faster and more accurate at anticipating opponents actions during time constrained situations (e.g. returning serve), compared to less skilled players. This can be attributed to their ability to identify and utilise their opponents postural cues to predict action outcomes, as well as make use of contextual information, such as their opponents action tendencies or habits in specific situations (e.g. serving wide when the point score is 30-30 in tennis). A large body of research has shown that skilled players fixate on postural cues, including their opponents ball toss, racquet and swing arm to facilitate anticipation. Yet, in contrast to the abundance of research investigating the use of postural cues (and the success of Andre Agassi against Boris Becker's serve), the use of contextual information has been rarely investigated. However, recent work has shown that contextual information, including the action tendencies of opponents (Mann, et al., 2014), the positioning of players on the court or field (Loffing et al., 2014; Murphy et al., 2016), the order of action sequences (Murphy et al., 2018) and action tendencies linked to the score in a match (Farrow & Reid, 2012) significantly contributes to successful anticipation performance.

Similar to the methods used to investigate the contribution of postural cue information to anticipation, the majority of research examining the contribution of contextual information has relied on video-based occlusion tasks that do not adequately represent the perception-action couplings that are present in the performance environment. Therefore, this means that most previous studies have only partly reproduced the task they are designed to represent, thereby compromising the validity of findings and how they explain real-world anticipatory behaviour (Pinder et al., 2011). It follows that more representative tasks need to be developed and used during anticipation research to provide greater insight into the anticipatory behaviours of skilled performers.

Building on the importance of task representativeness (Hadlow et al., 2018; Krause et al., 2018, Pinder et al., 2011), recreating testing environments that appropriately simulate perception-action cycles is essential. Equally important is allowing for these interactions to be measured or recorded to promote more natural anticipatory behaviours and uncover greater insights into anticipation expertise. Serendipitously, the emergence of VR technology has been demonstrated to have the capacity to; (1) adequately represent the perception-action couplings that exist during competition; and equally, (2) allow for contextual information to be easily manipulated. Consequently, VR has great potential for exploring how skilled performers use different types of contextual information to enhance anticipation performance. However, research is needed to assess the representativeness of VR environments for simulating real-world performance, and whether anticipation skill that is trained in the VR environment can elicit skill transfer to the competition setting.

## 1.2 Aims of this thesis

### 1.2.1 General Aims

The aim of this thesis was to increase our understanding of how VR technology can be applied to assess and train pattern recognition and decision-making skill in sport, specifically the sport of tennis. Moreover, this thesis aimed to build on the recently growing body of research concentrating on how contextual information is identified and utilised by skilled performers to enhance anticipation performance, and whether this skill can be trained using VR technology.

### 1.2.2 Specific Aims

- Examine the representativeness of a VR tennis environment for simulation of tennis performance, using measures of action fidelity and sense of presence.
- Measure the ability of skilled junior tennis players to identify two specific serving patterns related to the opponents action tendencies with a) a wide serve pattern connected to the side of the court the point was played on (advantage side of the court), and b) a tee serve pattern connected to the point score in the game (0-0).

- Use VR to train the ability of skilled junior tennis players to identify patterns of play and utilise this information to enhance anticipation and decision-making performance.
- Compare the effectivness of explicit instructions and no-instruction on learning and performance under pressure.

## 1.3 Chapter organisation

**Chapter 1** has introduced the topic of this thesis by providing a rationale for the research and describing the general and specific aims of the thesis. This chapter also outlined how the chapters will be organised throughout the thesis.

**Chapter 2** provides a review of the research encompassing the study of perceptual-cognitive skill in sport and its cognitive psychology origins. This literature review focusses on the factors that influence perceptual cognitive-skill expertise, the methods used to assess and train anticipation as well as the key issues associated with these methods, and the use of VR for simulating sport environments with the aim of assessing expertise differences and training perceptual-cognitive skill.

**Chapter 3** presents the first of three studies outlined in this thesis. To better understand how well VR technology can simulate the real-world tennis environment, study one examines the representativeness of a VR tennis environment for simulation of tennis performance. Participants movement behaviours when playing tennis in VR and the real-world were compared. Specifically, the number of steps taken and type of stance performed by participants was compared when reacting to the same ball trajectory in the VR and real-world environments. Additionally, participants sense of presence when playing tennis in VR was measured. In line with our hypothesis, the results showed that participants movement behaviours in the VR environment were highly representative of real-world tennis, and participants experienced a high sense of presence in VR. These findings illustrate that Tennis VR is able to adequately represent real-world tennis performance.

Given Tennis VR was shown to adequately represent the real-world environment, this provided a means to use this tool to assess anticipation skill in tennis. Therefore, **Chapter 4** presents study two which focuses on the use of VR to investigate the ability of skilled junior tennis players to identify and utilise contextual information linked to an opponent's serve to facilitate anticipation. Little is known about the relative difficulty of identifying different types of contextual information and the requisite regularity of patterns to influence anticipation. Therefore, study two used VR to assess the ability of skilled junior players to identify serving patterns that were linked to either the scoreboard or the side of the court the opponent served from. This study also assessed how frequently serving patterns need to occur for participants to utilise this information. We hypothesised that participants would be more successful at identifying patterns that were connected to the side of the court the opponent served from, as this pattern occurred more frequently during matches compared to patterns linked to the score. Additionally, we hypothesised that serving patterns that occurred at higher frequencies would be more easily identified compared to patterns occurring at lower frequencies. Three key findings are reported. First, a wide serve pattern that occurred 100% of the time resulted in more rapid improvements in response time. Second, participants had more difficulty explicitly identifying serving patterns that were connected to the current score, compared to identifying patterns based on the side of the court the opponent served from. Third, participants did not initiate a movement response until after the opponents' racquet-ball contact when returning serve. We conclude that contextual information needs to occur at a high frequency for skilled junior players to utilise this information.

Based on findings from study two that serving patterns need to occur 100% of the time for skilled junior players to utilise this information, **chapter 5** presents the final study of this thesis which focuses on training the ability of skilled junior players to identify and utilise a groundstroke pattern sequence that occurs at a lower frequency. Findings from the motor learning literature have found that learning via explicit instruction results in faster skill acquisition, however poorer performance under pressure. Additionally, more implicit instructional approaches have resulted in longer learning periods, however more stable performance under pressure. Therefore, study three explored the influence of different instructional approaches (i.e. no instruction vs explicit instruction) for eliciting learning and performing under pressure conditions. Using artificial intelligence (AI), a groundstroke pattern sequence was imbedded into the opponent's groundstroke tactics to create specific action tendencies. Participants could only win points in the VR task if they identified the action tendencies, learnt the pattern sequence, and utilised this information to inform decision-making behaviour (shot selections). We hypothesised that participants allocated to the no-instruction group would take longer to learn the pattern sequence compared to participants in the explicit group. However, the anticipation and decision-making performance of the no-instruction group would be maintained under pressure conditions, whereas the explicit group would see a decrease in performance under pressure. Unfortunately, due to the Covid19 pandemic there was a limited number of participants that took part in this study, therefore planned group-based analyses were not possible. Therefore, the analysis is focused on assessing performance at the individual participant level and extrapolating these findings to the original broader research aims.

The final chapter of this thesis (**Chapter 6),** provides a summary and general discussion of the studies presented and their findings. The methodological implications, practical applications and future research directions for the study of anticipation, and more broadly, the study of perceptual-cognitive skill in sport are discussed.

## 1.4 Covid19 Impact

It must be highlighted that the Covid19 pandemic in 2020 had a significant impact on the experimental design of study three of this thesis. The restrictions imposed by the Victorian government in Australia meant that I was not able to undertake the intended study design which included a minimum of 10 participants per experimental group, including a placebo and control group. Additionally, the study design included a transfer test to assess the level of skill transfer from the VR training environment to the real-world performance setting. Unfortunately, the limited funding and time left to complete this doctorate meant that I could not wait for restrictions to ease to test more participants. Therefore, what is presented in study three of this thesis is all the data that was able to be collected before the restrictions enforced by the State government halted (and has still halted) all testing.

# Chapter 2: Literature Review

## 2.1 Introduction

When spectators watch the most highly skilled athletes compete in their chosen sport, they are often in awe of how effortlessly the athletes execute highly complex skills, and how they appear to have all the time in the world. Experts competing in interceptive sports, such as tennis or invasive sports such as basketball, must process a collection of perceptual information from the environment in a short period of time to effectively execute an appropriate action (Farrow et al., 2013). For example, expert tennis players must consider their opponents court positioning, movement kinematics, behavioural tendencies, the scoreboard, his/her court positioning and the trajectory of the tennis ball when producing a successful action (Farrow & Reid, 2012). The consequential outcome of this perceptual-cognitive process can be referred to as anticipation skill, otherwise known as the ability that allows athletes to initiate a movement in response to an opponent's action or pattern of play in advance of it actually occurring. Tennis coaches have colloquially described players with strong anticipation skill as being able to move into advantageous court positions before their opponent has hit the ball, with basketball coaches describing strong anticipatory behaviour as the ability of players to seemingly know what will happen two passes ahead of time (Williams et al., 2007). Although these players may not be the fastest movers on the court, their ability to successfully predict future outcomes provides a distinct time advantage over opponents, and this can lead to superior performance (e.g., more interceptions in basketball or hitting more effective returns in tennis). Therefore, anticipation skill is deemed an essential component of expertise in sport (Williams et al., 2003).

This chapter of the thesis delves into the literature as it relates to sport expertise and describes the perceptual-cognitive processes underpinning expert athletes anticipation skill. The first section discusses the historical foundations of sport expertise and its cognitive psychology origins. The second section focuses on perceptual-cognitive skill expertise and the methods used to measure the ensuing differences in anticipation skill. Section three highlights the key issues associated with current anticipation skill measures, including the display stimuli, response methods, perception-action coupling and timing of responses. Section four highlights the most common perceptual-cognitive skill training approaches and key issues related to the representative design of these approaches. Section five discusses the use of VR for simulating the performance environment, how it can be used to train perceptual-cognitive skill, and its potential to overcome issues with current anticipation training and measurement tools. Finally, section six highlights the most common instructional approaches used in perceptual-cognitive skill training and how these approaches can impact performance.

## 2.2 A brief history of sport expertise

The emergence of the “nature versus nurture” argument first coined in 1874 by Francis Galton, described the extent to which individual differences are generated by inherited qualities (e.g., genetics), or a result of learning from ones experiences, and marked an important milestone in the human expertise debate. Since this time, disputes over whether an individual’s innate characteristics or environmental factors contribute more to individual expertise have occurred, which has taken on both political and social implications (Pinker, 2002). This issue has dominated scientific and non-scientific discussions over the past 150 years.

The notion that biology is the key determinant of individual expertise and achievement, gained significant momentum during the late 1800’s to early 1900’s with the preliminary published work of Galton (1869, 1883), William James (1890), and Lewis Terman (1925). Indeed, Terman was a major contributor to this notion, publishing his work titled *Genetic Studies of Genius* (Terman, 1925; Terman & Oden, 1947, 1959), which was one of the longest and most notable longitudinal studies ever completed. A similar notion was introduced by Fisher in 1918 termed heritability, which described a statistic used in the field of genetics to estimate the degree of variation in a phenotype trait within a population, that is due to genetic variation between individuals in that population. This statistic heritability described the degree of which the variation within a trait can be attributed to variations in genetic factors or variations in environmental factors.

During the same time period, the other side of the debate (the environmentalists), reinforced the idea that individuals are born with no innate characteristics, and that all forms of learning and behaviour result from interactions with the environment in which they live. This socialist idea is best described by Watson (1924): “Give me a dozen healthy infants and my own specified world to bring them up in, and I’ll guarantee to take anyone at random and train him to become any kind of specialist I might select – doctor, lawyer, artist…regardless of his talents, penchants, tendencies, abilities, vocations and race of his ancestors” (p.104). The past 150 years has seen an ever changing shift in opinions between a nature-based and nurture-based view on expertise and achievement.

The field of sport science, and more specifically the field of skill acquisition and sport expertise, has also seen vast shifts in theories for explaining human behaviour. Preliminary studies of skill acquisition and expertise were completed by Bryan Harter (1897, 1899), who explored learning duration effects during the skill acquisition of Morse Code. This work was significant in informing research over the next 100 years in areas including automaticity, variability, and improvements in performance over time (Lee & Swinnen, 1993). Similarly, early research studies focusing on enhancing the execution of simple motor tasks (e.g., typing, cigar rolling and mirror tracing) laid the foundations for future skill acquisition and expertise research (Newell & Rosenbloom, 1981).

### 2.2.1 Generalised motor ability hypothesis

The early 1900's saw the emergence of Spearman's G theory. This theory suggested that there was an underlying factor of intelligence that formed the foundation of which all intellectual abilities form (Spearman, 1904). This theory encouraged researchers to explore whether a similar concept could explain why certain individuals outperform others on athletic tasks. This gave rise to the generalised motor ability hypothesis, which conceptualised that, a) all motor skills are related to one another, b) a single generalised ability supports every individual ability, and c) if individuals perform well on a single motor skill they will perform well on all motor skills. During the mid-1900's, considerable research attention was given to build support for the generalised motor ability theory, hoping this could explain how some individuals perform multiple motor skills at a high level (often referred to as all-rounders). However, findings revealed very little evidence to support this theory, even when performing different forms of the same motor skill (e.g., balancing) (see Drowatzky & Zuccato, 1967). In general, the majority of evidence supported the concept that motor abilities, (as well as perceptual, cognitive and some psychological abilities) are largely independent and acquired based on the unique experiences and type of training individuals have.

### 2.2.2 Cognitive psychology and expertise research

With the overwhelming evidence rejecting the generalised theory of motor skills, researchers focused their attention on exploring the specific skills and characteristics that differ between highly skilled and novice athletes. The emerging field of cognitive psychology around this time significantly influenced the expertise research that followed (Starkes & Allard, 1993). Cognitive psychology focuses on the influence of mental processes such as attention, memory, language and perception, on the behaviour of individuals. Therefore, it was of great interest to early expertise researchers whether cognitive processes differed between expert and novice performers. Central to the progress of this area was the work examining chess expertise, that aimed to explain the performance of chess masters using a cognitive psychology paradigm (De Groot, 1965; Simon & Chase, 1973).

It was through the study of chess that researchers identified the ability to perceive patterns as a defining feature of expertise (Goldin, 1978, 1979). Key findings revealed that Grand Master chess players were more accurate at recalling the positions of pieces on a chess board, compared to less skilled players (Chase & Simon, 1973). Additionally, Grand Masters were superior at distinguishing or identifying previously seen configurations of chess pieces from new configurations, after only brief exposure to these formations (Goldin, 1978, 1979). Importantly, when pieces were randomly configured on the chess board, Grand Masters recall performance declined to that of less skilled players. This finding provided evidence that the perceptual-cognitive skill of Grand Masters, shown through their recall of structured or more game-like chess piece configurations, was not a result of an innate advantage in visual processing or memory function. Instead, it was a result of many hours of practice in which complex chess specific memory structures were developed, which allowed for superior processing, encoding, storage and retrieval of meaningful chess piece configurations.

The emerging field of cognitive psychology around this time significantly influenced the expertise research that followed. Cognitive psychology focuses on the influence of mental processes such as attention, memory, language and perception, on the behaviour of individuals. Therefore, it was of great interest to early expertise researchers whether cognitive processes differed between expert and novice performers.

Pioneering studies in sport during the 1980’s assessed the cognitive advantage in sports including field hockey and volleyball (Allard & Starkes, 1980, Starkes, 1987), and the specific qualities underpinning expert anticipation in racquet sports, such as squash and badminton (Abernethy & Russell, 1984, 1987). A range of reviews and empirical studies on expertise in sport around this time clearly indicated that expertise differences did not emerge on generalisable tests with non-sport specific stimuli, however did emerge when sport specific stimuli were provided (Abernethy, 1987; Starkes and Deakin, 1984; Starkes, 1987). Other early observations made included that expertise is context sensitive, experts are faster and more accurate at recognising patterns of play within their domain, experts have superior knowledge that is organised in a deeper and more structured form compared to novices, experts have greater knowledge of situational probabilities, experts can plan their own actions as well as anticipate their opponents actions better than novices, experts are superior perceivers of postural information, expert performance is less effortful and more automatic compared to novices which results in experts decreased capacity to self-report on many aspects of their expertise, and experts possess superior self-monitoring skills (i.e., are more aware of when they make errors).

The methods used to conduct cognitive psychology research, including the use of occlusion and verbal response methods, were deemed legitimate ways of measuring skill expertise around this time. However, the recent formation of concepts advocating the importance of movement in sport, and indeed the importance of coupling perception with representative actions, has led to a shift towards a more representative design approach when conducting sports expertise research (see Pinder et al., 2011). A more detailed discussion of this concept is seen in later sections of this literature review.

Whilst the early work of Abernethy, Starkes and others (including Ripoll, Allard and Alain), was being conducted in sport, Anders Ericcson was devising equally significant research focused on the influence of practice for explaining expert performance in domains including music and memory (e.g. Ericson, Chase & Faloon). Results demonstrated that a group of average undergraduate participants were successfully trained to recall up to 80 individual digits in a row, recited at one second intervals. In arguably his most significant and ground-breaking research, Ericcson, Krampe and Tesch-Romer (1993) developed the concept of deliberate practice, which proposed that prolonged engagement in practice that required high effort with the specific aim of improving performance over the long term (not immediate improvements), was necessary for achieving expertise (Ericson et al., 1993). Although deliberate practice was first explored in musicians, there was perhaps no domain that embraced this concept and applied it more rapidly than the sports expertise domain (see Baker & young, 2014 for a review).

Since the early 1990's, research contributions from the sports domain have made significant contributions to our understanding of human expertise more broadly, and is now recognised as a legitimate field of specialisation. More recent work has focused on issues of talent identification and development, and how to best merge current sport science and expertise knowledge into improved coaching practices (see Farrow et al. 2013, Vickers, 2007). Arguably the most explored aspect of sport expertise has been the examination of perceptual-cognitive skills, which will be discussed in the following sections.

## 2.3 Perceptual-cognitive skill expertise

One of the more impactful findings in the sport expertise literature has been that the measurement of expert performance must be sport or task specific and does not appear on generalised measures (Helsen & Starkes, 1999; Williams & Ericson, 2005). This notion has been explored in the context of anticipation skill, with some researchers suggesting that generic optometric measures (e.g., depth perception and visual equity), as well as neural processing capabilities (e.g., quickness in processing information and visual reaction time) contribute to expert performance and are key characteristics that differentiate expert and novice athletes (Blundell, 1985; Banister & Blackburn, 1931). However, the importance of general vision capabilities for enhancing sport specific anticipation skill has not been well supported in the literature (Abernethy & Wood, 2001; Schwab et al., 2011)

Key findings have demonstrated that generic visual skills such as simple reaction time, dynamic visual acuity, visual clarity and coincidence anticipation do not significantly contribute to predicting expertise in sports such as field hockey and cricket (Starkes, 1987; Mann, Abernethy, & Farrow, 2010). Indeed, the only generic visual skill thought to help predict performance for different levels of expertise is peripheral vision range in the horizontal direction, however this has been found to account for just 3% of variance, compared to 84% of variance being attributed to sport specific skills (Helson & Starkes, 1999). Collectively, the findings of studies exploring the role of general vision in sport performance have not demonstrated a strong link between the visual parameters tested and expertise in sport. This is most likely because non-sport specific tests only measure the visual reception of information, and not the sport specific, perceptual interpretation of visual information, which appears to be the most important feature that distinguishes expert and novice athletes (Abernethy & Wood, 2001).

In contrast, sport specific visual perception capabilities have been found to contribute significantly to sport expertise. Perceptual-cognitive skill can be defined as the ability to identify and acquire environmental information for integration with existing knowledge, such that appropriate responses can be selected and executed (Marteniuk, 1976). Perceptual-cognitive skills that underpin expert performance include a more efficient use of vision to scan the environment and extract the most relevant information (Williams, Ward, Smeeton, & Allen, 2004), the ability to recognise sport specific patterns of play (North, Williams, Hodges, Ward, & Ericson, 2009), and the capability to identify advanced cues from an opponent's postural movements (Williams, Ward, Knowles, & Smeeton, 2002). Moreover, expert performers can identify the likelihood of events occurring in any given situation based on refined use of situational probability information (McRobert, Ward, Eccles, & Williams, 2011). It is thought that these skills are developed through experts having more refined domain specific knowledge and memory structures, which have been built through years of experience and practice (Williams & Ward, 2007).

The development of these sport specific skills over time results in the ability to anticipate the outcome of opponent's movements, before they have been executed. Given the extreme time constraints in interceptive sports (Dicks, Button, & Davids, 2010), there is a wealth of research investigating how expert performers overcome these time constraints and circumvent information processing limitations to perform effectively (Moran, 2009). Indeed, experts have been shown to use postural cues and situational probability information to anticipate effectively, compared to their lesser skilled counterparts. However, there have been issues associated with the methods used to measure differences in anticipation skill expertise, which may affect the validity of findings and how they apply to athletes performance in the competition environment.

### 2.3.1 Utilisation of postural cues

The ability to predict outcomes based on an opponent's postural cues that occur before ball flight information becomes available has been a key discriminator between expert and lesser skilled performers (Goulet, Bard, & Fleury, 1989; Causer, Smeeton, & Williams, 2017). The common approach used to measure this difference has been to present video-based presentations of occluded movement patterns to performers', who watch the vision and register their judgments by pressing a button, using a pen and paper response or by verbally communicating their response. A number of different occlusion techniques have been used including progressive temporal occlusion, spatial occlusion and the use of point light displays. The occlusion technique has also been achieved by players viewing opponents' movements in-situ, and researchers occluding performers vision using liquid crystal occlusion goggles. Although these approaches are relatively easy to administer and can provide tight experimental control (key advantages of the occlusion method), concerns have been raised which limit the generalisability of findings using these techniques (see Abernethy et al., 1993). Below is a description of the various occlusion methods and their key findings related to postural cue utilisation. Some limitations associated with these methods will be offered in the description of each occlusion technique, however a more detailed description of these limitations will be provided in the later sections of the review.

#### *2.3.1.1 Progressive temporal occlusion*

The progressive temporal occlusion method is used to establish *'when'* performers are able to identify anticipatory information during a movement sequence. Using this technique, vision is occluded at various time points relative to a key event occurring (e.g. racquet-ball contact during a tennis serve motion). Anticipation is measured at each time point to establish differences between expert and novice athletes. Results from these measures have typically found that experts are superior at predicting event outcomes based on information presented earlier in the opponent's movement sequence (Abernethy & Russel, 1987; Farrow & Abernethy, 2003). This ability is thought to give skilled performers additional time to execute an action response, which is particularly helpful during extreme time constrained situations.

However, temporally occluding vision forces players to make uncoupled anticipation judgments and rely solely on the limited information seen up to the point of occlusion, thereby reducing the representativeness of the task. Therefore, the results from temporally occluded tasks may not be the most accurate representation of anticipatory behaviours seen in the competition environment.

#### *2.3.1.2 Point light displays*

Point light displays show the kinematic sequence of movements by displaying points of light at the location of critical joint centres. These displays remove all facial and figural information, ensuring that only essential kinematic information shown via points of light is available to use for anticipation. This technique offers a way to explore how anticipation skill responds to manipulations of movement kinematics, as joint centres can be manipulated, therefore changing the appearance of the movement pattern. Results have demonstrated the expert advantage of using raw kinematic information to anticipate upcoming actions effectively (Abernethy et al., 2001) and provides evidence of the underpinning role such information has on the use of postural cues. However, one issue with this specific technique is the lack of contextual information presented within the vision, which means the interaction between contextual information and kinematic information cannot be assessed.

#### *2.3.1.3 Spatial occlusion*

Spatial occlusion focuses on which specific postural cues are used to anticipate an opponent’s action. Researchers have used this technique by displaying a specific body region for the duration of the movement pattern and occluding at the precise moment a critical event occurs (Hagemann, Schorer, Canal-Bruland, Lotz & Strauss, 2010). If there is a significant decrease in anticipation performance when a specific body region is occluded, this region is deemed to be essential for accurate anticipation performance. Recently, the temporal and spatial occlusion paradigms have been merged to establish the time point whereby specific body cues are used during anticipation (Causer et al., 2017). Results have demonstrated that experts generally identify earlier arising postural cues from more proximal information sources (e.g. the hips in soccer and the trunk in fencing) (Causer et al, 2017; Hagemann et al., 2010), compared to lesser skilled athletes who rely more on distal information that occurs later in the sequence of the opponent's movement. Due to the nature of manipulations being displayed, this technique almost exclusively relies on the presentation of video rather than in-situ tasks (for an exception see Panchuk & Vickers, (2009) who used black curtains to occlude movement of ice hockey players in-situ). The spatial occlusion technique is limited by reducing the potential of players to use the interactions between specific kinematic cues present during full movements to inform anticipation judgments. Furthermore, just because players can make accurate anticipation judgments at specific occlusion points during movement, does not mean they do this during real competition where no occlusion is present.

#### *2.3.1.4 Visual search*

Recording the gaze behaviour of performers during anticipation tasks (in-situ or video-based) is another method used to make inferences about the locations whereby information pick up takes place. Skilled tennis players have been shown to spend more time fixating on more proximal areas of the opponent's body (e.g. trunk, hips and head-shoulder region), compared to lesser skilled players who spend more time on distal features (e.g. the opponent's tennis racquet) (Williams et al., 2002; Goulet et al., 1989). Additionally, highly skilled athletes have been frequently shown to have fewer and longer lasting fixations compared to lesser skilled athletes when anticipating an opponent's action (Alder, Ford, Causer, & Williams, 2014; Goulet et al., 1989). Although this technique provides an indication of gaze behaviour using central vision locations, it does not include peripheral vision, which may be equally important than central vision when picking up information. Additionally, players gaze behaviour may be focused on a specific feature, however they may not be picking up useful information from that area. Therefore, the use of gaze behaviour displays that afford the manipulation of peripheral and central vision may provide a way to overcome these limitations. The next section focuses on advance sources of contextual information performers use to inform anticipation behaviour.

The abovementioned methods of measuring anticipation have established; (1) *'when'* performers are able to identify anticipatory information, (2) how anticipation skill responds to manipulations of movement kinematics, (3) the specific postural cues experts use to anticipate an opponent's action, and (4) the locations whereby information pick up takes place. Despite limitations associated with these techniques, all methods collectively point to the systematic pick up of postural cues early in an event sequence that underpin anticipation performance.

## 2.4 The use of contextual information

Compared to the use of postural cues, research assessing other sources of contextual information used to facilitate anticipation has been scarce. It has been shown that skilled performers can anticipate effectively based on contextual information identified in advance of relevant postural cues becoming available (Abernethy, Gill, Parks, & Packer, 2001; Triolet et al., 2013). Context can be referred to as a set of circumstances that form the setting for an event. Therefore, context produces useful forms of information that can be interpreted for evaluating and predicting the likely outcome of an upcoming event.

It has been suggested that a larger knowledge base of domain specific situations can facilitate the ability of experts to assign highly accurate probabilities of future outcomes occurring. This advantage has been shown to underpin anticipation performance in racquet sport players (tennis, badminton, squash, racket ball), with findings showing a strong relationship between players allocating probabilities to their opponents shot and performing anticipatory movements prior to the opponent making racquet – ball contact. (Alain & Proteau, 1978). Additionally, goalkeepers have been found to improve anticipation performance when exposed to behavioural tendencies of opponents, however only if the opponent continues to bias their action towards their preferred direction (Mann, Schaefers, & Canal-bruland, 2014). Results have shown that if an opponent goes against their action preference, a decrease in anticipation performance is seen. These findings highlight that skilled performers identify action preferences of their opponents and utilise this information to enhance anticipation performance. However, doing so may be disadvantageous when the opponent's action no longer matches the performers expectations (Mann, et al., 2014).

Research has also assessed the specific types of contextual information that underpin anticipation, and how specific scenarios influence how contextual information is used (Schlappi-Lienhard & Hossner, 2015). Skilled players have been shown to use the current score, strengths, weaknesses and action preferences of opponents, and player positioning information during defensive situations to anticipate effectively and assist decision-making performance (Farrow & Reid, 2012; Millazzo, Farrow, Ruffault, & Fournier, 2016). Indeed, the anticipation accuracy of skilled performers, compared to less skilled performers, has been found to be more prominent when no postural cue information is available and players must rely solely on prior contextual information (Abernethy et al., 2001). The ability of skilled performers to utilise contextual information has resulted in making anticipation responses up to 580 m/s before their opponents' racquet-ball contact (Abernethy et al., 2001), which is assumed to be advantageous for making decisions (e.g. selecting an appropriate action that matches the current situational constraints) (Millazzo et al., 2016).

Moreover, patterns of play identified by skilled performers have resulted in significantly faster anticipation speed (i.e., response times), compared to less skilled performers (e.g., Farrow & Reid, 2012). However, past research has typically only explored the identification of patterns when they occur 100% of the time, with few studies assessing the influence of pattern frequency on the ability to identify patterns. A rare exception includes the early work of Alain and Proteau (1980), who found an 80% probability of a pattern occurring was sufficient for pattern identification to occur and to elicit faster response times. However, this study used single response trials and de-coupled perception action responses which may have caused patterns to be identified more easily at lower frequencies. Future research is warranted using more representative anticipation tasks to further explore the difficulty of identifying patterns when they occur at different frequencies (e.g. 70%, 80%, 90% or 100% of the time), and the effect this has on anticipation and decision-making processes.

The integration of contextual information and progressively unfolding kinematic information when anticipating has also been examined (Gredin et al., 2018). Results have shown that when kinematic information is less relevant or less reliable, the provision of contextual information biases the gaze behaviours and anticipatory judgments of experts, but not novices. Additionally, experts have been found to use kinematic information to confirm or change their judgments towards the end of an opponent’s movement sequence. These results align with the Bayesian framework for probabilistic inference which predicts that the reliance on contextual information is subject to the relative uncertainty associated with other sources of available information. However, this research would be strengthened if more representative tasks were used which do not involve occlusion and decoupling of perception and action processes. Virtual reality technology may offer a more representative method of assessing the effect of contextual and postural cue information on anticipation.

With VR technology in mind, Gray and Canal-Bruland (2018), have showed how situational probability information can be merged with ball trajectory information when testing anticipation skill using a VR baseball task. Results demonstrated that batters relied more on probability information when occlusion of ball flight information occurred earlier compared to later. This showed that batters used situational probability information more when they were less certain of the upcoming flight of the ball. However, this study did not address how different levels of uncertainty around ball flight influences the integration of kinematic and situational probability information. Additionally, it is unclear how the ambiguity of kinematic information related to the actions of performers would influence the integration process between situational and kinematic information, compared to ball flight information in this study.

A way to increase the ambiguity of kinematic information is to disguise movements. Helm et al., (2020) used a VR handball simulation to test whether players use situational or kinematic information more when anticipating, relative to the certainty of the kinematic information available. Findings illustrated that participants relied more strongly on situational probability information when the reliability of the movement kinematics became less certain. When the opponent’s tendency to disguise their movement was lowest (25% of the time), participants were significantly more likely to think ambiguous throws were genuine, compared to when their disguise tendency was highest (70%) and participants reported the ambiguous movements as being disguised. However, a key limitation of this study was that participants responded to stimuli by pressing a button on a remote control device. Future research using VR technology needs to use more representative action responses to enable measures such as response time and response accuracy to be taken in a way that reflects behaviours seen in the real performance environment.

Furthermore, verbal reports taken in-situ and post-task have revealed that skilled fighters, tennis and squash players can form more refined domain specific knowledge compared to novices (Milazzo et al., 2016; Murphy et al., 2016; Schlappi-Lienhard & Hossner, 2015). This suggests that anticipatory expertise is underpinned by more effective processing of contextual information. Therefore, in-performance interviews and post-task questionnaires should become a feature of future research in order to gain further insights about the specific types of information athletes of differing skill levels and age groups use when anticipating.

Although past research has captured the expert advantage of anticipating future events, there are questions yet to be answered regarding how skilled performers identify and utilise contextual information to enhance performance. These questions include, the relative difficulty of identifying different types of contextual information (e.g. scoreboard information versus behavioural tendencies of opponents) to facilitate anticipation, what amount of exposure to specific contextual information is needed for skilled performers to identify this information, and whether more representative task designs that evolve after the initial anticipation response (e.g. playing the rest of the point out after returning a serve in tennis) prolongs the identification of contextual information, therefore reducing response time and accuracy. Furthermore, technologies such as VR are capable of simulating contextual information found in the real performance environment, including situational probability information and postural cues. Therefore, VR simulations may be a useful tool for exploring the interactions between different forms of contextual information used to enhance anticipation and decision-making performance.

## 2.5 Key issues associated with techniques used to measure anticipation

Although the common approach used to measure how performers utilise postural cues and contextual information has been through the use of occlusion techniques, issues have been raised regarding the representativeness of these techniques and how they apply to real-world anticipation performance. The following section provides an in-depth discussion of the key issues associated with current anticipation measures including the display stimuli, response methods, lack of perception-action couplings, and response timing.

### 2.5.1 Display stimuli

Video-based displays provide a reliable way of presenting movements in a repeatable fashion that can be occluded at consistent moments during movement patterns. However, the issue with video-based displays is that they are filmed from a fixed, allocentric viewpoint that does not represent the dynamics of the real performance environment. Additionally, video-based displays do not allow for the players own movements to effect change to the stimuli presented (Craig, 2013). Furthermore, the type of display used to present the stimuli, including small computer screens and large projector screens, lack immersive qualities and significantly changes players perception of information. Studies have shown that when tasks are not representative of the performance environment, sources of information that are relevant to performance are absent, therefore the expert-novice expertise difference is diminished (Abernethy, Thomas, & Thomas, 1993; Dicks, Button, & Davids, 2010). Attempts have been made to address this issue, including capturing footage from a player’s viewpoint during real competition scenarios in tennis (Williams et al., 2002), and basketball (Farrow & Fournier, 2005). However, this vision is not completely egocentric as it does not change based on the head movements of the performer in real time, therefore failing to represent the players individual optical flow that would be present in the real-world environment (Craig, 2013).

### 2.5.2 Response methods

Studies examining anticipation skill have required participants to make action responses that are far removed from those performed in the performance setting (e.g., verbal responses, touching a screen). Although these decoupled perception action responses allow for more experimental control, they have been criticised for leaving out a crucial part of expert performance (Abernethy et al., 1993; van der Kamp et al., 2008). Indeed, perception and action are interdependent of each other, and therefore any separation of the two during measures of anticipation fails to portray the true essence of expertise (Gibson, 1979). Therefore, the validity of findings from past measures of anticipation that have incorporated unrepresentative or uncoupled movement responses must come into question. Research focused on decision-making has illustrated that the removal of representative movements can be detrimental to decision-making behaviour, and that including representative movements when making responses can enhance decision-making accuracy (Oudejans et al. 1996a; Oudejans et al. 1996b). Therefore, in order to improve the validity of findings anticipation testing should include more representative movement responses, coupled with perceptual information. Given researchers have used a spectrum of methods to measure anticipation performance (i.e., response accuracy and response time), further work is needed to establish general scientific principles of reliability that can be applied to future anticipation research. To my knowledge, general principles of reliability towards anticipation research do not currently exist in the literature.

Furthermore, the expert advantage when anticipating has been more dominant when representative action responses are used during testing. This has been shown in skilled tennis players who were found to better anticipate the direction of serves when they actually moved in the anticipatory direction compared to responding verbally (Farrow & Abernethy, 2003). Interestingly, this advantage was only seen when ball flight information was available and not when actions were based on pre-ball flight information. This suggests that skilled players are better at using all perceptual information in the lead up to performing an action, including the combination of pre-ball flight information and the resultant velocity of the ball – a more natural perception-action process, compared to only performing actions using pre-ball flight information – an unnatural perception-action process caused by occlusion.

Including representative movement responses during measures of anticipation is also supported by the field of neuropsychology using the dual pathway theory of vision (Milner & Goodale, 2008). This theory proposes that skilled athletes are more likely to depend on the dorsal (vision for action) pathway when producing movements, therefore it should be best practice to test this pathway in order to provide the most accurate representation of skilled performance. However, it has been argued that most studies measuring visual anticipation skill in sport have tested the ventral pathway (vision for perception), and have removed movement which results in a collection of findings that are limited and biased towards conscious processing (Van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008). Van der Kamp et al., (2008) emphasised that contributions from the dorsal pathway are important for both the identification of actions and movement control. In turn, the dorsal system interacts with and aids the ventral system during the process of visual guidance. However, the relative contribution of the two systems alters during the course of making an interceptive action. For example, when returning serve in tennis the ventral system is predominantly used at the beginning of the service action, and then progressively decreases its dominance as the ventral system takes more control following racquet ball contact (see van der Kamp et al., 2008). Future studies measuring anticipation need to focus on the interaction between these two pathways, by including more representative movement responses.

### 2.5.3 Action response timing

Skilled athletes have been shown to perform early anticipatory judgments during anticipation tasks, which has led to the assumption that they use this information to start moving as soon as possible. However, movement responses when responding to actions that are occluded (the majority of work in the anticipation field) do not represent what skilled athletes do in the real performance environment, where there is no occlusion. Indeed the occlusion technique forces athletes to make anticipatory judgments with limited information. Therefore, it may be that skilled athletes wait for later occurring visual information before responding in the real performance environment, as this information is more strongly linked to their actual movement outcomes. Therefore, when using highly representative anticipation tasks which include perception-action coupling in ball sports (e.g., tennis), it may not come as a surprise if skilled performers responded after their opponent strikes the ball. This suggests that just because athletes have the ability to move earlier when they are forced to, does not necessarily mean that they do so in the real competition environment.

However, little is known about how performers regulate their movements using advance information. Shim et al., (2005) found that skilled tennis players initiated anticipatory movements earlier when returning balls hit by an opponent, compared to when projected from a ball machine. This demonstrated that skilled players use information about their opponents' movements patterns to initiate earlier responses. In the contrary, when faced with video of soccer penalty kicks, skilled goalkeepers were shown to wait longer to initiate responses using a joystick, and also produced more accurate responses compared to lesser skilled goalkeepers (Savelsbergh et al., 2002). Furthermore, skilled goalkeepers who had greater movement speed were found to wait longer before initiating movement responses in situ (Dicks et al., 2010b). Together, these findings support the notion that even though skilled performers have the ability to move earlier to make anticipation judgments effectively, they may still wait until further information becomes available to initiate movements during real competition. More research is needed to establish how information is used to regulate actions. Key to this, is the utilisation of measurement tools such as force plates or kinematic movement tracking to provide information about how movement is modified when the information available to performers is manipulated.

## 2.6 Summary

Grasping a better understanding of anticipation expertise in sport requires better methodological techniques that adequately simulate perception-action cycles and allow researchers to assess anticipation skill from a player's egocentric perspective. Technologies that recreate an athlete's three-dimensional perspective of events unfolding in the competition environment is crucial, as well as the ability to control, update and manipulate these events in real time. Additionally, the specific information presented in the environment must correspond to the real-world setting, be easily manipulated, and allow for the same conditions to be replicated across multiple performers (Tarr & Warren, 2002). Importantly, the immersive environment must be interactive, and allow the information presented to be directly influenced by the performers action behaviours, whilst at the same time allowing for these interactions to be measured or recorded (Craig & Watson, 2011; Dessing & Craig, 2010). The technology that has potential to achieve these methodological attributes is VR. However, it is still unknown whether VR is capable of simulating the perception-action couplings of the real-world performance environment to an adequate level that results in skill transfer across environments. Indeed, VR also has its own limitations which may result in negative skill transfer. This is discussed in more detail in later sections of this literature review.

## 2.7 Perceptual-cognitive skill training

Sports coaches and researchers alike are constantly looking for new ways to improve the performance of athletes to gain an advantage over their competition. An area of focus over the past decade has been the introduction of training programmes designed to develop the perceptual-cognitive skill of athletes. However, the effectiveness of these training programs rests on three key assumptions, 1) that perceptual-cognitive skill is directly related to sports performance outcomes, 2) that key perceptual-cognitive skills such as decision-making, anticipation and pattern recognition can be trained, and 3) that improvements to perceptual-cognitive skill can transfer to better performance in competition (Abernethy & Wood, 2001). The first assumption is true and has been described in earlier sections of this literature review. We will now address the other two assumptions by concentrating on the representativeness of past perceptual-cognitive skill training methods.

### 2.7.1 The representative design of perceptual-cognitive skill training

Many researchers have criticised the use of laboratory-based perceptual training tasks for their lack of representativeness with the real competition environment. These criticisms have specifically related to the training stimuli, and the representativeness of responses required from learners being unlike the natural performance setting (Broadbent, Causer, Williams et al., 2015). The idea of action responses during training being representative of responses used in the performance setting, has stemmed from evidence suggesting a distinction of functional specialization in the ventral and dorsal visual pathways (Milner, Goodale, 1995). As it stands, ventral pathways seem specialised for tasks requiring vision for perception (e.g. identifying a moving object in space as a ball), and dorsal pathways are thought to be primarily used in vision for action tasks (e.g. perceiving the trajectory of an upcoming ball and controlling movement towards that ball) (Loffing et al., 2017). As the demands of most sports are thought to require the use of more vision for action processes, maintaining couplings between perception and action during training is thought to be crucial for optimal advances in learning to occur (van der Kamp et al., 2008). However, most perceptual-cognitive training studies have required participants to make uncoupled perception and action responses to training (e.g. button presses, verbal responses) (Klostermann, Vater, Kredel et al., 2015; Loffing, Stern, & Hagemann, 2015). Furthermore, laboratory or field based training interventions that require a simulated action response without actually intercepting the ball (e.g. when using 2D video or occlusion spectacles), may cause unwanted effects to motor skill technique, which may negatively affect motor skill execution in the competition setting (Loffing et al., 2017).

Given these complications, it has been proposed that the design of perceptual-cognitive skill training can be enhanced through utilising key concepts from ecological dynamics, which focuses on athlete interactions with task and environmental constraints (Stone et al., 2019). It is thought that the most effective training settings are those that provide key interacting constraints that are present in the performance environment. These constraints can then form boundaries for individuals to develop perceptual processes and functional goal directed actions that may enhance performance during competition (Anson, Elliot, & Davids, 2005).

An early framework termed representative design (Brunswik, 1956) describes how closely task constraints present in the training environment reflect the constraints found in the competition environment (Araujo et al., 2006; Davids, 2008). Brunswik emphasised the importance of understanding how to recreate constraints found in the performance environment when designing empirical research, to discover how individuals adapt to challenges in their natural performance setting (Brunswik, 1956). Progressing the early work of Brunswik, the term representative learning design was conceptualised (Pinder et al., 2011), which highlights the importance of considering interacting constraints on movement behaviours, and coupling perception and action processes during practice tasks (Renshaw & Gorman, 2015; Vilar, Araujo, Davids, & Renshaw, 2012). Moreover, this framework captures how coaches and researchers alike might use key insights from ecological dynamics to ensure practice task constraints are representative of the specific performance context toward which they are intended to generalise (Pinder et al., 2011; Chow, Davids, Hristoviski, Araijo, & Passos, 2011).

To guide practitioners and researchers in the development and assessment of training tasks, representative learning design endorses two key terms that are suggested to be essential for reflecting the performance environment, namely functionality and action fidelity. Functionality refers to athletes achieving success during practice tasks by basing their decision-making and actions on comparable information to that of the real competition environment (Loffing et al., 2016; Pinder et al., 2011). Comparatively, action fidelity refers to whether a performer’s action or behaviour remains the same in the training and performance environment (Araújo, Davids, & Passos, 2007; Stoffregen, Bardy, Smart, & Pagulayan, 2003). Therefore, to enhance the representative design of perceptual-cognitive skill training, practice simulations should sample informational variables that are found in specific performance environments and ensure the functional coupling of perception and action processes (Pinder et al., 2011). Doing so would ensure that the amount of success performers have when performing actions in practice can be compared between contexts, as well as allow performers to regulate their movement behaviours in practice based on comparable information found in the performance setting (Araújo et al., 2007; Pinder et al., 2011). These aspects of representative learning design are thought to enhance skill transfer from the practice simulation to real-world competition settings.

Underpinned by key concepts of representative learning design (i.e. action fidelity and functionality), the modified perceptual training framework offers a method to assess the effectiveness of perceptual-cognitive training tools (Hadlow et al., 2018). This framework is an extension of the work by Abernethy and Wood (2010) and their three key assumptions that determine the effectiveness of perceptual-cognitive training. The framework targets three key factors – the perceptual skill trained, the training stimuli (functionality), and the action response (action fidelity). The perceptual skill trained refers to whether the training targets a skill ranging from low order visual skills (e.g. visual acuity, depth perception, Erickson, 2007) to high order perceptual skills (e.g. sport specific decision making or anticipation; Williams & Ford, 2008; Muller & Abernethy, 2012). The type of training stimuli used tackles how similar the stimuli presented during training is with that found in competition. Training stimuli can range from generic (e.g. shapes; Smeeton et al., 2013) to sport specific training stimuli (e.g. real opponents; Mitroff, Friesen, Bennett et al., 2013; Oudejans, Heubers, Ruitenbeek et al., 2012). The final factor, action response, includes how similar the response method required during training is to a typical response performed in competition. This framework predicts that the more sport specific each of these three factors are the greater the level of skill transfer to competition (Hadlow et al., 2018). Therefore, this framework can help guide the design of new training tools and allows researchers to conduct assessments around which current perceptual tools are most likely to induce skill transfer to the competition setting.

### 2.7.2 Common training approaches

The majority of researchers have focused on training a player's ability to identify and utilise relevant postural cues to enhance anticipation of sport specific actions. Field-based tasks have been used to train the utilisation of postural cues using vision occlusion goggles (e.g. Muller & Abernethy, 2014). These studies have been shown to enhance the ability of players to utlise advanced postural cues to anticipate an opponents action outcome before the completion of that action. Similar findings have been reported when using laboratory-based tasks which have aimed to simulate the real performance environmant using video of sport specific events, presented on computer screens or life sized projectory screens.

Moreover, despite the literature detailing expert advantages in pattern recognition (Gorman, Abernethy, & Farrow, 2012; Helsen & Starkes, 1999; North, Ward, Ericsson, & Williams, 2011; Starkes, 1987), very little research has attempted to train this aspect of perceptual-cognitive skill (see North, Hope, & Williams, 2017). It has been reasoned that pattern recognition allows a player to recognise rapidly what is developing in terms of an offensive or defensive pattern of play and thus take advantage of this awareness of what a teammate or opponent is likely to do next (Starkes, Allard, Lindley, & O'Reilly, 1994). Therefore, it seems logical to pursue the development of pattern recognition skill through training.

Positive training effects have been seen in racquet based sports and team sports including tennis (Farrow & Abernethy, 2002; Farrow, Chivers, Hardingham, & Sachse, 1998), badminton (Hagemann & Memmert, 2006; Hagemann, Strauss, & Cañal-Bruland, 2006), goalkeeping in soccer ( McMorris & Hauxwell, 1997; Poulter, Jackson, Wann, & Berry, 2005; Savelsbergh, Van Gastel, & Van Kampen, 2010), field-hockey (Williams, Ward, & Chapman, 2003), and team handball (Abernethy, Schorer, Jackson, & Hagemann, 2012; Schorer, Cañal-Bruland, & Cobley, 2010; Schorer, Loffing, Hagemann, & Baker, 2012). However, whilst many of these training studies have reported positive training effects, the majority are characterized by their limitations in experimental design. These limitations include the absence of control and placebo groups, relatively short training periods, a lack of process tracing measures (e.g., gaze behaviour) to assess precisely what changes as a result of training, and missing or inadequate retention and transfer tests. Indeed, transfer tests are key for assessing the use of training programs for enhancing performance in competition. While some of these limitations have been addressed to some extent (see Broadbent, Causer, Ford, & Williams, 2015), there remains few publications that have used well-designed and controlled training interventions.

The next section will discuss VR technology, which has recently emerged as a prospective perceptual-cognititve training tool best suited for simulation of real-world performance conditions. The current state of VR technology and the types of fidelity associated with its effectiveness will be discussed. Moreover, VR technology has recently been used to train perceptual-cognitive skill, therefore these studies will be outlined in this section.

## 2.8 The use of virtual reality for simulating and training perceptual-cognitive skill

### 2.8.1 Features of virtual reality

Virtual reality can be referred to as a computer-simulated environment that aims to stimulate a sense of being physically and psychologically present in another place (Banos et al., 2000; Sherman & Craig, 2002). An important aspect of VR simulation is that individuals can perceive the information presented and physically interact with features of the environment (Craig, 2013; McMenemy & Ferguson, 2007). In essence, VR simulations aim to reproduce perceptual information and behavioural constraints found in the real-world environment, whilst reducing the risk of injury and costs associated with creating the simulation (Stoffregen, Bardy, Smart, & Pagilayan, 2003). Virtual reality environments are thought to have high fidelity if they include detailed visual scenes; however, other elements including the level of functionality, sense of presence and level of immersion in the simulation, are equally important. Furthermore, VR can be presented using different formats, including on large screen displays (flat or curved screens), Cave Automatic Virtual Environment (CAVE) systems, and head mounted displays (HMD). Therefore, the type of VR format used is a further consideration researchers and practitioners must make when incorporating the use of VR in performance settings.

#### *2.8.1.1 Presence and immersion*

To better understand the impact VR has on its users and how it reproduces real-world environments, the terms immersion and presence need to be conceptualised. Immersion is described by Slater and Wilbur (1997) as a description of a technology that illustrates the extent to which the computer display can deliver an inclusive, extensive, surrounding and vivid illusion of reality. Presence on the other hand can be defined as a sense of being in the virtual environment and is thought of as a cognitive state that results from various senses processing information in the VR environment (Slater & Wilbur, 1997). Therefore, the level of presence individuals experience in VR simulations is directly influenced by the level of immersion that is present in the VR system.

Technological factors, including the format and quality of VR technology, have proved to directly influence users' sense of presence and the ability to perform tasks in VR environments. It is thought that a greater sense of immersion and presence is produced when VR environments include (a) larger field of view, (b) high resolution capabilities, (Slater and Usoh, 1993), and (c) action methods that are akin to the real-world performance setting. Head mounted displays have commonly been used in research, as this VR format is capable of presenting a high number of perceptual cues in stereovision 3D (normal human vision including depth perception), which has been shown to produce similar levels of depth perception to that experienced in the real-world setting, and a greater sense of presence (Craig, 2013). Research has also explored the influence of including stereoscopic 3D presentations and altering the visual field size of VR simulations, as well as the effect of using different types of control methods within the VR environment. Key findings show that participants experience the highest level of presence and immersion when the VR experience is equipped with stereoscopic 3D, a larger visual field, and more natural control methods (McMahon, Bowman et al., 2012). These technological aspects of VR are thought to be essential for creating highly immersive experiences that produce a high sense of presence.

However, researchers have referred to presence and immersion as subjective states in their own right, without referring to technological influences. Witmer and Singer (1998) defined the term immersion as "a psychological state categorized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (Witmer & Singer, 1998, p. 227). They defined the term presence as "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer and Singer, 1998, p. 225). Presence has also been suggested to include the concept of involvement. Involvement is a psychological state, whereby individuals focus attention, and attach meaning or significance to the task at hand (Witner & Singer, 1998). Therefore, presence and immersion can be a subjective experience, with technological aspects of VR also contributing to the users experience of the VR environment.

Combining technological and psychological aspects of VR presents a multi factorial approach to immersion and presence in the following way: Presence is felt when high levels of immersion are experienced, and focusing attention is necessary for attaining immersion. Virtual reality technology (via the use of VR headsets) promotes immersion by occluding the real-world to allow focused, sustained attention and provides high sensory resolution (multi-sensory) (Procci et al., 2018). The user must then subjectively scale the characteristics of the VR based on the level of immersion experienced.

### 2.8.2 Types of fidelity

Fidelity can be defined as the extent to which a VR simulation represents the real-world environment, in terms of the appearance, cognitions, behaviours, and affective states it elicits (Gray, 2019; Perfect et al., 2014). To achieve VR designs that are likely to produce skill transfer to the real-world setting, it is important to ensure there is a sufficient level of fidelity in the relevant aspects of the VR simulation (Harris, Bird, Smart, Wilson & Vine, 2020). For example, when implementing a VR simulation for training perceptual-cognitive skill in sport, it is important to assess the fidelity of contextual information presented in the environment and the movement behaviours of users. The following section describes the types of fidelity that are deemed to be the most important when developing VR simulations.

#### *2.8.2.1 Physical Fidelity*

Physical fidelity relates to the realism that physical parts of the environment create. This includes visual information, field of view, and the behaviour of objects, in terms of whether they adhere to the normal laws of physics and levels of functionality present in the real-world (Harris et al., 2020). The physical fidelity of the VR environment is likely to be important for eliciting a high sense of presence and creating the illusion of plausibility (Slater, 2009). High graphical realism is likely to increase motivation and engagement in the display, adding to the 'wow' factor of the experience. Therefore, a high physical fidelity is crucial for the efficient processing of perceptual information in the environment.

#### *2.8.2.2 Psychological Fidelity*

Psychological fidelity relates to how the VR simulation replicates the perceptual cognitive demands of the real-world setting (Gray, 2019). Important considerations for having high psychological fidelity include whether individuals use similar gaze behaviours as they do in the real-world setting (Vine et al., 2014), utilise similar perceptual information to facilitate their actions (Bideau et al., 2010), and experience similar cognitive demands (Harris, Wilson, & Vine, 2019) (a key difference between physical and psychological fidelity). High psychological fidelity may be one of the hardest aspects to replicate. For instance, expert surgeons have been found to make more frequent, shorter fixations during real-world operations compared to VR simulated operations (Vine et al., 2014). This suggests that the additionally auditory and visual distractions, coupled with the stress of real-world operations was the reason behind these differences. Therefore, effective VR simulations of high psychological fidelity require an understanding of the perceptual-cognitive processes that contribute to expert performance in the task being simulated.

#### *2.8.2.3 Emotional fidelity*

Emotional fidelity focuses on effective simulation of realistic emotional responses such as fear, stress, anxiety and excitement. There has been considerable interest in how VR can administer high levels of psychological fidelity, particularly in training tasks that are too dangerous to practice in the real-world, or for subjecting individuals to high levels of stress they may face during real-world tasks (e.g. military defence or critical incidents). A high psychological fidelity is particularly required for VR simulations that aim to train skills in highly stressful or dangerous situations. Strong stress responses have been elicited in the past through threatening VR experiences (e.g. Slater et al., 2006; Meehan et al., 2002); however, creating stress responses akin to those experienced during high level sport may be more challenging, therefore further research is warranted.

#### *2.8.2.4 Functional fidelity*

Functional fidelity relates to the physical reactions users make in response to stimuli in the VR simulation. It is thought that when individuals act in a VR environment, the consequences of that action should be appropriately expected by the user (McGreevy, 1992). Noticeable delays or unusual reactions between the action and the result of that action are thought to diminish the sense of presence in VR (Held & Durlach, 1992). Functional fidelity is thought to play an extremely important role in achieving a high sense of presence, as well as the potential of skills to transfer from the virtual to real-world environment (Pinder et al. 2009; Jacobs & Michaels, 2002).

## 2.9 Virtual reality perceptual-cognitive skill training

Few studies in sport have trained the perceptual-cognitive skill of performers using VR technology. A common training approach has been to use head mounted displays to present 360-degree video of real game footage to performers. This technique increases the visual correspondence of the video simulation compared to traditional 2D vision, by offering a 360-degree field of view, and a greater sense of immersion in the training environment (Craig, 2013). However, a major downfall of this approach is that it only allows viewers to watch the vision with no way of interacting or changing the course of events depicted in the scene. Therefore, the representativeness of perceptual information and action methods used during this type of VR training is compromised (Fadde & Zaichkowsky, 2018).

However, this approach has been used to train the decision-making skill of basketball players (Page, Bernier, & Trempe, 2019). Decision-making was assessed on-court before and after the training sessions using two types of plays - trained plays (presented during training sessions), and untrained plays (presented during the on-court tests only). When facing the trained plays in the post-test, the VR training group and a 2D video training group significantly outperformed the control group. However, when facing the untrained plays, the VR training group outperformed the 2D and control groups. These results demonstrate that VR training using 360-degree video can result in improved on-court decision-making performance in new situations, compared to 2D video training. This result is in line with past research suggesting that greater immersion and visual representativeness in the training environment is essential for skill transfer to occur (Craig, 2013; Hadlow et al., 2018).

Virtual reality training can also present animated scenes of visual information to viewers during training, allowing them to interact with virtual objects and influence the course of events depicted in the VR environment. One limitation with animated VR is that the graphical realism and behaviour of objects may not adequately represent that of the performance environment. Indeed, the cost involved in developing an animated VR simulation that has high physical and functional fidelity can be quite high. However, there are sophisticated graphical and object tracking systems available (e.g. Hawkeye) that can develop highly representative animated information.

To our knowledge, just one study exists that has used VR animated technology to train the perceptual-cognitive skill of athletes in sport. Gray (2017) investigated transfer of training from a VR baseball simulator to real-world baseball performance. Participants were assigned to groups undertaking adaptive hitting training using VR, extra sessions of batting practice in VR, extra sessions of real batting practice, or a control condition. Training involved two 45-minute sessions per week for 6 weeks. Results showed that the VR adaptive training group significantly improved from pre to post-test on a VR batting test, on-field batting test, and a pitch recognition test. Additionally, the VR adaptive training group showed superior batting statistics in the competitive baseball season after the intervention, and reached higher levels of competition across a 5-year period. These results suggest that VR animated training can be used to improve real-world performance, particularly when researchers or practitioners take advantage of the adaptive nature of animated simulations (i.e. adapting types of pitches) and do not simply recreate the training environment (Gray, 2017).

Animated VR simulations have become increasingly more common in the military for simulating stressful situations and managing responses through stress management training (Casey, 2011; Rizzo et al., 2013; Stetz et al., 2011). The key findings drawn from a review of VR based stress management training programs (see Pallavincini et al., 2016), is that VR training can help military personnel cope with emotional and physiological responses to stressors in order to maintain performance in highly stressful situations (Hourani et al., 2013). Interestingly, VR also appears to be a promising tool to assess individuals' resilience to stress and to identify the impact stress can have on physiological reactivity and performance

(Winslow et al., 2015). Stressful scenarios simulated through VR technology can also be used to assess physiological responses to stressors and connect these specific responses to task performance. This allows the military to identify resilient individuals or those at risk of stress related performance issues and offer supplementary training as necessary. Animated VR can also provide interactive stress management training that is useful for decreasing levels of perceived stress and negative emotions in military personnel (Bosse et al., 2012; Morie et al., 2011; Stetz et al., 2011). Results have shown that VR environments coupled with arousal reduction strategies (e.g. desensitization through exposure to stressful situations, relaxation techniques and biofeedback techniques) can effectively increase resilience to stress.

In summary, VR is shaping to be a promising tool for training perceptual-cognitive skill in sport. Although the initial studies using VR have shown positive training effects, more research is needed to establish which specific aspects of VR are important for skill transfer to the competition setting, and what the true advantages of VR really are (e.g. manipulation of contextual information, perception-action coupling, simulating pressure). Another aspect to consider that can impact the effectiveness of perceptual-cognitive skill training is the instructional method that is used. The following section provides a review of the most common instructional approaches used during the training of perceptual-cognitive skill and how these approaches can impact on performance.

## 2.10 Instructional approaches used during perceptual-cognitive skill training

Instructions given to athletes during perceptual-cognitive skill training can either direct the performer to specific information or guide the performer to information indirectly (Jackson & Farrow, 2005). A traditional form of instruction that is commonly used is to provide explicit instructions that directly inform the athlete what to do. By definition, explicit learning refers to the intentional acquisition of skills that result in verbalisable knowledge (Maybery & O'Brien- Malone, 1998). This form of instruction is used to make connections between specific movement patterns or cues and relevant behavioural outcomes. This provides two key information sources: (1) it directs athletes to the most important movements or cues of the opponent needed for successful anticipation, and (2) it states the outcome of those movements (Williams, Ward, Knowles, & Smeeton, 2002). This can take the form of 'if then' rules that apply to certain situations (e.g. if your opponent's ball toss is left, then they will serve out wide). A by-product of explicit instructions is the accumulation of verbalised knowledge, or 'rules', about how to perform the task.

As one shifts along the continuum (see Figure 2.1), another instructional approach to train perceptual-cognitive skill is via the use of guided-discovery. This method involves directing the attention of athletes to regions or sources in which the most relevant information to facilitate anticipation is found. This process can be achieved using colour cueing which highlights the most relevant information (i.e. highlighting an opponent's hip's), or by verbally instructing athletes to look at certain body regions (Abernethy, Schorer, Jackson, & Hagemann, 2012; Hagemann, Strauss, & Canal-Bruland, 2006; Klostermann et al., 2015; Savelsbergh et al., 2010). The guided-discovery method does not explicitly tell the learner about the outcome of specific movement patterns, or precisely what to look for to predict specific movement outcomes. The athletes are simply guided to the areas where key information relevant to anticipation is situated, leaving them to hypothesise over action outcomes. Typically, athletes report fewer explicit rules to guide their anticipation or decision-making performance using this method compared to using traditional explicit instruction, albeit the accrual of some rules suggests this method is still somewhat explicit in nature.

At the opposite end of the instructional continuum are indirect instructional approaches. One such approach relies on the use of dual tasking. This procedure involves athletes performing two tasks simultaneously (primary and secondary task) to limit the use of working memory on a single task and reduce explicit processing. In turn, this procedure encourages implicit processing of information (knowledge that is difficult to verbalise). Secondary tasks that have been used in golf putting, baseball, and soccer have involved non-context specific tasks such as tone frequency judgement (Gray, 2004), tone frequency monitoring, and word monitoring tasks (Beilock, Carr, MacMahon, & Starkes, 2002). Another indirect instructional approach is incidental learning, whereby learners are given instructions that their performance is dependent on one factor, when really it is dependent on another that drives perceptual-cognitive learning of salient information (also referred to as task-related, goal-irrelevant instructions). Such an approach may promote implicit learning since athletes do not accrue explicit knowledge about the primary task. Such instructions offer an opportunity for encouraging implicit learning in the field setting where it can be difficult to decrease an athlete’s intent to learn (Jackson & Farrow, 2005).

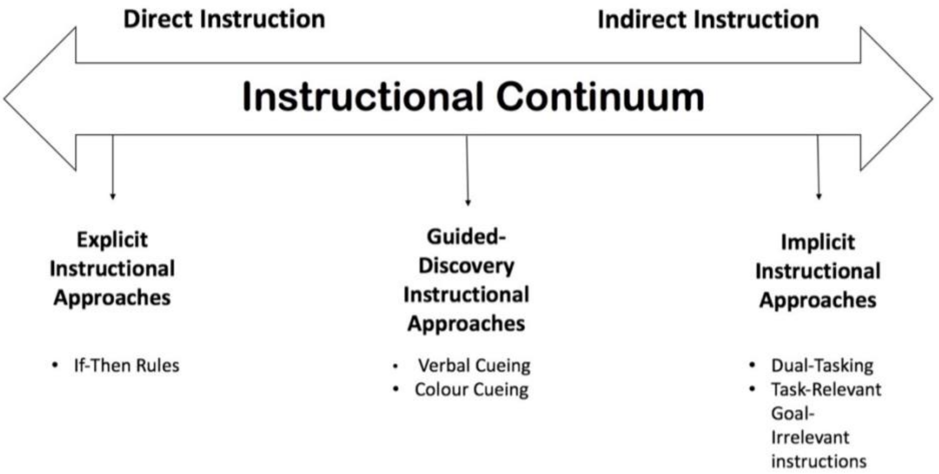


Figure 2.1. Instructional Continuum ranging from direct to indirect techniques.

### 2.10.1 How different instructional approaches effect performance

#### *2.10.1.1 Direct instruction approaches*

Direct instructions that link perceptual cues to a subsequent action have been the most extensively studied approach in the perceptual-cognitive skill training literature. Results from these studies have demonstrated that direct instructions can enhance the response time and response accuracy of athletes in sports including tennis (Singer et al., 1994) and squash (Abernethy, Wood, and Parks, 1999), compared to placebo and control groups. However, decision making time has been shown to slow significantly (relative to post-test results) under high anxiety conditions or pressure (Smeeton, Williams, Hodges, and Ward, 2005). Additionally, increased decision time in explicit groups has been positively related to the number of problem-solving rules accumulated during training. This supports the idea demonstrated in the motor skills literature that greater explicit knowledge results in decreased performance under pressure (e.g. Beilock & Carr, 2001; Masters, 1992). Therefore, explicit instructional approaches should be used with caution when training perceptual-cognitive skill. Moreover, the majority of studies have used video-based conditions that do not involve physical responses, and consequently the issue of whether perceptual learning transfers to real-world performance is seldomly addressed. The lack of appropriate transfer tests is a reoccurring limitation of most perceptual-cognitive training studies, with very few researchers assessing the transfer effect of anticipation training to a real-world context. Therefore, future research that includes adequate transfer tests is warranted.

#### *2.10.1.2 Guided-discovery approaches*

Progressing along the instructional continuum, slightly less prescriptive approaches have been used to guide the attention of performers to critical anticipatory information. Results have shown improvements in decision-making and anticipation accuracy, and decision-making speed, with improvements in decision making accuracy transferring to the field environment (Gabbett, Rubinoff, Thorburn & Farrow, 2007; Hagemann et al., 2006). Additionally, improvements in anticipation have been found to be retained after an unfilled 4-week retention period. However, no further improvements have been seen during retention periods, suggesting that skills learnt using more direct instructional approaches (i.e., guided-discovery) may need to be consistently revisited over time.

#### *2.10.1.3 Indirect instructional approaches*

There has been a smaller body of work focussing on enhancing anticipation and decision making using indirect approaches (for a review, see Jackson & Farrow, 2005). The key findings in the motor learning literature over the last 20 years suggest skills that are learned without an accrual of explicit knowledge about how to perform the task may lead to superior retention, and better performance under pressure or fatigue (Masters, 1992; Masters, Poolton, & Maxwell, 2008). Consequently, researchers have focussed on what knowledge the performers accrue during the learning process. Compared to placebo and explicit instructional groups, indirect instructional approaches have been shown to enhance anticipation in tennis and decision-making accuracy in basketball (Farrow & Abernethy, 2002). Indirect instructional groups have been shown to verbalise significantly less problem-solving rules compared to explicit groups, providing evidence that indirect methods of instruction successfully reduces rule formation, encouraging more implicit learning (Gorman & Farrow, 2009; Raab, 2003). Moreover, improvements made by implicit instructional groups have been maintained after a 4-week retention period (Raab, 2003).

In the most comprehensive investigation of instructional approaches, Abernethy et al. (2012) found that an implicit learning group showed an improvement in response accuracy from pre to post-test, although this was not significantly higher than the control group. A retention test was employed five months later and demonstrated that none of the training groups (explicit instruction, guided instruction groups) experienced a reduction in performance. It is interesting to note that the implicit learning group showed further improvement in the retention test which supports the hypothesis that implicit learners show greater resistance to performance loss over time (Abernethy et al., 2012).

Results from a rare pattern recognition training study have shown that indirect instructional approaches can enhance the ability to predict the trajectory of a ball based on situational probability information (Green & Flowers, 1991). Interestingly, the explicit group made greater joystick movement errors when attempting to catch the ball compared to the indirect instructional group. Stylistic differences were also observed between groups, with the indirect group making far less movements earlier in the ball trajectory pattern (where a predictive feature may have occurred), with equal or more activity later in the pattern, compared to the explicit group. Further research is needed to investigate whether similar methods can be applied to train pattern recognition skill is sports such as tennis, where the ability to identify and utilise patterns of play can significantly enhance anticipation skill (Farrow & Reid, 2012).

### 2.10.2 Summary

In summary, perceptual-cognitive skills can be trained using direct instructional methods (e.g., Abernethy et al., 1999), guided discovery strategies (e.g., Savelsbergh, et al., 2010), as well as through indirect instructional approaches (e.g., Farrow & Abernethy, 2002; Raab, 2003). Notwithstanding slower learning rates generally associated with more indirect instructional approaches, this approach may be the most beneficial it terms of sustained improvement and develop greater resilience under stressful situations (Abernethy et al., 2012).

## 2.11 Conclusions

Research has shown a clear expert advantage of utilizing postural cues and situation probabilities to inform anticipation judgments. However, the methods used to assess anticipation to date have not been adequately representative of the real performance environment. With the development of technologies such as VR, designing tasks that are more representative of the real-world performance environment has never been more possible. In future, researchers can utilise this technology to effectively manipulate the presence or absence of postural cues, patterns of play and pressure, to investigate the value of various methods of perceptual-cognitive skill training. Compared to the use of postural cues, there has been an under representation of studies assessing and training pattern recognition skill in sport. Therefore, future research should use the capability of VR technology to manipulate contextual information, such as event probabilities and patterns of play, to fill this gap in the literature. Additionally, indirect instructional approaches can be more easily developed in VR environments (e.g. implicit presentation of recurrent patterns of play) allowing researchers to continue to expand on the prospect and limits of such training.

A key issue remains the lack of studies that have included adequate control and placebo groups, appropriate training intervention periods, and retention or transfer tests (Broadbent et al., 2015; Zentgraf, Heppe, & Fleddermann, 2017). Moreover, few researchers have included explicit and implicit types of training methods, coupled with adequate measures of explicit rule formation to assess the amount of explicit knowledge that is formed across instructional conditions. Even fewer researchers have included a stress manipulation that examines the robustness of training effects under increased cognitive anxiety (Jackson & Farrow, 2005). These issues should all be addressed in future perceptual-cognitive training studies if possible. Collectively, the issues presented lead to many opportunities to enhance the design of future training interventions within the perceptual-cognitive skills training domain.

# Chapter 3: Examining the representativeness of a virtual reality environment for simulation of tennis performance

# Abstract

There has been a growing interest in using virtual reality (VR) for training perceptual-cognitive skill in sport. For VR training to effectively simulate real world tennis performance, it must recreate the contextual information and movement behaviours present in the real-world environment. It is therefore critical to assess the representativeness of VR prior to implementing skill training interventions. We constructed a VR tennis environment designed for training perceptual-cognitive skill, with the aim of assessing its representativeness and validating its use. Participants movement behaviours were compared when playing tennis in VR and real-world environments. When performing groundstrokes, participants frequently used the same stance in VR as they did in the real-world condition. Participants experienced a high sense of presence in VR, evident through the factors of spatial presence, engagement and ecological validity being high, with minimal negative effects found. We conclude that Tennis VR is sufficiently representative of real-world tennis. Our discussion focuses on the opportunity for training perceptual-cognitive skill and the potential for skill transfer.

## 3.1 Introduction

The use of virtual reality (VR) training has received significant attention in recent years and is a growing area of interest in high performance sport. Researchers and practitioners have anticipated that immersive VR systems, such as head mounted displays, can effectively simulate sporting environments and, therefore, be used as a training tool to fast-track learning and athlete development (Craig. 2013; Gray, 2017; Tirp, Steingröver, Wattie, Baker, & Schorer, 2015). Critically, however, there has been a lack of research examining how closely VR represents the key dynamics of real-world sporting environments. Consequently, it is unclear whether VR training augments sports performance compared to more commonly used training tools (e.g., the use of 2D video presentations; for recent reviews of VR training, see Neumann et al. (2018), Düking et al. (2018), and Faure et al. (2020)).

Harris et al. (2020) recently developed a framework for testing and validating simulated environments for training purposes. The authors outlined a taxonomy of the types of fidelity and validity considered essential to achieve skill transfer from simulated environments to the real-world performance setting. The framework includes psychological fidelity (perceptual and cognitive features of the display), affective fidelity (emotional responses), ergonomic fidelity (action responses), face validity (structural and functional behaviour of objects) and construct validity (how accurately the simulation matches the real-world). Essentially the taxonomy highlights that there are at least three important factors that need to be considered when determining the potential of VR in sport. These include: (1) the perceptual information needs to closely replicate the real-world environment; (2) athletes decision making should be based on comparable information found in the real-world; and (3) athletes need to able to interact with the environment using actions that closely represent competition (Gray, 2019; Pinder et al., 2011). Achieving these are not an easy feat, and some researchers have posited that VR can impair users processing of sensory information, therein hindering the ability to naturally intercept the virtual objects (Harris et al., 2019; Squires et al., 2016). It is therefore important to assess the representativeness of the VR environment prior to implementing skill training interventions.

Representative learning design is a framework used for designing and testing field-based practice tasks in sport (Pinder et al., 2011). It was adapted from an earlier framework (i.e., representative design; Brunswik, 1956), which emphasised the importance of recreating the performance environment when designing empirical research. The motive underpinning the framework was to better understand how individuals adapt to challenges in their natural performance setting (Araújo et al., 2007; Brunswik, 1956). Consequently, representative learning design highlights the need to couple perception and action in sports training, and to consider how interacting constraints influence movement behaviours (Renshaw & Gorman, 2015; Vilar, Araujo, Davids, & Renshaw, 2012). It is proposed that training tasks that are more representative of the performance setting are more likely to produce learnings that can be applied to the real-world, therein enhancing performance. To guide practitioners and researchers in the development and assessment of training tasks, representative learning design endorses the importance of two factors – functionality and action fidelity (Pinder et al., 2011). Functionality refers to athletes achieving success in training by basing their decision making and actions on comparable information to that of the real competition environment (Loffing et al., 2016; Pinder et al., 2011). Comparatively, action fidelity refers to whether a performer's action or behaviour remains the same in the training and performance environment (Araujo, Davids, & Passos, 2007; Stoffregen, Bardy, Smart, & Pagulayan, 2003). These two factors are closely linked to Harris and colleagues (2020) taxonomy of fidelity and validity and, in essence, focus on the same key message of ensuring that the perceptual information presented, and actions performed in training (whether it be in a VR or real-world training setting) are highly representative of the performance environment. Therefore, to facilitate skill transfer, perceptual information found in real competition should also be present in the VR training environment, and the perceptual information in VR should be coupled with the ability to perform actions that also occur in real competition (Pinder et al. 2009; Jacobs & Michaels, 2002).

Underpinned by action fidelity and functionality, the modified perceptual training framework offers a method to assess the effectiveness of perceptual training tools (Hadlow et al., 2018). This framework targets three factors – the perceptual skill trained, the training stimuli (functionality), and the action response (action fidelity). The perceptual skill trained refers to whether training targets a lower order visual skills (e.g. visual acuity, depth perception, vergence; Erickson, 2007) or higher order perceptual skills (e.g. sport specific decision making or anticipation; Williams & Ford, 2008; Muller & Abernethy, 2012). The type of training stimuli used addresses the similarity between the stimuli presented in training compared to competition. Training stimuli can range from generic (e.g. shapes; Smeeton et al., 2013) to sport specific (e.g. real opponents; Mitroff, Friesen, Bennett et al., 2013; Oudejans, Heubers, Ruitenbeek et al., 2012). The final factor, action response, pertains to whether the response method (i.e., the action in response to the stimuli) in training is analogous to competition. The modified perceptual training framework predicts that skill transfer to competition is heightened when these three factors are more sport specific (Hadlow et al., 2018).

Despite previous work illustrating best practice for designing VR training tools in sport, there has been little research testing the representativeness of training environments prior to their use. As a rare exception, however, Harris et al. (2019a) tested the fidelity of a VR golf putting simulator by (a) assessing expert and novice golfers in VR and real-world environments (action fidelity measure), (b) assessing the perceptual and cognitive demands of the golf simulation using a self-report measure of task load (functionality measure), and (c) comparing the perceived distance to the hole in VR and real-world environments (functionality measure). Results showed that the simulation successfully distinguished expert from novice golfers, and provided task demands comparable to real putting (Harris et al, 2019). Additionally, sense of presence was assessed, which is defined as the sense of being in a VR environment and is thought of as a cognitive state that results from various senses processing information (Slater & Wilbur, 1997). Results showed participants reported a good level of presence, although high variance was reported across participants (Harris et al., 2019). Nonetheless, this work provides a useful example of how to assess and validate the representativeness of VR environments in sport.

The main aim of the present study was to examine the representativeness of a VR tennis simulation. In line with previous suggestions for assessing the validity of VR, we measured action fidelity and the sense of presence when skilled tennis players played VR tennis. Action fidelity was assessed by comparing movement responses (type of stance used and number of steps taken to perform groundstrokes) between VR tennis and the real-world, while sense of presence was measured using the Independent Television Commission- Sense of Inventory (ITC-SOPI) questionnaire. This questionnaire addressed four factors of presence – sense of physical space, level of engagement, ecological validity and negative effects. We hypothesized that Tennis VR would show high levels of representativeness relative to real-world tennis, evidenced by movement responses that closely reflected real-world tennis and a high sense of presence in each factor.

## 3.2 Methods

### 3.2.1 Participants

Skilled male (n = 14) and female (n = 14) tennis players aged between 12 to 17 years (M = 14.4, SD = 1.6) were recruited from a high-performance tennis academy to participate in this study. This academy brings together talented junior tennis players to train and play under the guidance of three coaches that hold the highest level of qualification. Notably, participants had no experience using VR technology. Informed consent from the participant's and their parents/guardians was provided prior to the participant commencing the study, and the study was approved by the ethics committee at the lead researcher's university.

### 3.2.2 Virtual reality system design

#### *3.2.2.1 Development of virtual opponent*

A 12-camera Vantage opto-reflective motion capture system (Vicon Motion Systems Ltd, Oxford, UK; 250 Hz) was used to dynamically record the positions and movements of a human actor (skilled tennis player) performing various tennis strokes, and a range of common movements seen during tennis matches (e.g. running forward or out to the side). Static and dynamic calibrations were conducted within the 10 x 10-meter capture space to set up the global reference system and calibration volume. The aim of this was to capture all movements performed during tennis matches and import this information into the virtual opponents' characteristics to make their movements as realistic as possible. The actor wore a motion capture suit, fitted with fifty-two retroreflective markers (12.7 mm diameter) on key anatomical locations. A further five markers were affixed to the racquet used to perform strokes to ensure representative swing techniques were captured for each shot type (forehand, backhand, serve, volley). The recorded marker trajectories were then modelled and visualized as a humanoid character that became the virtual opponent that users played against in the VR tennis environment. Positive X was set to the right (displacement along this axis is referred to as lateral or left/right), positive Y was forward (displacement along this axis is referred to as forward/backward), and positive Z upward (displacement along this axis is referred to as vertical).

#### *3.2.2.2 Development of hitting trajectories*

HawkEye was used to capture hitting trajectories of tennis shots. HawkEye is a computer-vision solution that uses six cameras positioned around the tennis court to generate 3D representations of ball trajectories (tennis shots). This capture involved a coach feeding balls to specific parts of the court, and the actor hitting different groundstrokes towards various positions on the court. Additionally, the actor performed serves from the deuce and advantage sides of the court in various hitting directions (wide, tee and body serves). The overall intent being to capture a range of shots that could otherwise be considered to represent the vocabulary of shots (Kovalchik & Reid, 2017) in tennis. These trajectories were then imported into the Tennis VR system. This meant that all shots hit by the virtual opponent were representative of the hitting trajectories of an opponent in a real tennis scenario. Furthermore, the tennis ball in the VR environment was animated to show the type of spin (topspin, backspin or sidespin) accompanying each trajectory. This therefore allowed players to use this information to perceive the trajectory of the ball (as is the case in the real-world). The VR environment was also designed to align with the physics of the real-world environment (e.g., the effect of gravity on the trajectory of an oncoming ball) which allowed the tennis ball to move naturally within the VR environment. Furthermore, the hitting trajectories were also imported into a customised software tool within the VR system to further develop the artificial intelligence (AI) of the virtual opponent.

#### *3.2.2.3 Artificial intelligence software development*

An artificial intelligence (AI) software program was developed and imported into the VR system. This was created by the VR company Lightweave through the VR development platform Unity. This program gave researchers complete control over the virtual opponent’s actions, including the type of shot they had available to hit (forehand, backhand, slice etc.), and the direction and velocity of each shot (including the speed, spin and net clearance height). This meant that the researchers could control how the virtual opponent played on a shot-by-shot and point-by-point basis, allowing for patterns of play to be embedded into the VR opponent’s playing style. The length and outcome of points could also be pre-determined by manipulating the virtual opponent’s abilities (making the opponent hit the ball into the net or hit an unreturnable shot). This allowed the duration of each match to be tightly controlled.

The AI software program was also applied to the human player’s experience. The hitting trajectories that the human player had available to choose from were the sum of all the hitting trajectories captured by Hawkeye. This equalled 1600 shots and included several different ball trajectories for all types of shots (forehands, backhands, volleys and serves). For example, if the player swung their racquet with the aim of hitting a forehand cross court, the AI would select one of the ball trajectories from the system that was the closest match to the shot the player intended to hit. During this process, the AI considers the way the player swung their racquet, the swing speed, the angle of the racquet as it contacts the virtual ball (based on sensors attached to the racquet), and the amount of spin the player intended to put on the ball, and then decides which ball trajectory is the closest match to these variables. How closely this matched was determined by the number of trajectories in the system which were similar to the shot intended to be hit by the player. Indeed, one of our aims when capturing trajectories using Hawkeye was to capture as many as possible (1600 trajectories) in order to increase the chance that the players intended shot matched the trajectory outcome in VR. This is a time consuming process, however in the future more trajectories will be added to the system, thereby enhancing how closely the trajectory matches the players intended shot.

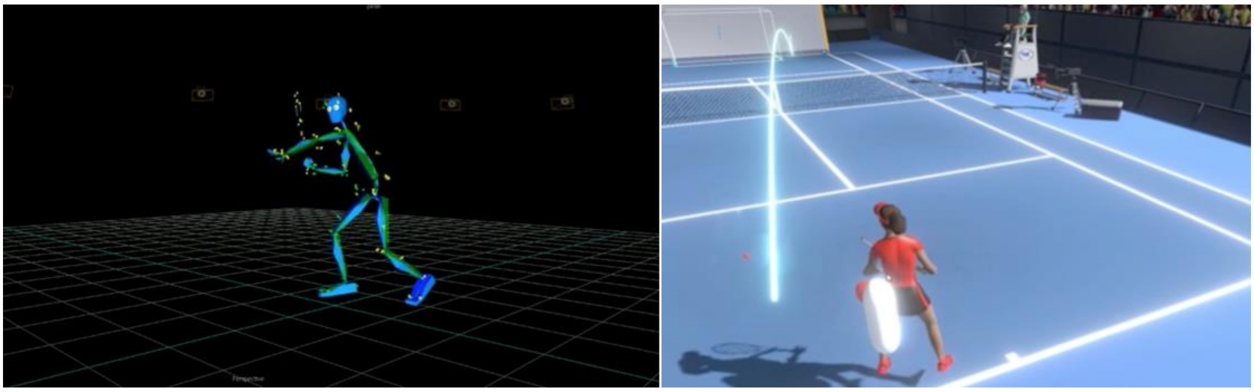


Figure 3.1. The left image shows the marker trajectories modelled and visualised into a humanoid character. The humanoid in this case is performing a forehand groundstroke. The image on the right is an example of a ball trajectory (light blue coloured arch) that has been captured using Hawkeye and imported into the VR environment. Notably, the light blue coloured arch showing the flight path of the ball is removed when playing a match.

### 3.2.3 Experimental Design

A repeated measures design was used whereby all participants performed a tennis task in three conditions. These conditions included playing tennis in VR using a tennis racquet (VR racquet), using a tennis racquet handle (VR handle), and playing tennis in the real-world (real- world). The order in which the VR conditions were performed were counterbalanced across participants. That is, half of the participants completed the VR racquet condition first, followed by the VR handle condition, with the other half of participants completing the VR handle condition first, followed by the VR racquet condition. All participants completed the real-world condition last. We included two VR conditions to assess the influence of using a tennis racquet versus a smaller racquet handle on participant's sense of presence scores, specifically related to presence factors ecological validity and spatial presence. We then assessed the representativeness of VR tennis by using a range of subjective and objective measures related to the action fidelity and functionality of the task. The subjective measures assessed sense of presence in the VR environment whilst the objective measures compared movement behaviour in VR tennis compared to real-world tennis.

### 3.2.4 Procedure

The VR racquet and VR handle conditions followed the same procedure. Initially participants were provided with an opportunity to become familiar with the VR environment. This involved wearing the HTC VIVE PRO headset (470 grams) for 2 minutes, therein providing time to scan and walk around in the VR environment, and rally with the virtual opponent. Once participants felt ready, they commenced the first 10-minute testing block. Immediately after completing the first 10-minute block in each VR condition, participants filled out a presence questionnaire. Participants then completed the second 10-minute block which involved hitting 10 forehand and backhand ground strokes. The real-world tennis condition followed a similar procedure, with the only differences being: 1) participants played on a real tennis court, 2) participants did not complete a sense of presence questionnaire after the first 10-minute block (the presence questionnaire does not apply to experiencing the real-world if no forms of media are present), and 3) a ball machine was used in the second 10-minute block to feed balls to the forehand and backhand sides of participants.

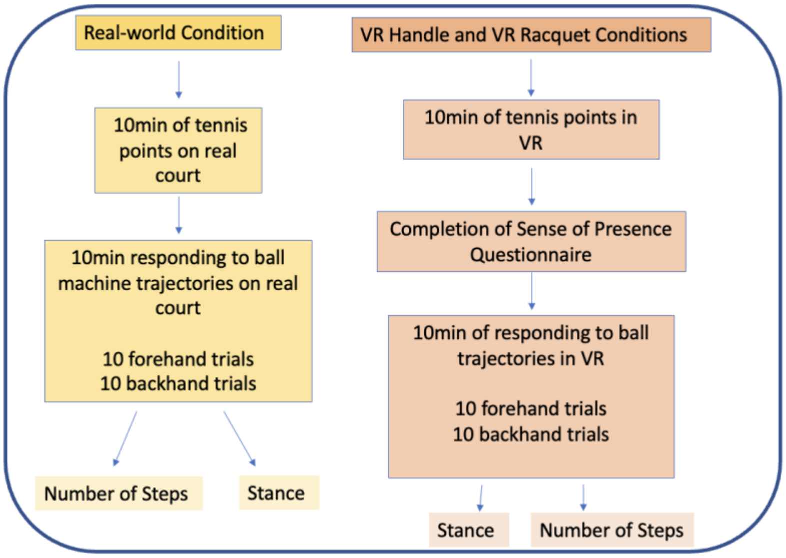


Figure 3.2. Illustrating the procedure for participants in the real-word condition and VR handle and VR racquet conditions.

### 3.2.5 Virtual reality task: Conditions 1 and 2

The Tennis VR task took place in an indoor gymnasium (16m x 10m). The HTC VIVE Pro VR headset was worn by participants to experience the tennis VR environment. The Tennis VR environment was carefully designed to closely represent that of a real-world professional tennis environment (see Figure 3.2). This included a hardcourt tennis court surrounded by stands with a crowd of virtual people and a live scoreboard. The appearance of the virtual ball was typical of real-world tennis. A tennis handle device (a tennis racquet handle, excluding the frame) was used by participants to hit the virtual ball in the *VR handle* condition. Comparatively, in the *VR racquet* condition, participants used a tennis racquet. In this condition, a small sensor **(**7cm x 4cm x 3cm, 90 grams) was placed on the participant's handle section of their tennis racquet which allowed it to be used for hitting the virtual tennis ball. The first 10-minute block was used to assess the sense of presence of participants during a VR tennis match. Participants played a virtual tennis match using the scoring system typical of real-world tennis, the only difference being the virtual opponent served for the entirety of the match (typically, a total of 18 games were played). Immediately after this match, participants completed a sense of presence questionnaire (5 minutes in duration). The second 10-minute block was dedicated to assessing movement (type of stance used and number of steps taken). This involved the participants positioning themselves in the centre of the court behind the ‘T’ on the baseline. The opponent then fed a ball out to the forehand side of the participant. Participants moved to hit the shot and were asked to direct this shot back down the middle of the court as fast as possible whilst maintaining control of the ball. This was repeated a total of 10 times on the forehand and backhand side. Participants had 6 seconds to recover in between shots. Importantly, the ball trajectories of the forehand and backhand feeds were pre-recorded using a ball machine and inserted into the VR system. This allowed for these ball trajectories to be used in both VR and real-world conditions, therefore participants reacted to ball trajectories that were as close as possible to each other in all conditions (i.e., the ball machine cannot reproduce the exact same trajectory every time, even if the settings are the same). Additionally, a camera (Sony HDR-CX405 HD Camcorder) was positioned in front of participants to film their footwork and stance selections when hitting groundstrokes.

Figure 3.3. Images of the Tennis VR environment, including (a) the court surface, line judges, camera’s, scoreboard and crowd in the stands, and (b) the sky and buildings that

surround the court. These details were included in the VR environment to enhance sense of presence and immerse participants in the environment.

### 3.2.6 Real world tennis: Condition 3

In the real-world condition, the first 10-minute block involved participants playing a tennis match against an opponent on a real tennis court. Differing from the VR environment, this tennis court did not include a surrounding stadium. The opponent in this condition was the same player used during the hitting trajectory capture on the Hawkeye tennis court, whereby their hitting trajectories were transferred into the VR environment and used by the virtual opponent to hit shots. Therefore, participants played against the same opponent in the real-world and VR conditions (participants were not aware of this). The second 10-minute block followed the same process as both VR conditions with two exceptions. First, a ball machine was used to feed balls to participants forehand and backhand sides (instead of the virtual opponent in the VR conditions). Every ball trajectory sent by the ball machine was identical to the trajectories used in both VR conditions. Second, participants did not complete the post task sense of presence questionnaire.

### 3.2.7 Subjective Measures

#### *3.2.7.1 Sense of presence questionnaire*

The Independent Television Commission- Sense of Inventory (ITC-SOPI) questionnaire (Lessister, Freeman, Keogh, Davidoff, 2001) was used to assess sense of presence. This questionnaire is measured on a 5-point Likert scale, with 1 corresponding to “strongly disagree”, and 5 corresponding to “strongly agree”, and has been shown to be a reliable and valid tool for assessing presence using interactive displays and other types of media (e.g. VR, television, computer, IMAX). It consists of 44 items divided into four factors, including: 1) spatial presence (r = 0.94), 2) engagement (r = 0.89), 3) ecological validity (r = 0.76), and 4) negative effects (r = 0.77). The r values listed indicate the reliability or repeatability of the presence questionnaire scores for each factor. Spatial presence indicates a sense of physically being in the VR environment, including interacting with and having control over the different parts of the environment. This factor is strongly related to the sense of ‘being there’. Engagement describes the level of psychological involvement in the VR environment and the level of enjoyment the user experiences. Ecological Validity indicates how strongly the user believes the VR environment is lifelike and real. This includes how lifelike the user rates their movements. For these three factors, a score of 5 is considered the highest level of presence possible and a score of 1 is the lowest. Negative Effects relates to any negative physical or psychological reactions the user experiences, including dizziness, feeling tired, nauseas, developing a headache and eyestrain. In this factor, a score of 1 is considered the least amount of negative effects experienced with a score 5 being the maximum amount.

### 3.2.8 Objective Measures

#### *3.2.8.1 Stance*

The stances that participants used to hit forehand and backhand groundstrokes were recorded using a video camera (Sony HDR-CX405 HD Camcorder). This involved a tennis coach (level 3 coaching accreditation) watching vision of participants hitting groundstrokes and assessing the type of stance used. Types of stances included open, closed and semi-open stance. A closed stance was defined as when the feet and body were turned sideways to the net. The open stance was defined as when the feet were aligned parallel to the net. The toes may have pointed forward or to the side, however if participants were aligned parallel to the net, this was an open stance. The semi-open stance is a stance in between closed and open, and was defined as when the feet were diagonal relative to the net. Like the open stance, the toes may have pointed forward, to the side or obliquely. This measure was taken at the point in which the participants racquet was in position to contact the ball. When there was question over which stance was used, a second opinion was obtained from a level 3 accredited coach and a decision was made after critiquing and discussing the case.

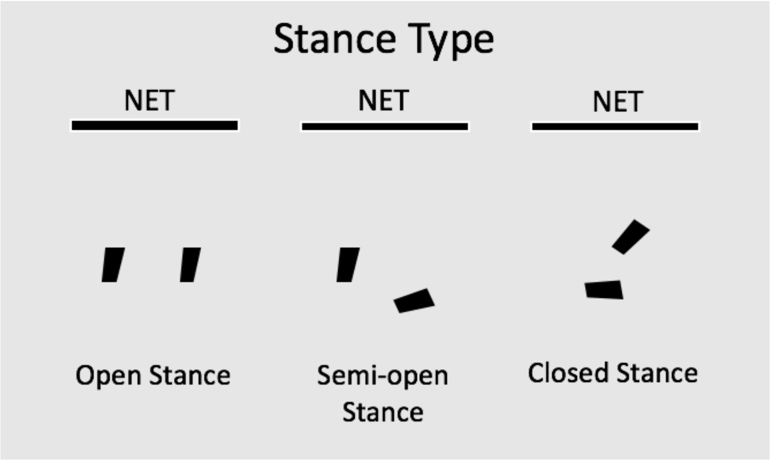


Figure 3.4. Illustrating the three different types of stance players used when performing groundstrokes during the second 10-minute block of the VR Task.

#### *3.2.8.2 Number of steps*

A video camera (Sony HDR-CX405 HD Camcorder) was used to assess the footwork of participants when performing forehand and backhand groundstrokes in VR and real-world conditions. Footwork referred to the number of steps participants took between the moment when the ball was fed to the moment when participants finished their forehand or backhand follow through with their racquet.

### 3.2.9 Statistical Analysis

Mixed effects regression models were used to estimate differences between each condition. For numeric variables including the presence factor scores, a mixed effects model was used with random effects for each participant and a fixed effect for the condition (VR racquet, VR handle). Likelihood ratio tests were run to assess the effect of shot type and condition by comparing the full model against the model without the effect in question. Assessments about the magnitude of effects between groups were based on linear contrasts of the model fixed effects and their 95% confidence intervals using the Holm method to adjust for multiple comparisons. The variable stance was assessed by transforming each type of stance into numeric format. Mixed effects regression models were then used with random effects for each participant and a fixed effect for condition type to observe whether stance type differed between conditions**.** Proportions were then calculated by summing the times each participant used the same stance when hitting forehands and backhands in the real-world as they did in the VR conditions. This number was then divided by the total number of participants to reveal the proportions for each shot type and condition. The assumptions of the statistical tests were examined by visually inspecting the data using QQ plots and density plots, and all assumptions were met. A total of 8 participants (4 male and 4 female) did not complete the real-world condition (4 missed due to being absent and 4 were injured). This was treated by removing the comparison of real-world and VR conditions for these participants. All analyses were performed in the R language (R Core Team, 2014) and the *lme4* package (Bates et al., 2015) was used for the mixed modelling.

## *3.3* Results

### 3.3.1 Sense of presence questionnaire

#### *3.3.1.1 Spatial presence*

Participants spatial presence scores were considered to be in the high range in the VR racquet (M = 3.60, SD = 0.58, 95% CI [3.39, 3.80]), and VR handle (M = 3.69, SD = 0.47, 95% CI [3.49, 3.9]) conditions (p = 0.18).

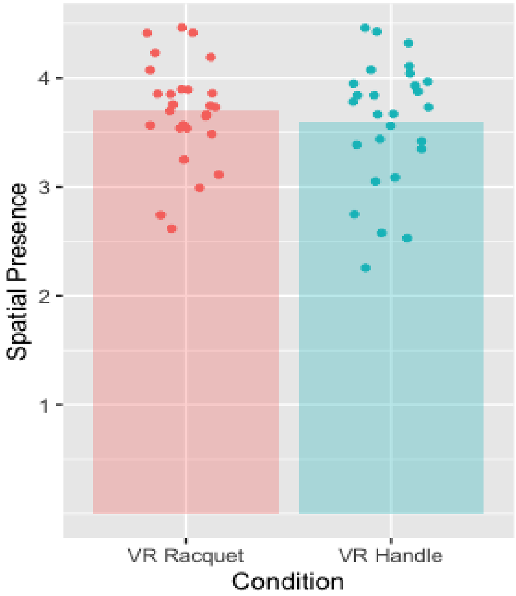


Figure 3.5. Comparison of the mean and individual spatial presence scores across VR Conditions.

### *3.3.1.2 Engagement*

Engagement scores were considered to be in the high range in the VR racquet (M = 3.89, SD = 0.59, 95% CI [3.66, 4.11] and VR handle (M = 3.84, SD =0.58, 95% CI [3.62, 4.07] conditions. There was no significant difference in the level of engagement found between VR conditions (p = 0.7).

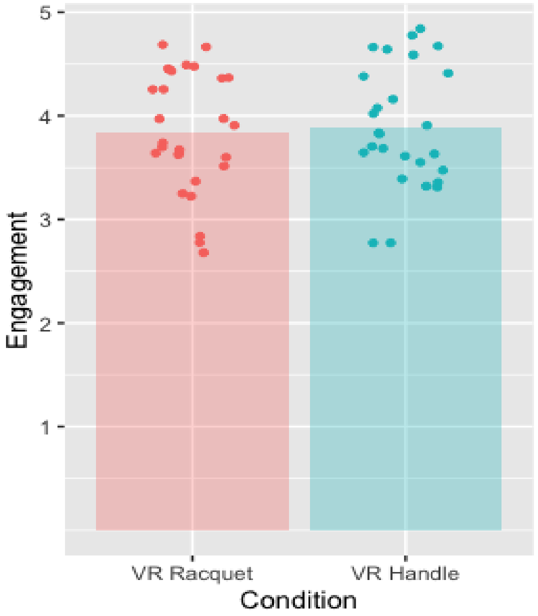


Figure 3.6. Comparison of the mean and individual engagement presence scores across VR conditions.

### *3.3.1.3 Ecological validity*

Participants scores in ecological validity were considered to be in the high range in the VR handle (M = 3.79, SD = 0.47, 95% CI [3.6, 3.97] and the VR racquet condition (M = 3.69, SD = 0.5, 95% CI [3.5, 3.88], p = 0.29). No significant difference in ecological validity scores was found between VR conditions.

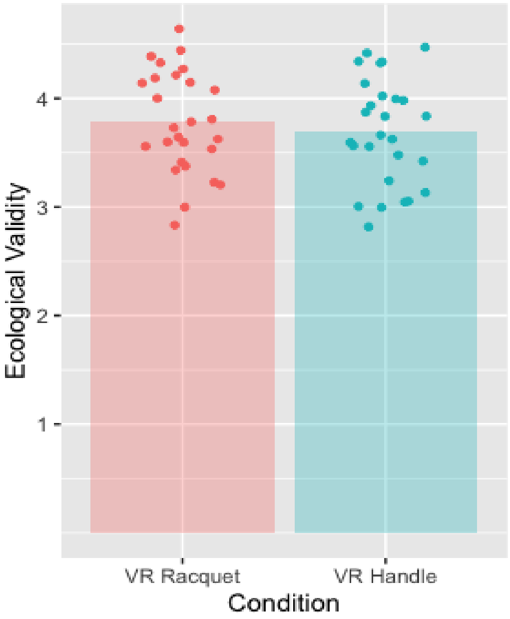


Figure 3.7. Comparison of the mean and individual ecological validity presence scores across VR conditions.

#### 3.3.1.4 *Negative effects*

Based on the 1 – 5 scaling system with 1 being the lowest possible score, negative effects scores were similarly low in the VR racquet condition (M = 1.37, SD = 0.74, 95% CI [1.13, 1.61] as well as the VR handle condition (M = 1.26, SD = 0.45, 95% CI [1.02, 1.50] (p = 0.5).

### 3.3.2 Objective measures

#### 3.3.2.1 *Stance*

Analyses revealed that participants used the same stance when hitting forehand groundstrokes in the VR conditions as the real-world condition for 85% (17/20) of forehands and 70% (14/20) of backhands. A likelihood ratio test revealed no significant effect of condition in our model (p = 0.12). Notably, all participants used the same type of stance for all ten shots hit (i.e. if they used an open stance on shot 1, they continued using this stance for the remaining nine shots). A significant effect for shot type (p = 0.0001) was found, with participants using an open stance to hit forehand groundstrokes 96% (95% CI [89, 100]) of the time, compared 14% using an open stance (95% CI [7, 22]) when hitting backhand groundstrokes. The interaction in our model (condition x shot type) was not significant (p = 0.55).

#### *3.3.2.2 Steps*

The effect of condition on our model was found to be significant (p = 0.0001). This equated to participants taking 0.6 less steps in both the VR racquet condition (M = 5.0, 95% CI [4.8, 5.3]) and the VR handle condition (M = 5.0, 95% CI [4.8, 5.2]) compared to the real-world condition (M = 5.6, 95% CI [5.4, 5.9], p = 0.001). The effect size of the real-world and VR conditions was 0.5 which was deemed to be a moderate effect size. A likelihood ratio test revealed that the interaction in our model (condition × shot type) had no significant effect on the number of steps taken prior to performing a forehand or backhand groundstroke (p = 0.08).

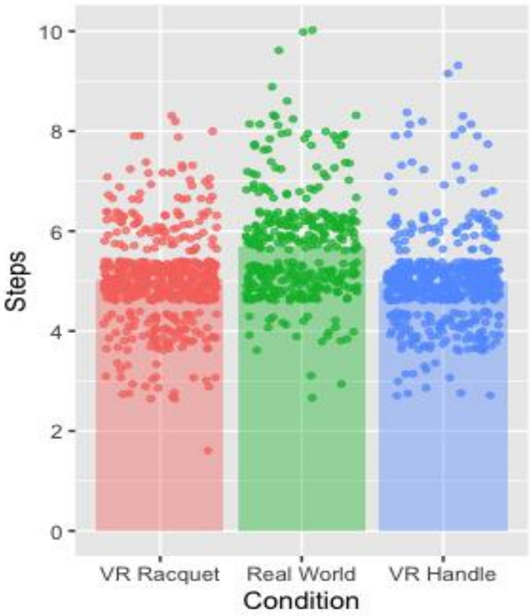


Figure 3.8. Comparison of the mean and individual number of steps taken across VR and real- world conditions.

## 3.4 Discussion

This study examined the representativeness of a VR tennis environment relative to a real- world tennis setting. There were two key findings from this study. First, participants scored in the high range for presence factors (engagement, ecological validity and spatial presence) during both VR conditions. Notably, this result occurred without any accompanying reports of negative effects. Second, the action responses of participants – namely the type of stance used to perform groundstrokes – were representative of real-world tennis.

Results from the sense of presence questionnaire revealed that participants experienced a high sense of presence during both VR conditions. The high range of scores for engagement (VR racquet condition, M = 3.89 out of a possible max score of 5) suggest that participants were highly engaged in the VR experience. Likewise, the high scores found for spatial presence and ecological validity indicate that participants felt they could effectively interact with the VR environment with a strong sense of control. One could argue that a limitation of common training tools used by coaches (e.g., watching 2D vision) is their lack of engagement, with many tools inhibiting the ability to interact and therefore influence the course of events shown in the display. The results from this study suggest that players using Tennis VR will have a subjective learning experience that feels enjoyable, engaging and interactive, whilst having a strong sense of 'being there' in the performance environment. Notably, there is little research assessing sense of presence in sport simulations (e.g., 2D video presentations or VR environments). Harris et al., (2018) is a rare exception, but we cannot compare our results with their study as different questionnaires were administered.

Future research should explore whether sense of presence is associated with the novelty of the VR experience or whether it is preserved over time.

With regards to the action responses, the type of stance used to perform groundstrokes in VR tennis paralleled the stance used in real-world tennis (85% match between VR and real-world for forehands, 70% for backhands). This is indicative of *action fidelity* – a core tenant of representative learning design. We acknowledge, however, that a significant difference was observed between VR and real-world tennis in the number of steps taken when performing groundstrokes. This difference equated to 0.6 fewer steps (mean difference) in VR tennis. We suspect this might have been caused by player's movements being constrained by the VR headset (e.g., the wire attached to the headset, and the headset's mass). Additionally, although field of regard (total area that can be captured by a person) was not restricted in the VR environment, field of view (the extent of the environment that can be seen at a given moment) was limited, which may have influenced perception and action when playing VR tennis. It is also possible that players actions (such as number of steps) were influenced by the presence of the crowd in the VR environment, therein causing differences to the real-world condition where no crowd was present. Certainly research has shown that surroundings within VR environments can induce a sense of anxiety (Stinson and Bowman, 2014). Further research is warranted to understand the factors that potentially influence movement behaviour.

Representative learning design contends that for skills to transfer from training to competition, players must base decision making and action responses on comparable information to that of the real competition environment (Loffing et al., 2016; Pinder et al., 2011). It has been shown that skilled tennis players use ball flight information to anticipate the falling point of the ball and decide the type of stance they will use to perform the upcoming shot (Williams, Vickers, & Rodrigues, 2002). Therefore, our results suggest that the ball flight information presented in the VR simulation prompted participants to move to the ball and position their bodies (type of stance used) in a representative way, thus prompting real-world action responses. However, because participants responded to the same ball trajectory ten times in a row for both types of groundstrokes, participants may have used prior knowledge of the ball's landing position to anticipate some shots, rather than using ball flight information. Future research should aim to use several different ball trajectories to eliminate the chance of participants using prior knowledge to facilitate anticipation. Nevertheless, these findings show that real-world action responses can be reproduced in this VR Tennis simulation, which is promising for transferring skills from VR to the real performance environment.

The similarity in results between the two VR conditions in this study is worth noting. Specifically, our results revealed that using a smaller racquet handle device did not significantly change action behaviours (stance and number of steps taken) and sense of presence compared to using a tennis racquet. However, future research should compare the arm biomechanics and swing velocities of groundstrokes when using the handle device as compared to the tennis racquet. This may provide insights about whether using the handle device creates any negative effects on swing technique in the real-world (e.g., different swing patterns, racquet head speed changes). Likewise, follow-up investigations should explore the ability of players to control the direction of their shots (e.g., ability to hit cross court and down the line towards a target) in VR during different match-play situation (e.g. high-pressure situations) and whether this is influenced by the type of racquet used.

Given that our tennis VR environment effectively simulated real-world tennis performance by simulating stepping and stance behaviour, we hypothesise that VR tennis can be used as a training tool to enhance perceptual-cognitive skill in tennis (presuming the training program is appropriate for the player engaging with the tool). With this in mind, a unique feature of VR technology is the capability of manipulating any aspect of the environment in real time. This includes utilising AI to control the strengths, weaknesses and tactics of opponents on a point by point basis, changing the speed abilities of the opponent, and altering other environmental variables such as crowd noise to induce a sense of pressure on players. This provides an opportunity to expose athletes to specific situations they will face during real competition (e.g., experiencing booing or loud cheers from a crowd during a close tie break in tennis). This level of environmental manipulation is not possible in the real-world training environment and is therefore a significant advantage of VR.

## 3.5 Conclusion

This study applied key principles of representative learning design and the modified perceptual training framework to examine the representativeness of a VR tennis environment for simulation of tennis performance. The assessment of spatial presence, engagement and ecological validity suggest that Tennis VR provides a high level of presence with minimal negative effects. The movement behaviour in the VR environment indicates that Tennis VR represents real-world tennis movements. The next step in this line of research is to examine whether Tennis VR can facilitate the development of pattern-recognition skill; that is, the ability of players to identify patterns of play or an opponent’s tactics during a match. An exciting question is whether it is possible to use Tennis VR’s AI capabilities to prepare players for patterns of play that are likely to be used by upcoming opponents.

# Chapter 4: Can skilled junior tennis players identify and utilise contextual information that occurs at different frequencies? Exploring anticipatory behaviour using a virtual reality tennis simulation

# Abstract

It is well established that skilled performers can effectively use prior sources of contextual information to enhance anticipation performance, compared to less skilled performers. However, little is known about the relative difficulty of identifying different types of contextual information and the requisite regularity of patterns to influence anticipation. This study used a virtual reality tennis simulation to assess the ability of tennis players to identify two specific serving patterns being used by the opponent. The two serving patterns were related to the opponent’s action tendencies, with a wide serve pattern connected to the side of the court the point was played on (advantage side of the court), and a tee serve pattern connected to the point score in the game (0-0). We assessed skilled junior players ability to identify serving patterns by controlling how frequently they occurred during matches (e.g. 100%, 90%, 80% and 70% of the time). There were three key findings. First, a wide serve pattern that occurred 100% of the time resulted in more rapid improvements in response time. Second, players had more difficulty explicitly identifying serving patterns that were connected to the current score, compared to identifying patterns based on the side of the court the opponent served from. Third, players did not initiate a movement response until after the opponents’ racquet-ball contact when returning serve. The discussion focuses on the advantages of using virtual reality for investigating the processes involved in anticipation skill due to the representativeness of the task. We conclude that contextual information needs to occur at a high frequency for skilled junior players to utilise this information.

## 4.1 Introduction

It is clear that contextual information, such as an opponent's action tendencies, significantly contributes to anticipation expertise in sport, particularly in situations where considerable time pressure exists (e.g., returning serve in tennis) (Abernethy et al., 2001; Triolet et al., 2013). Yet, in contrast to the abundance of research focusing on the use of postural cues for facilitating anticipation, contextual information has rarely been investigated (Farrow & Reid, 2012; Loffing & Hagemann, 2014; Murphy et al., 2016) despite the early work of Alain and Proteau (1980) who found athletes to allocate probabilities to likely events as a means of decreasing uncertainty. Similar to the methods used to investigate postural cues, the majority of research examining the contribution of contextual information has relied on video-based occlusion tasks that are not adequately representative of the real performance environment (e.g. Gredin et al., 2018). Therefore, this study seeks to add to the existing knowledge of anticipation behaviour through the application of virtual reality (VR) technology, which has the capability of providing a representative testing environment (see Le Noury et al., 2020). Specifically, VR technology can adequately represent the perception-action couplings that exist during competition, and equally allows for contextual information to be easily manipulated to further explore its contribution to anticipation expertise.

Compared to their less skilled counterparts, skilled performers have been found to use multiple sources of contextual information to facilitate anticipation in advance of postural cues becoming available. These sources include the action tendencies of opponents (Barton et al., 2013; Mann, et al., 2014; Gredin, et al.,, 2018), the positioning of players on the court or field (Loffing et al., 2014; Loffing, et al., 2016; Murphy et al., 2016), the order of action sequences (Loffing, et al., 2015; Murphy et al., 2018) and action tendencies linked to the score in a match (Farrow & Reid, 2012; Runswick et al., 2018a, Runswick et al., 2018b).

Specifically, expert tennis players have reported during interviews that they frequently use contextual information related to a server's action tendency linked to the score to form event probabilities when returning serve; “ Statistically, if you know a guy prefers a certain serve on a certain point, or a big point, say key points in the matches, then you can take a calculated risk or a guess” (Vernon et al., 2018, p. 85). Expert performers have demonstrated their ability to actively search for, identify and utilise sources of contextual information to update their event expectations ‘on the fly’ and inform anticipation responses (Mann et al., 2014; Crognier & Fery, 2005).

A recent body of work has demonstrated that skilled tennis players can accurately anticipate an opponent's stroke above chance levels, even when postural cues are removed and players are reliant on contextual information sources (Murphy et al., 2016). In a series of follow up studies, it was reported that the positions of players on the court, movements of players and the ball, shot sequence patterns, and the angles between players and various court markings (e.g. side lines and baseline) all contributed to successful anticipation performance (Murphy et al., 2018; Murphy et al., 2019a; Murphy et al., 2019b). Therefore, these sources of contextual information may be the minimal essential information needed for successful anticipation, with later-arising postural cues from an opponent's action being confirmatory in nature (Muller & Abernethy, 2012; Murphy et al., 2018). Indeed, it has been suggested that earlier identified contextual information reduces the number of action possibilities considered by experts, with later occurring postural cues acting to further decrease the options available to the opponent, therefore enhancing anticipation performance (Murphy et al., 2019a). Collectively, past research has clearly demonstrated the expert advantage over less skilled performers to identify and utilise contextual information to enhance anticipation performance.

However, there are at least three key issues that remain unresolved. These issues include (1) the relative difficulty of partitioning the contribution of different types of action tendencies (e.g. information connected to a specific score relative to court position), (2) the amount of exposure to a recurrent pattern required for skilled performers to utilise it as a probabilistic information source, and (3) whether progressing the current anticipation testing paradigm from a single response measure (e.g. Farrow & Reid, 2012) to more representative tasks that require further responses after the initial response is measured (e.g. playing the rest of the point out after returning a serve in tennis) masks the identification of patterns, therefore reducing the contribution of anticipation.

Additionally, there have been issues associated with the techniques used to measure the contribution of contextual information to anticipation expertise. The common approach has been to present video-based presentations of occluded movement patterns to performers who register their judgments by pressing a button (e.g. Loffing et al., 2015; Farrow & Abernethy, 2003) or verbally communicating their response (e.g. Smeeton et al., 2005). A central criticism of this approach is that the response methods used to make anticipatory judgments are far removed from the actions produced in the real performance setting (see Hadlow et al., 2018). Although some studies have used representative actions (e.g., passing a ball into a screen), these actions are not coupled with perceptual information in a way that is adequately representative of the performance environment. Together, these limitations mean that most previous anticipation studies have only partly reproduced the task they are designed to represent, therefore reducing the validity of these findings and how they explain real world anticipatory behaviour (Pinder et al., 2011).

An improved understanding of anticipation expertise in sport requires more representative methodological techniques. Recreating testing environments that appropriately simulate perception-action cycles to draw out more natural anticipatory responses from performers will allow researchers to assess anticipation skill from a player's egocentric perspective (Tarr & Warren, 2002; Murphy et al., 2018). Additionally, the anticipation testing environment should allow for the information presented to be directly influenced by the performers action behaviours, whilst at the same time allowing for these interactions to be measured or recorded (Craig & Watson, 2011; Dessing & Craig, 2010). It follows that the emergence of VR technology has potential to be used for exploring the interactions between different forms of contextual information used by skilled performers to enhance anticipation performance (see Le Noury et al., 2020).

Therefore, this study aimed to assess the ability of tennis players to identify two specific serving patterns being used by opponents during a VR tennis simulation. The two serving patterns were related to the opponent's action tendencies, with a wide serve pattern connected to the side of the court the point was played on (advantage side of the court), and a tee serve pattern connected to the point score in the game (0-0). Further, the ability of players to identify the serving patterns was assessed by manipulating how frequently they occurred during tennis matches (e.g., 100%, 90%, 80% and 70% of the time). Uniquely, the anticipatory task required participants to play full tennis points after the initial anticipation response (serve return) was performed. This provided a more natural assessment of real competition anticipation performance. We hypothesised that greater exposure to serving patterns would result in faster and more accurate responses on points where the pattern was present. Furthermore, we predicted that participants would have more difficulty identifying recurrent patterns based on the scoreboard information as compared to the action tendencies of the opponent as evidenced through verbal report responses of participants (e.g., in-match interviews and post-task questionnaires). This would occur based on the tee serve pattern occurring less frequently compared to the wide serve pattern, and the stimulus of the scoreboard in the tee serve pattern not being as obvious, compared to the stimulus of the advantage side of the court whereby the wide serve pattern occurred.

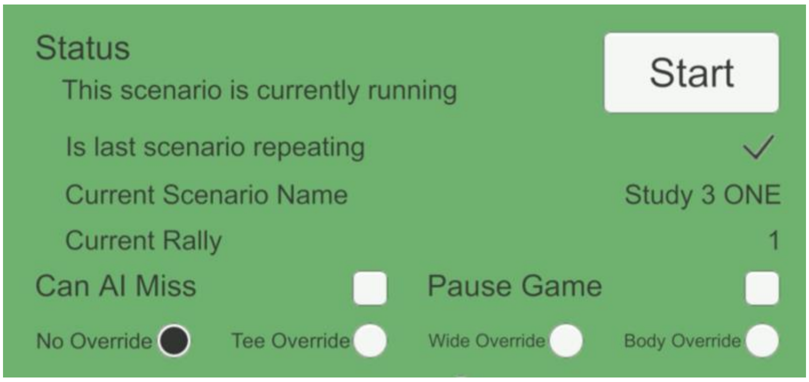
## 4.2 Method

### 4.2.1 Participants

Skilled male (n = 16) and female (n = 12) tennis players aged between 13 and 18 years (M = 15.7, SD = 1.4) from high performance tennis academies volunteered to participate in this study. These academies bring together talented junior tennis players to train and play matches under the guidance of coaches that hold the highest level of coaching qualification in Australia. Prior to the study commencing, participants averaged six hours of on-court tennis training and played two competitive singles matches on a weekly basis. All participants had a minimum of two hours of experience playing the VR tennis simulation used in this study (Le Noury et al., 2020). Informed consent from the participant's and their parents/guardians was provided prior to the participant commencing the study, and the study was approved by the ethics committee at the lead researcher's university.

### 4.2.2 Apparatus – Development of tactical behaviour in the VR simulation

Artificial intelligence (AI) software was created to enable researchers to manipulate the serving tactics used by the virtual opponent during VR tennis matches. The aim of the AI design was to control the virtual opponents serving tactics on a point by point basis across the course of a tennis match. The AI software was split into three developmental sections – (1) scenario editor, (2) match editor, and (3) match player. The scenario editor was focused on creating the structure of individual points on a shot by shot basis. This meant that for each point created, a specific type of serve (e.g., wide, tee or body serve) could be given to the virtual opponent and used to start the point. The match editor focused on assembling the individual points created in the scenario editor to construct a full match. Every odd numbered point listed (e.g. point 1, 3 etc.) was allocated a point which started on the deuce side of the court, and even numbered points were allocated points that started from the advantage side. This ensured players started each point in the correct position in relation to the point score. A match file was then created and used in the match player section for playing matches between a real player and the virtual opponent. The match player consisted of a dashboard (see Figure 4.1) which enabled researchers to control the virtual opponent’s serve type for each point, and how often each serve type was to be hit at particular moments in a match (e.g., 80% of points played on the advantage side would start with a wide serve). This therefore gave researchers complete control over the opponents serve tactics and allowed patterns of play to be developed over the course of a match.



Status
This scenario is currently running
Is last scenario repeating ✓
Current Scenario Name Study 3 ONE
Current Rally 1
Can AI Miss ☐
Pause Game ☐
No Override ●
Tee Override ○
Wide Override ○
Body Override ○

Figure 4.1. The dashboard in the match player section displaying the push buttons used to control the serving patterns of the virtual opponent. These buttons include No Override, Tee Override, Wide Override and Body Override.

### 4.2.3 Experimental Design

All participants played two tennis matches (total of 20 games per match) in a VR tennis simulation (see Figure 4.2) against two different virtual opponents of equal playing ability. To give participants the impression that they were playing against two completely different opponents in each match, one of the opponents presented as male whilst the other presented as female. The virtual opponent used one specific serving pattern in each match. In the first match, the opponent used a wide serve pattern, whereby a wide serve was hit when a point was played on the advantage side of the court (every 2nd point). The wide serve pattern was included to assess the ability of participants to identify patterns that occurred based on the opponent's action tendency to perform a wide serve on the advantage side of the court. In the second match, the opponent used a tee serve pattern that was directly connected to the point score in the game. That is, a tee serve was hit on the first point of each new game (i.e., when the point score was 0-0). The tee serve pattern was included to assess whether participants could identify a tee serve pattern that was directly connected to the point score. The gender of the virtual opponent and type of serving pattern they used was counterbalanced across experimental groups.

Participants were divided into four groups, with the key difference between groups being the amount of exposure to the wide and tee serving patterns (see Figure 2). These groups included a 70%, 80%, 90% and 100% group, with the percentage referring to how often the pattern occurred during the match. For example, in the 80% group, when participants were playing the match where the wide serve pattern occurred, a wide serve would be played by the opponent on 80% of points that begun on the advantage side of the court. During the next match, whereby the tee serve pattern was being used by the opponent, a tee serve was hit on the 1st point of a new game 80% of the time (16 out of 20 games).

Figure 4.2. The frequency of serve pattern occurrence for match one (wide serve pattern) and match two (tee serve pattern) across experimental groups.

### 4.2.4 Procedure

All experimental groups followed the same procedure. First, a HTC VIVE headset was placed on participants' heads and they had 5 minutes to familiarise themselves with the VR environment. This included scanning the environment, walking around, performing forehand and backhand groundstrokes, and having a warm-up rally with the virtual opponent. Participants were then told they would be playing 2 matches in VR against 2 different opponents, whereby the opponent would serve throughout the entire match. They were then asked to try and win as many points as possible during the matches, and to attempt to finish the points as quickly as possible by returning serve aggressively using topspin. These instructions were given to encourage participants to focus on reacting fast when returning serve (a key aim of the study). Once participants felt ready, they commenced the first match (approximately 20 minutes) whereby the virtual opponent implemented one of the serving patterns mentioned above. After the completion of the first match, participants came out of the VR environment and completed a post-task questionnaire (5 minutes). Participants then put the VR headset back on and completed the second match against the next opponent who implemented the second serving pattern (opponents counter-balanced amongst groups). The second match followed the same procedure as the first match, including the completion of the post-task questionnaire.

### 4.2.5 Objective Measures

#### *4.2.5.1 Response Time*

Response time was analysed when the player was returning the virtual opponent's serve and only during points whereby the serving pattern occurred (every point played on the advantage side during the wide pattern match, and every 1st point of each game during the tee pattern match). This was recorded as the time taken (m/s) for the participant to indicate their first response by moving to the left or right with any part of their body (e.g., shoulder, foot, knee, hands etc.) relative to the moment the virtual opponents racquet contacted the ball during the serve motion. Hence, response time was either a positive or negative number (Farrow & Reid, 2012). A negative time indicated the participant responded before the opponent's racquet-ball contact, whereas a positive time indicated the participant waited for ball flight information before making their response. Response time values were generated by simultaneously recording the field of view of the player in the virtual environment and players movements in the real-world, using a digital video camera (Sony HDR-CX405, 1920 x 1080p at 60fps). This video footage was then synced using video editing software so that the timing of players movements in the real-world and in the virtual environment matched. A single MP4 video file (30fpt) was then created and imported into an application called 'Tracker' which was used to analyse all returns of serve and generate response time values (precision value of ± 33 m/s).

#### *4.2.5.2 Response Accuracy*

The ability of players to move to the correct side (right or left) when returning serve was recorded. This was recorded only on points whereby either the wide or tee serving patterns were being implemented by the virtual opponent.

#### *4.2.5.3 Response type*

Response type specified whether players decided to return serve using a slice or topspin groundstroke. This was recorded only on points whereby the tee and wide serve patterns occurred.

### 4.2.6 Subjective measures

#### *4.2.6.1 In- match interview*

In-match interviews were conducted to capture participants in-performance thoughts. Participants were interviewed after every 3$^{rd}$ game in both VR tennis matches. The purpose of this interview was to assess whether participants had any explicit knowledge of the serving pattern being implemented by the virtual opponent as the much progressed. The interview questions were:

1. What are you doing to help you return serve aggressively?
2. Are you doing anything to help you win points more quickly?
3. Are there any other insights you can give me about the match or your opponent so far?

Participants were considered to have identified the serving pattern if they mentioned the service direction (wide or tee serve), the side of the court it was occurring on (advantage or deuce side) and made an accurate statement about how often it was occurring (e.g., “the opponent is serving out wide on the advantage side of the court most of the time", or "the opponent is serving down the tee on the first point of each game").

#### *4.2.6.2 Post-task questionnaire*

This measure considered whether participants were explicitly aware of the existence of serving patterns after the match had been completed. This was included to ascertain whether participants were consciously aware of the existence of a serve pattern but were not able to take advantage of it. The questions included:

1. Did you use or identify any information that helped you return your opponent's serve?
2. Are there any other insights you can give me about the match or your opponent?

### 4.2.7 Statistical Analysis

Mixed effects models were used to detect differences between each pattern exposure group and match type (tee and wide serve patterns). In the wide pattern match (opponent served out wide on the advantage side of the court), points whereby the pattern occurred were divided into 4 blocks of 10 points (e.g., block 1 = pattern exposures 1-10, block 2 = pattern exposures 11-20). In the tee pattern match, the points were divided into blocks of 5 because the pattern occurred less frequently (once per game when the point score was 0-0). For the variable response time, a mixed effects model with a Gaussian distribution was used. For the variable's response accuracy and response selection a generalised mixed effects model with a binomial distribution was used. These models included random effects for each participant and fixed effects for match type and exposure group. Verbal report data (e.g. explicit pattern identification) was analysed using a generalised mixed effects model with a binomial distribution. This model included random effects for each participant and fixed effects for age and exposure group.  Likelihood ratio tests were run to assess the effect of pattern exposure, match type, group and age by comparing the full model against the model without the effect in question. Assessments about the magnitude of effects were based on linear contrasts of the model fixed effects and their 95% confidence intervals using the Holm method to adjust for multiple comparisons. Statistical significance was accepted at $p < .05$. All analyses were performed in the R language (R Core Team, 2014) and the *lme4* package (Bates et al., 2015) was used for the mixed modelling.

# 4.3 Results

## 4.3.1 Objective measures

### *4.3.1.1 Response time*

#### *4.3.1.1.1 Wide pattern match*

There was a significant effect for pattern exposure (*p* = < .001) and the interaction between group x pattern exposure (*p* = < .001), however no significant effect for group was found (*p* = .07).  Indeed, all groups reduced response time from the start to the end of the match, but the rate at which groups improved differed (see Figure 4.3). Specifically, the 70% group significantly improved response time from exposures 1 to 10 to exposures 21 to 30 (M = 44.18, SD = 10.43, 95% CI [23.71, 64.65]) (*p* = .005). The 90% group improved significantly from exposures 1 to 10 to exposures 11 to 20 (M = 51, SD = 12.59, 95% CI [26.28, 75.72]) (*p* = .004). Moreover, the 100% group significantly improved between exposures 1 to 10 and 11 to 20 (M = 51.20, SD = 11.26, 95% CI [29.09, 73.31]) (*p* = .005). The 100% group was the only group to significantly improve between exposures 11 to 20 and 21 to 30 (M = 39.80, SD = 11.26, 95% CI [14.69, 58.91]) (*p* = .039).

##### *4.3.1.1.2* ***<u>Tee pattern match</u>***

There was a significant effect for pattern exposure (*p* = < .001), whilst the effect for group was less clear (*p* = .05), and there was no significant group x pattern exposure interaction (*p* = .88). Across each group, response times improved from exposures 1 to 5 and 6 to 10 (M = 17.09, SD = 6.77, 95% CI [-0.87, 35.05]), (*p* = .04); however, response times ceased to improve significantly after that. Group differences and variability is shown in Figure 4.3.

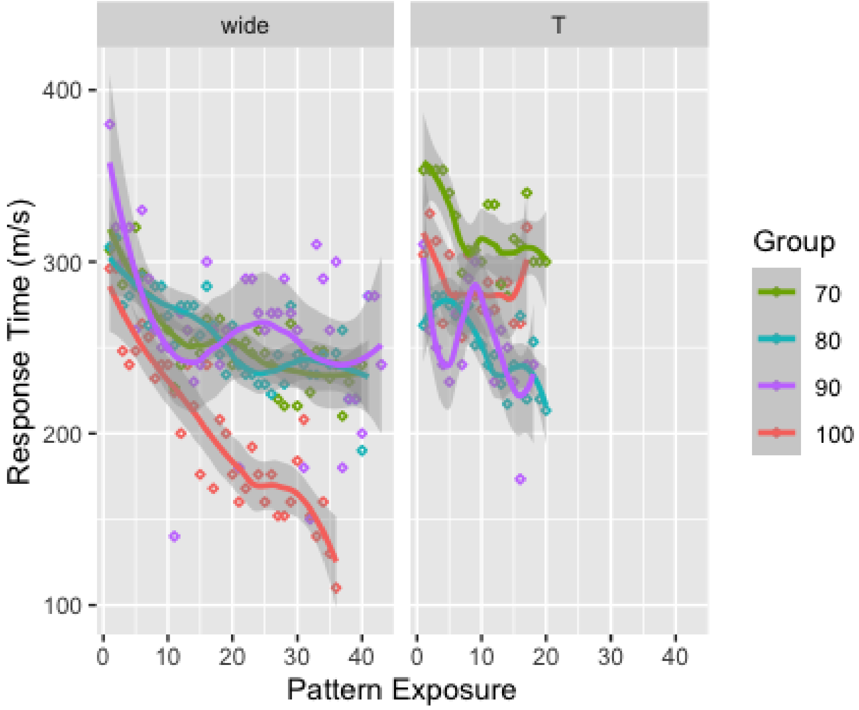


Figure 4.3. Group changes to response time across pattern exposures for the tee and wide pattern matches. The coloured lines represent the mean response time for each group across pattern exposures, with the shaded area representing their 95% confidence intervals. The points further display the variability of response time data across participants for each group.

#### *4.3.1.2 Response Accuracy*

##### *4.3.1.2.1 Wide pattern match*

There was no significant effect of group (*p* = .28), pattern exposure (*p* = .85), nor an interaction between group and pattern exposure (0.54). Mean response accuracy was high in all groups from the start to the finish of the match, and across pattern exposures (see Table 4.1).

Table 4.1. Group changes in mean response accuracy across pattern exposures in the wide match.

| | **Group** | | | |
|---|---|---|---|---|
| ***Exposures*** | **70%** | **80%** | **90%** | **100%** |
| **1-10** | M = 96%<br>SD = 0.30 | M = 94%<br>SD = 0.28 | M = 93%<br>SD = 0.38 | M = 100%<br>SD = 0.35 |
| **11-20** | M = 98%<br>SD = 0.31 | M = 96%<br>SD = 0.28 | M = 90%<br>SD = 0.28 | M = 98%<br>SD = 0.34 |
| **21-30** | M = 98%<br>SD = 0.31 | M = 96%<br>SD = 0.28 | M = 95%<br>SD = 0.38 | M = 100%<br>SD = 0.34 |
| **31-43** | M = 91%<br>SD = 0.34 | M = 99%<br>SD = 0.30 | M = 91%<br>SD = 0.39 | M = 100%<br>SD = 0.42 |
| **Total** | M = 95%<br>SD = 0.32 | M = 96%<br>SD = 0.28 | M = 92%<br>SD = 0.36 | M = 99%<br>SD = 0.36 |

##### *4.3.1.2.2 Tee pattern Match*

There was no significant effect of group (*p* = .62), pattern exposure (*p* = .17), nor an interaction between group and pattern exposure (*p* = .64). Mean response accuracy was high from the start to the end of the match, and across pattern exposures (see Table 4.2).

Table 4.2. Group changes in mean response accuracy across pattern exposures in the tee match.

| | **Group** | | | |
|---|---|---|---|---|
| **Exposures** | **70%** | **80%** | **90%** | **100%** |
| **1-5** | M = 97%<br>SD = 0.52 | M = 94%<br>SD = 0.48 | M = 90%<br>SD = 0.63 | M = 96%<br>SD = 0.57 |
| **6-10** | M = 93%<br>SD = 0.52 | M = 94%<br>SD = 0.48 | M = 95%<br>SD = 0.64 | M = 100%<br>SD = 0.57 |
| **11-15** | M = 83%<br>SD = 0.52 | M = 91%<br>SD = 0.48 | M = 100%<br>SD = 0.64 | M = 96%<br>SD = 0.57 |
| **16-20** | M = 85%<br>SD = 0.63 | M = 100%<br>SD = 0.51 | M = 100%<br>SD = 0.12 | M = 86%<br>SD = 0.10 |
| **Total** | M = 89%<br>SD = 0.55 | M = 95%<br>SD = 0.49 | M = 96%<br>SD = 0.51 | M = 95%<br>SD = 0.45 |

#### *4.3.1.3 Response type*

##### *4.3.1.3.1 Wide pattern match*

No significant effect was found for group ($p$ = .59), pattern exposure ($p$ = .15), nor the interaction between group and pattern exposure ($p$ = 0.46). Players consistently performed a higher number of topspin returns, compared to slice returns, over the duration of the match (see Table 4.3).

Table 4.3. The mean percentage of topspin and slice groundstrokes players hit when returning serve on points whereby the opponent was implementing the wide serve pattern.

| | **Topspin** | | **Slice** | |
|---|---|---|---|---|
| | **Mean (%)** | **SD** | **Mean (%)** | **SD** |
| **70% Group** | 90% | 0.30 | 10% | 0.30 |
| **80% Group** | 94% | 0.23 | 6% | 0.23 |
| **90% Group** | 94% | 0.23 | 6% | 0.23 |
| **100% Group** | 97% | 0.17 | 3% | 0.17 |
| **Total** | **94%** | **0.23** | **6%** | **0.23** |

#### *4.3.1.3.2 Tee pattern match*

There was no significant effect found for group (*p* = .07) nor the interaction between group and pattern exposure (*p* = .07), whilst the effect for pattern exposure was less clear (*p* = .03) (see Table 4.4).

Table 4.4. The mean percentage of topspin and slice groundstrokes players hit when returning serve, on points whereby the opponent was implementing the tee serve pattern.

| | **Topspin** | | **Slice** | |
|---|---|---|---|---|
| | **Mean (%)** | **SD** | **Mean (%)** | **SD** |
| **70% Group** | 49% | 0.50 | 51% | 0.50 |
| **80% Group** | 68% | 0.47 | 32% | 0.47 |
| **90% Group** | 88% | 0.29 | 12% | 0.29 |
| **100% Group** | 62% | 0.49 | 48% | 0.49 |
| **Total** | **67%** | **0.44** | **36%** | **0.44** |

#### *4.3.1.4 Verbal reports*

##### *4.3.1.4.1 __Wide match__*

In the wide match pattern, 68% (19/28) of players were able to explicitly identify the wide serve pattern. These players explicitly identified the pattern during the in-match interviews after an average of 6 service games had been completed. This equated to an average of 13 pattern exposures. Additionally, these players reported the existence of the wide serve pattern in the post-task questionnaire. There was no significant effect of age (p = .42), group (*p* = .39) or the interaction of age x group (*p* = 1.00).

##### *4.3.1.4.2 __Tee Match__*

11% (3/28) of players explicitly identified the tee serve pattern. The players who did identify this pattern did so during the in-match interviews after an average of 11 service games had been completed. These players also reported the existence of the tee serve pattern in the post-task questionnaire. One 16-year-old and two 18-year-old players in the 80% group identified the tee serve pattern.

## 4.4 Discussion

This study assessed the ability of skilled junior tennis players to identify serving patterns of play that were connected to the scoreboard (tee serve pattern) and the side of the court the serve was performed from (wide serve pattern) using a VR tennis simulation. Additionally, we examined the effect of using a representative VR tennis task (see Le Noury et al., 2020) on the anticipatory behaviours of tennis players. We unearthed three key findings. First, the wide serve pattern that occurred 100% of the time resulted in more rapid improvements in response time. Second, players had more difficulty explicitly identifying serving patterns that were connected to the current score, compared to identifying patterns based on the side of the court the opponent served from. Third, players did not initiate a movement response until after the opponents' racquet-ball contact when returning serve.

Response time was the measure used to capture differences in anticipatory behaviour between groups and across pattern exposures. In the wide pattern match, whereby opponent behavioural tendencies was the salient information source, all groups improved response time over the first 20 pattern exposures (50% of total exposures). Similar improvements occurred during the tee pattern match (scoreboard information was the salient information source) whereby all groups improved response time over the first 10 exposures (50% of total exposures). However, in the wide pattern match the 70%, 80% and 90% groups saw a plateauing effect in their response time from exposures 20 until the last exposure, compared to the 100% group who continued to improve response time from exposures 20 onwards (see Figure 3). This result suggests that the initial improvement in response time made by the 70%, 80% and 90% groups was due to task familiarity, and that the 100% group was the only group to improve their response time based on their ability to anticipate the serve using contextual information. In the wide pattern match, the opponent in the 100% group had the strongest tendency to serve out wide on the advantage side of the court (100% of the time), and players had no reason to believe the opponent would serve in a direction inconsistent with their action tendency. This may have led players to develop a greater sense of certainty in their ability to anticipate serve direction and contributed to a continuous improvement in response time. In the tee pattern match, none of the groups showed a significant change in response time from the 10th pattern exposure onwards, suggesting that the initial improvement seen in this match was also due to task familiarity. Therefore, we conclude that all improvements in response time were due to task familiarity, except for the 100% group in the wide pattern match who improved based on anticipation of the serve. Our result that a

100% pattern frequency is required for pattern identification and subsequent improvements in response time conflicts with past research, demonstrating a 75% (Green & Flowers, 1991) and 80% (Alain & Proteau, 1986) probability of a pattern occurring is sufficient for pattern identification to occur and to elicit faster response times. However, these studies used single response trials and de-coupled perception action responses which may have caused patterns to be identified more easily at lower frequencies, compared to the present study that used a more representative task approach. Our results suggest that serving patterns need to occur 100% of the time to elicit faster response times, and that patterns are more likely to be identified if they occur quite frequently during the match (e.g. a wide serve that occurs every 2nd point, versus tee serve that occurs once per game in tennis).

Importantly, however, despite the 100% group anticipating the wide serve pattern (mean response time of 150 m/s in the final 10 pattern exposures), players did not perform a movement response until after the opponent made racquet- ball contact. This suggests players were waiting for confirmatory ball flight information before actioning a response. The 75% of players who were explicitly aware of the wide serve pattern in the 100% group, may have waited for ball flight information before initiating a response because the serve speed and placement was not challenging enough to warrant an earlier response, hence they could afford to wait and still successfully perform a return. This reasoning aligns with the Bayesian framework for probabilistic inference which predicts that the reliance on contextual information is subject to the relative uncertainty associated with other sources of available information. Indeed, this reasoning also supports the results of another study incorporating VR technology that found baseball batters to utilise contextual information more when they were less certain of the upcoming flight of the ball (Gray and Canal-Bruland, 2018). It is also possible that players may have been unaware of how to take advantage of the contextual information or felt that the cost of making an inaccurate judgment outweighed the benefits of anticipating prior to the opponent's racquet-ball contact (e.g. moving before the opponent's racquet-ball contact risked moving to the wrong side and being aced) (James & Bradley, 2004; Loffing et al., 2015; Mann, Schaefers, & Canal-Bruland, 2014). Notably, however, the 25% of players who were not explicitly aware of the wide serve pattern also improved response time at the same rate as players who were explicitly aware of the pattern. This suggests that players implicitly identified the pattern without acquiring explicit knowledge, therefore improving response time (see Farrow & Reid, 2012, Abernethy et al., 2012). Indeed, implicit learning has been shown to be more effective when performing tasks under pressure conditions, compared to explicit learning approaches (e.g. Farrow & Abernethy, 2002; Abernethy et al., 2012). Therefore, future research should explore the efficacy of VR for implicit learning of pattern identification and utilisation (Le Noury et al., 2019).

Response type (topspin or slice return) was a measure used to capture shot decision-making behaviour when players returned serve. Topspin returns are more frequently performed during tennis matches when the serve is directed closer to the returner, compared to slice returns that are more frequently performed when the serve is directed further away from the returner, which often places them in a more defensive situation (i.e. players may need to lunge or stretch to make racquet-ball contact) (Crespo & Miley, 1998). Results from the wide pattern match showed that players used topspin when returning serve 95% of the time on average, compared to performing a slice return 5% of the time. Since the wide serve performed by the virtual opponent landed within a one-step reach of players (allowing a topspin groundstroke to be more easily executed), this supports the notion that more topspin returns are performed when serves are directed closer to players. However, the serve in the tee pattern match was directed further away from players (closer to the centre line), and therefore players were in a more defensive return situation. This resulted in players performing a slice return 36% of the time (30% more than they did during the wide serve pattern match on average), with 67% of returns being hit with topspin (28% less than they did during the tee match on average). Although supplementary research is needed to further establish this result, the more frequent use of the slice during the tee pattern match may suggest that players were able to adapt their decision-making behaviour based on different perceptual information (unique ball flight information of the wide and tee serves) being presented in the virtual environment.

Furthermore, past research exploring anticipation skill has used a combination of in-situ tasks that require participants to perform in the real-world environment, and video-based tasks that present a simulation of a real-world environment in a 2D video format. Interestingly, our results are broadly in-line with past research using in-situ tasks that have shown skilled performers to make anticipatory actions after the opponent’s racquet-ball contact (e.g. Howarth, Walsh, Abernethy, 1984; James & Bradley, 2004, Troilet et al., 2013). One incongruity does exist with past research findings that demonstrated skilled performers make anticipatory judgments up to 580 m/s before their opponents make racquet-ball contact (e.g., Farrow & Reid, 2012; Abernethy et al., 2001). One possible explanation for this is that the anticipatory responses used in these video-based tasks (e.g., button presses and verbal responses) have not been representative of responses seen in real-world competition settings (see Dicks, Araujo, & van der Kamp, 2019). Consequently, past research has examined the perceptual processes involved in anticipation, however failed to couple these processes with representative actions (Loffing et al., 2015). Therefore, the applicability of results from past research using de-coupled tasks to the real-world setting is questionable. Comparatively, players in our study were required to perform representative actions which maintained the perception-action loop (e.g. responding to representative ball trajectories and performing forehand and backhand groundstroke returns) (see Le Noury et al., 2020) and ultimately play the entire point after their return of serve was completed. This provided another dimension of representativeness not observed in previous anticipation research and necessitated that players allocate additional mental effort into decision-making processes (e.g. deciding where to direct their return of serve and shots thereafter, deciding to hit with topspin or slice, executing groundstrokes with appropriate swing technique, footwork and accuracy). Therefore, VR technology may be a better alternative to using in-situ and video-based anticipation tasks, because it can, a) provide a representative competition environment that couples perception and action (similar to an in-situ task), and importantly, b) allow for contextual information to be tightly controlled and replicated across multiple participants (a key characteristic of video-based tasks, but a difficult undertaking during in-situ tasks).

The results from players verbal reports demonstrated that players had more difficulty explicitly identifying the tee serve pattern connected to the score, compared to the wide serve pattern based on the side of the court opponents served from. This likely happened because the tee pattern occurred less frequently than the wide serve pattern (once per game compared to every second point). Another reason may be that the scoreboard stimulus in the tee pattern was not as obvious as the side of the court stimulus (advantage side) in the wide serve patterns. However, evidence from Farrow and Reid (2012) suggests that a scoreboard is a powerful enough stimulus for experienced players to identify a serving pattern. Therefore, perhaps junior skilled players are not as attuned to scoreboard information, and players become more attuned to this information as they get older and gain more experience. We conclude that patterns of play used more frequently by opponents during match play increase the chance of players identifying the pattern and using this information to facilitate serve return performance. In line with past research, players reported attempts to use information around the opponent's swing and ball toss kinematics to predict incoming serve direction (Milazzo et al., 2016; Murphy et al., 2016), albeit failed to recount any specific positive serve return predictions. This may have been due to the opponents serve kinematics not matching to the exact ball trajectory outcome. However, a different service action was used by the virtual opponent for each service direction (wide, body and tee), therefore if this information was identified it could have been used to assist anticipation.  Further research is warranted to establish whether players can be trained to identify patterns more quickly with less exposure, and if learnt patterns established through a high exposure frequency can be maintained over time (days, weeks, months, years) (Abernethy et al., 2012; Williams & Jackson, 2019).

Another key finding of this study is that players did not decrease their response accuracy as improvements in response time were seen. Therefore, there was no speed-accuracy trade off when performing the VR anticipatory task. An issue with past research has been the existence of a speed-accuracy trade off, which can occur in tasks that de-couple perception and action, and that do not include realistic consequences for poorly executed actions or having poor accuracy (Farrow & Reid, 2012; Farrow & Abernethy, 2003; Farrow, Abernethy, & Jackson, 2005). Therefore, our results further highlight the benefits of using VR in future research to grasp a more reliable or representative understanding of anticipatory behaviour and the relationship between anticipation speed and accuracy.

It should be noted that one of the limitations of this study was that there was no control group. A control group that experienced no exposure to patterns in this study would have been beneficial for comparing against other levels of exposure (i.e., the 70%, 80%, 90% and 100% groups). Indeed, participants in each group may have had other differences apart from the level of pattern exposure they experienced, which may have impacted the results of this study. One of these differences may have been their working memory capacity which affected their ability to recognise the tee and wide serve patterns. Therefore, future research should aim to assess the influence of working memory capacity on the ability of participants to identify and hold information about patterns in mind whilst performing the primary task at hand.

## 4.5 Conclusion

To our knowledge, this study is the first to examine the ability of junior tennis players to identify and utilise situational probability information using VR technology. Our results illustrate that a wide serve pattern that occurred 100% of the time resulted in more rapid improvements in response time when returning serve, however players did not initiate anticipatory movements until after the opponent's racquet-ball contact. Moreover, players had more difficulty identifying serving patterns that were connected to the current score, compared to identifying patterns based on the side of the court the opponent served from. It is clear that further consideration is needed for understanding how to develop junior players awareness of situational probability information, and how to train their ability to take advantage of this information to enhance their performance (Williams & Jackson, 2019). Virtual reality simulations have several advantages over past tools used to assess anticipatory behaviours, including perception-action coupling, requiring representative action responses, consequences for poorly executed responses that correspond to real-world consequences, and the ability to apply pressure on players through manipulating contextual information in the VR environment (e.g. crowd noise). We conclude that contextual information needs to occur at a high frequency for skilled junior tennis players to utilise this information. Therefore, further research should explore whether skilled junior players can be trained to utilise contextual information that occurs at lower frequencies. Additionally, further research is needed to establish whether decision-making behaviour can be trained in various tennis situations using this VR environment, and whether these decision-making skills can be transferred to the real performance environment.

# Chapter 5: Using VR to assess the influence of explicit instructions vs no-instruction on the development of pattern recognition and utilisation skill in tennis

# Abstract

Expert performers can use the postural cues and contextual information generated from an opponent’s action tendencies to predict future events (Williams, Ward, Knowles, & Smeeton, 2002; McRobert, Ward, Eccles, & Williams, 2011; Farrow & Reid, 2012). Consequently, the training of players to identify and utilise these sources of information to enhance decision-making performance has been of strong research interest. However, most perceptual-cognitive training studies have focused on the use of postural cues, with only a small minority focused on the identification and utilisation of an opponent’s action tendencies or patterns of play. This study sought to enhance the decision-making skill of skilled junior tennis players using virtual reality technology by exposing players to a virtual opponent’s pattern sequence coupled with explicit instructions or no-instruction. In doing so, we compared the effectiveness of explicit instructions and no-instruction on learning to identify and utilise an opponents pattern sequence and performing under pressure conditions. Participants recruited for this study included skilled male (n = 3) and female (n = 2) junior tennis players aged between 14 and 18 years (M = 16, SD = 1.67) with an average of 8.5 years experience playing matches at a competitive level. A series of paired t-tests were run to explore differences in response time, response accuracy, response type, and the number of steps taken at the individual participant level. Key findings demonstrated that exposure to a pattern sequence coupled with explicit instructions resulted in faster changes to response time and response accuracy performance, compared to no-instruction learning. Contrary to *priori* predictions, instruction during training was not detrimental to performance under pressure. Future research should aim to give participants additional exposure to patterns of play. Furthermore, implicit instructional approaches that further limit rule formation during learning should be used in the future to assess their influence on performance under pressure, compared with more explicit instructional approaches.

## 5.1 Introduction

Expert performers can use postural cues and contextual information evolving from an opponent’s action tendencies to predict future events (Williams, Ward, Knowles, & Smeeton, 2002; McRobert, Ward, Eccles, & Williams, 2011; Farrow & Reid, 2012). Consequently, over the past decade, researchers have sought to train athletes to identify and utilise these sources of information with the hope of enhancing anticipation and decision-making performance in competition. However, the effectiveness of these training interventions rests on two key assumptions; (1) that perceptual-cognitive skill can be trained; and (2) that improvements to perceptual-cognitive skill can transfer to better performance in competition (Abernethy & Wood, 2010). Most training studies to date have focused on the use of postural cues, with only a small minority focusing on the ability to identify and utilise an opponent’s action tendencies or patterns of play (e.g., Williams, Herron, Ward & Smeeton, 2008; North et al., 2017; Gray, 2017). Furthermore, many training studies have been characterised by methodological shortcomings such as deficiencies in the representative design of training tasks and limited comparisons of the efficacy of various instructional approaches on skill development or performance under pressure (see Le Noury et al., 2019 for a review). The present study aims to address these issues by training the anticipation skill of skilled junior tennis players using virtual reality (VR) technology and comparing the effectiveness of explicit instructions and no-instruction on learning and performance under pressure.

A key consideration when devising a perceptual-cognitive skill training program is the instructional method used to elicit learning. Direct instructional approaches have largely been used in past perceptual-cognitive training studies, including explicit instructions in the form of if-then rules (e.g., Smeeton et al., 2005; Abernethy et al., 1999) and guided instructional approaches using colour cueing, directional arrows or verbal instruction (e.g., Abernethy, et al., 2012; Hagemann, Strauss, & Canal-Bruland, 2006; Klostermann et al., 2015). Although these methods have produced positive training effects, they result in the development of declarative knowledge that potentially causes performers to reinvest in this consciously acquired information, resulting in poorer performance under pressure (Abernethy et al., 2012). In contrast, more implicit approaches that aim to facilitate learning without players accruing explicit knowledge (e.g. Farrow & Abernethy, 2002, Gorman & Farrow, 2008) have been shown to result in more stable performance under pressure (Abernethy et al., 2012), albeit when coupled with longer learning periods (Green & Flowers, 1991). Indeed, findings from the motor learning literature have also found implicitly learned skills to be more robust under stress compared to skills learned explicitly (Masters, 1992; Liao and Masters, 2002). Therefore, it has been assumed that the positive effects of implicit learning over explicit methods of instruction will also be evident when training pattern recognition skill in sport.

Although research assessing the influence of different instructional approaches on the development of pattern recognition skill is scarce in sport, some attempts have been made to train novice soccer players (North et al, 2017) and skilled basketball players (Gorman & Farrow, 2009). The results of these training studies have shown improvements in pattern recognition skill when using explicit instructions, implicit instructions and guided instructional approaches, however these improvements have not yielded significantly better results than placebo and control groups (Gorman & Farrow, 2009, North et al., 2017). Furthermore, improvements in basketball players’ pattern recognition skill from pre-post training intervention showed no positive transfer to on-court performance. While these findings are not encouraging, given past research has demonstrated the effectiveness of instructional techniques, particularly the use of implicit methods for performing under pressure, further research is warranted to establish whether similar benefits are observed when training pattern recognition skill.

To this end, the design of future pattern recognition training in sport can be guided by the results of pattern recognition training in other research domains (e.g., Green & Flowers, 1991; Nissen & Bullemer, 1987; Milllward & Reber, 1972). For example, Green and Flowers (1991) trained participants to identify and utilise situational probability information about a moving ball that was presented on a computer screen. The ball followed a specific movement pattern that could be used to predict its final position and ultimately help participants catch the ball using a joystick. Results showed that repeatedly exposing participants to the ball's movement pattern with and without instructional guidance, enhanced their ability to predict the ball's end location compared to a contol group. Notably, participants given explicit instructions improved ball prediction performance but made greater joystick movement errors. Moreover, the no-instruction group made significantly fewer joystick movements earlier in the ball's trajectory (where a predictive pattern feature often occurred). These results suggest that more indirect instructional approaches (e.g., giving no-instruction) may be as effective as explicit instructions when training the identification and utilisation of patterns. It remains unclear whether the same pattern learning approach can be used to inform the design of sport-specific decision-making training. Arguably, pattern learning of this nature may be particularly beneficial in interceptive sports such as tennis, where the ability to identify and utilise patterns of play has been shown to significantly enhance anticipation performance (Farrow & Reid, 2012).

The historical work in sports-specific pattern recognition has also been hampered by several methodological limitations. For example, insufficient exposure to patterns has been a concern, which is thought to be particularly important when devising implicit learning approaches (North et al., 2017). There has also been a lack of control over the consistency of opponent’s movements in pre- and post-transfer tests (North et al., 2017; Gorman & Farrow, 2009), and the influence of instructional approach on performance under pressure has not been assessed. The use of video clips from a bird’s eye perspective and the use of a button press to denote a decision-making response limits immersiveness of the experiences and the generalisability of this work. In a similar vein, the poor representativeness of training conditions (i.e., lack of perception action couplings) also contributes to the mixed transfer effects observed in the real performance environment (Gorman et al., 2009; Hadlow et al., 2018). Noting these challenges, especially around the low efficacy of the training experience, a technology that has shown promise in simulating the perception-action couplings of actual sports skill performance is VR (see Le Noury et al., 2020). VR technology has been used to train anticipation and decision-making skill in baseball (Gray, 2017), revealing improvements from a pre to post-test on a VR batting test, on-field batting test, and a pitch recognition test. It also positively impacted batting statistics in the competitive baseball season post-intervention. This suggests that VR is a promising training tool in eliciting skill transfer to performance settings. It appears as though it may be most effective when researchers take advantage of the adaptive nature of animated VR simulations (i.e., manipulation of contextual information) and do not simply recreate the training environment (Gray, 2017).

Using a representative design approach through the use of VR technology, the present study aimed to enhance the capacity of skilled junior tennis players to identify patterns of play and utilise this information to enhance decision-making performance. Moreover, this study aimed to compare the effectivness of explicit instructions and no-instruction on learning and performance under pressure. Based on the work of Green and Flowers (1991) it was expected that participants in the explicit instruction group would learn to utilise patterns at a faster rate, compared to participants in the no-instruction group. However, participants in the explicit group would see a decline in performance under pressure conditions (as seen in measures of response time and response accuracy), compared to participants in the no-instruction group who would maintain their performance under pressure. Additionally, we expected that participants in the explicit group would see a change in their movement behaviours (e.g. number of steps) and type of shot performed (topspin or slice) under pressure conditions, compared to training conditions. Comparatively, we expected that participants in the no-instruction group would maintain their movement behaviour and type of shot performed under pressure conditions.

## 5.2 Method

Unfortunately, it must be highlighted that the Covid19 pandemic in 2020 had a significant impact on the experimental design of this study. The intended study had a minimum of 10 participants per experimental group, including a placebo and control group. Additionally, the study design included a transfer test to assess the level of skill transfer from the VR training environment to the real-world performance setting. Unfortunately, what is presented in the following sections is all the data that was able to be collected before the pandemic halted (and has still halted) all testing.

### 5.2.1 Participants

Skilled male (n = 3) and female (n = 2) junior tennis players aged between 14 and 18 years (M = 16, SD = 1.67) were recruited from a high performance tennis academy to participate in this study (see Table 5.1). All participants had a minimum of three hours of experience playing the VR tennis simulation used in this study (Le Noury et al., 2020). Informed consent from the participant’s and their parents/guardians was provided prior to the participant commencing the study, and the study was approved by the ethics committee at the lead researcher's university.

Table 5.1 Describing the characteristics of each participant in this study.

| **Participants** | **Experimental group** | **Age** | **Gender** | **Match-play experience (years)** | **Match frequency (weekly)** | **On-court training time (weekly)** |
|---|---|---|---|---|---|---|
| Participant 1 | No-instruction | 15 | Male | 6 | 2 | 6 hours |
| Participant 2 | Explicit | 16 | Male | 6 | 2 | 6 hours |
| Participant 3 | Explicit | 14 | Male | 8 | 2 | 7 hours |
| Participant 4 | Explicit | 18 | Female | 12 | 3 | 7 hours |
| Participant 5 | No-instruction | 18 | Female | 10 | 2 | 7 hours |

### 5.2.2 Experimental design

Participants' were randomly divided into two groups, including a no-instruction group (participants one and five) and an explicit group (participants two, three and four). The experimental design included two consecutive days of training with a *pressure test* at the end of each day. On day one (50 minutes) participants completed the first training session which consisted of playing 150 points against a virtual opponent in a VR tennis simulation. Participants then performed a further 20 points in a *pressure test* whereby we aimed to heighten the pressure experienced by participants'. Day two (30 minutes) required participants to complete a second training session which consisted of 50 points, followed by a further 20 points in a second *pressure test*. Participants were instructed during the training sessions and pressure tests to win as many points as possible against the virtual opponent (the length of points during training and pressure tests varied randomly between 4 and 8 shots).

Critically, imbedded within the VR simulation was a specific pattern sequence with three distinct features which will now be explained in more detail.

#### *5.2.2.1 Pattern sequence features*

The first two features of the pattern sequence were focused on the opponent's action tendencies (see Figure 5.1). The first feature included the opponent hitting a *short ball,* defined as a shot that landed close to or on the service line. A short ball was played by the opponent only once, and at a random time during each point that was played. When the VR opponent hit a short ball during the point, this indicated that their next shot in the rally would be directed towards the *deuce side corner position* of the court, landing close to the baseline (deep in the court) (see Figure 5.1). The deuce side corner shot was the second feature of the pattern. This shot was hit 80% of the time, with the other 20% of shots directed towards the middle part of the court. This created a pattern sequence that if identified, could be used to facilitate participants anticipation.

The third feature of the pattern was focused on participants decision-making. That is, when participants received the opponents deep corner shot (second feature), if they decided to direct their next shot *down the line* (towards the VR opponent's backhand side) they automatically won the point by the opponent not reaching the ball. However, if participants directed this shot towards the middle or cross court position of the court (towards the VR opponent's forehand side), they automatically lost the point by the opponent hitting a winner that was impossible for participants to return. Therefore, the third feature of the pattern sequence needed to be identified for participants to win points.

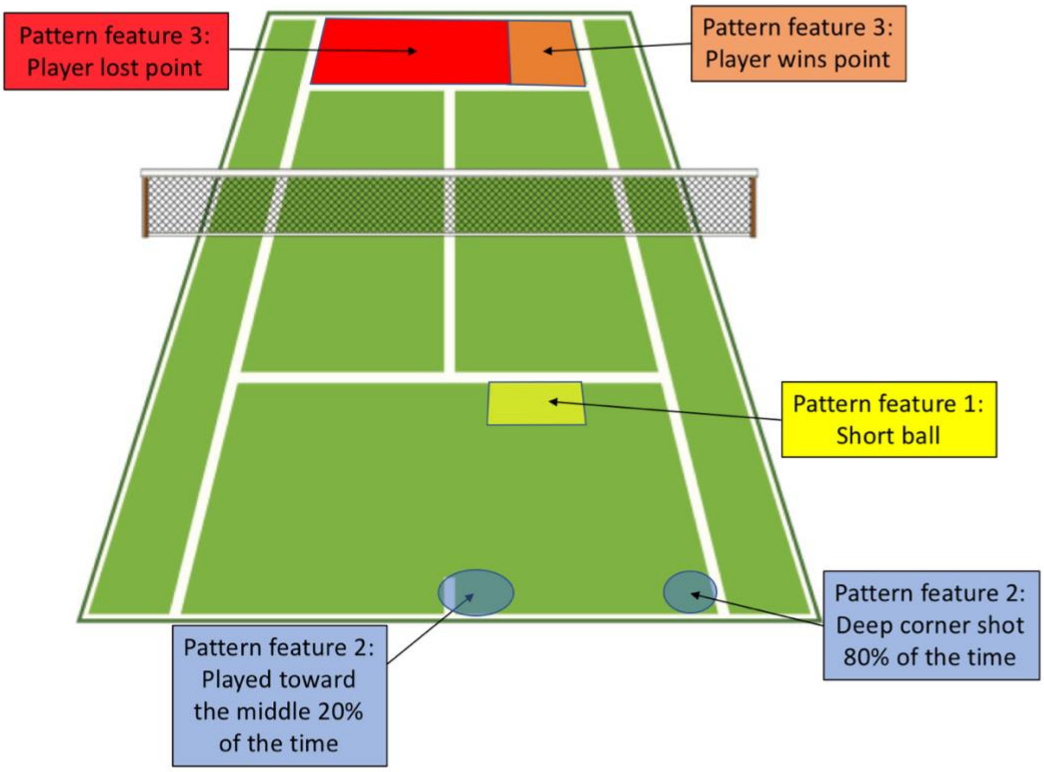


Figure 5.1. Displaying the three features of the pattern sequence. Pattern feature one = VR opponent hits a short ball. Pattern feature two = VR opponent hits a deep corner shot 80% of the time, and towards the middle 20% of the time. Pattern feature three = Participants won points if they hit down the line and lost points if they hit middle or cross court.

#### *5.2.2.2 The virtual reality task*

Participants were instructed to win as many points as possible against a VR opponent. Prior to commencing the task, a VIVE PRO VR headset (470 grams) was attached to participants head which immersed them in a VR tennis simulation (see Figure 5.2). This VR environment was designed to replicate a real-world tennis stadium, equipped with a hardcourt tennis court surface, large surrounding stand with a crowd of virtual people, a chair umpire, line judges and buildings that could be seen outside of the stadium. Additionally, participants could hear sounds that are typical of a real-world tennis environment, including the bounce of the ball, the sound of hitting the ball and the chair umpire calling the score. The first 5 minutes was dedicated to ensuring participants could accurately perform forehand and backhand groundstrokes using a racquet handle device used to simulate a real tennis racquet (see Le Noury et al., 2020). Specifically, participants practiced performing forehand and backhand groundstrokes in different directions including to the left and right of the VR opponent (i.e. down the line and cross court). Practice continued until participants could successfully control the direction of their groundstrokes, as this skill was an important aspect of the task and specifically related to the third pattern feature. At the start of each point, the participants positioned themselves at the centre ‘T’ location on the baseline and waited for the VR opponent to start the point by hitting a forehand groundstroke. The opponent fed the ball in from the centre ‘T’ position on the opposite baseline by hitting a forehand groundstroke towards the right-hand side of participants (close to participants). The point was then played out until the participant or VR opponent won the point by hitting a winning shot. After each point, participants had five seconds to move back to the ‘T’ position before commencing the next point. After every 10th point, the task was paused and participants were asked what they were doing to help them win points during the task. Immediately after each training session participants completed a five-item questionnaire (5 minutes).

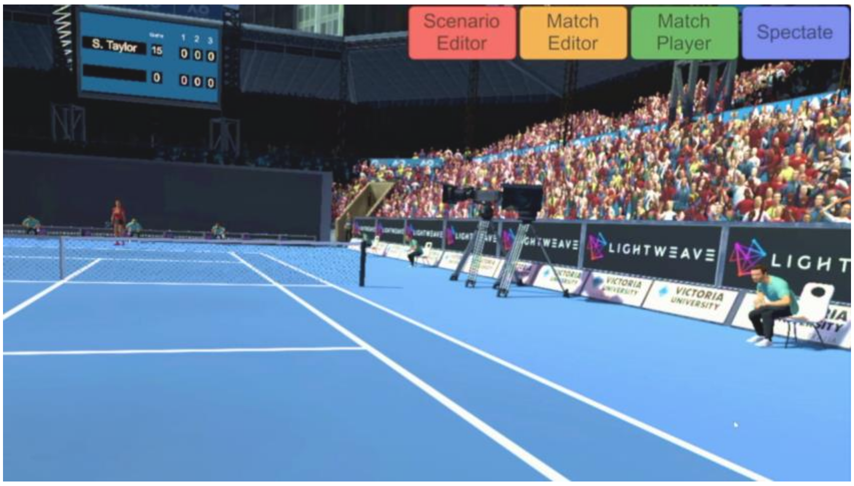


Figure 5.2. The VR tennis environment, displaying the court surface, line judges, camera's, scoreboard, crowd in the stands, virtual opponent. These details were included in the VR environment to help immerse participants in the environment.

#### *5.2.2.3 Pressure Test*

After completing the post-task questionnaire, participants played a further 20 points in the VR simulation which assessed performance under pressure. The format of the pressure test was identical to the training sessions with some exceptions. First, to induce a sense of pressure participants were told that their results from the next 20 points were being recorded and their coach would be analysing their results and giving them a ranking compared to other members of the training squad. Second, as participants were waiting for the initial point to begin, the crowd made loud booing, cheering, and chanting sounds which created a sense of atmosphere or intensity in the virtual stadium. Additionally, the crowd made booing sounds when the participant won points, and a cheering sound when participants lost points throughout the pressure test. Two pressure tests were included in the experimental design to assess whether previous exposure to pressure conditions (i.e. pressure test one) effects future performance under the same pressure conditions (i.e. pressure test two).

### 5.2.3 Experimental conditions

#### *5.2.3.1 Explicit instruction condition*

Prior to commencing training session one, participants allocated to the explicit group were asked to read a document which outlined the aim of the task, explicitly stated all three pattern sequence features, and informed them that if they used this information correctly they would win each point. Equally, the document outlined that if they did not identify and utilise all three pattern features the VR opponent would hit a winning shot and they would lose the point. This information was also verbally communicated to participants. Additionally, participants were asked to verbally describe what the pattern features were and draw each feature using lines and arrows on a sheet of paper which had the image of a tennis court on it. This process was completed to ensure all participants understood the three pattern features and how to implement them to win points during the task.

#### *5.2.3.2 No-instruction group*

The no-instruction group did not receive any information about the three pattern features before commencing the experiment. They were simply instructed to try and win as many points as possible against the VR opponent.

### 5.2.4 Objective Measures

#### *5.2.4.1 Response time - Reading the opponents next shot*

Response time was analysed when participants made an initial decisive movement to the right or left between the opponent hitting a short ball (first pattern sequence) and the opponent implementing the second pattern feature (deuce side corner shot 80% of the time). This was recorded as the time taken (m/s) for the participants to indicate their response by moving to the left or right relative to the moment the virtual opponent's racquet contacted the ball as they were performing the second pattern feature. Hence, response time was either a positive or negative number (Farrow & Reid, 2012). A negative time indicated the participant responded before the opponent's racquet-ball contact, whereas a positive time indicated the participant waited for ball flight information before making their response. Response time values were generated by simultaneously recording the field of view of participants in the virtual environment via a screen recording (60fps) and recording participants movements in the real-world using a digital video camera (Sony HDR-CX405, 1920 x 1080p at 60fps). This video footage was then synced so that the timing of the participants movements in the real-world and in the virtual environment matched. A single MP4 video file (60fpt) was then created and imported into an application called ‘Tracker’ which was used to generate response time values (precision value of ± 17 m/s).

#### *5.2.4.2 Response accuracy – Seizing the opportunity to hit a winner*

Response accuracy related to the third feature of the pattern sequence. That is, the direction participants decided to hit the ball was recorded when they received the deuce side corner shot 80% of the time. Participants scored one point if they directed the ball down the line and zero points if they directed the ball cross court or down the middle part of the court. The participants total score was then divided by the total number of points played to generate a percentage accuracy score. This was done by watching the synced video footage of the real-world and virtual environments in the application Tracker.

#### *5.2.4.3 Response type*

Response type related to the third feature of the pattern sequence. Whether participants decided to perform groundstrokes with topspin or slice was recorded when participants received the deuce side corner shot 80% of the time. This was done by watching the synced video footage of the real-world and virtual environments in the application Tracker. This allowed for changes to participants response type to be compared between training sessions and pressure tests, therefore assessing the effect of pressure on response type performance.

#### *5.2.4.4 Number of steps*

The number of steps participants took from the moment the VR opponent contacted the ball when implementing the second feature of the pattern sequence, to the moment the participants completed their upcoming groundstroke technique was recorded. This allowed for changes to the number of steps taken by participants to be detected when performing in training sessions compared to pressure tests, therefore assessing the influence of pressure on movement. This was also done in the application Tracker.

### 5.2.5 In-match interviews

During each training session, after every 10th point the task was paused and participants were asked about what they were doing to help them win points against the opponent. This provided information about if and when participants identified the specific pattern sequences that occurred during the task. Participants responses were recorded using an audio recorder device.

### 5.2.6 Post-task questionnaire

After the completion of each training session, participants completed a questionnaire consisting of four items. These items questioned participants about whether they identified the pattern sequence features and whether they could control the direction of the ball when hitting forehand and backhand groundstrokes. The questions are listed below:

a) Did you do anything that helped you win points against the opponent during the virtual reality tennis task?

b) Did you feel like you could control the direction of the ball when hitting forehand groundstrokes?

c) Did you feel like you could control the direction of the ball when hitting backhand groundstrokes?

d) Please comment on how you think you performed on your groundstrokes in the task.

### 5.2.7 Statistical analysis

Our focus was to explore differences at the individual participant level. Therefore, data was aggregated for each individual participant and a series of paired t-tests were run to observe differences between session type and pattern exposures for each dependant variable.

To help inform the structure of the paired t-tests, visual inspection of data was used to detect changes in response time for each participant across pattern exposures in training sessions one and two. Importantly, the final 20 points of each training session were used to compare with performance on the pressure tests. The final 20 points gave a more accurate representation of the participants' learning over the course of each training session, which in turn allowed for the influence of pressure on performance to be more accurately examined. Data was checked for normality using visual inspection and the Shipiro-Wilk's test. All assumptions pertaining to the statistical tests were met, and statistical significance was accepted at $p < .05$ with all p-values adjusted using the holm method to correct for multiple comparisons. All analyses were performed in the R language (R Core Team, 2014) using the *lme4 and dplyr* packages (Bates et al., 2015).

## 5.3 Results

### 5.3.1 Response time - Reading the opponent's deep corner shot

#### *5.3.1.1 Pattern exposure comparison*

Participants in the explicit group decreased response time at a faster rate compared to participants in the no-instruction group (see Figure 5.3). Specifically, participant three (explicit group) significantly decreased response time from the start until the end of training session one (M = 149, 95% CI [26.19, 268.26]) (*p* = .031), and training session two (M = 76, 95% CI [35.07, 116.94]) (*p* = .013). Participant four (explicit group) also significantly decreased response time during training session one (M = 95, 95% CI [-70.71, 262.45]), however saw an increase in the final 10 exposures of this session (M = 96, 95% CI (-264.59, 72.85]).

In contrast, participant five was the only participant in the no-instruction group to significantly decrease response time (M = 74, 95% CI [31.50, 117.07]) (*p* = .012), which occurred in the first 20 exposures of training session two.

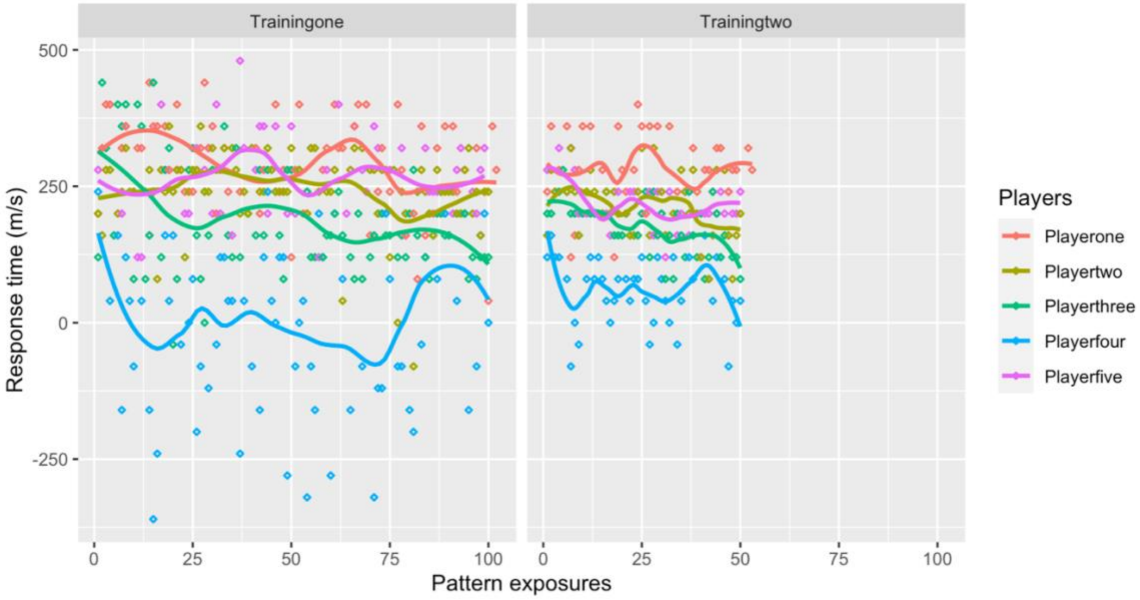


Figure 5.3. The individual changes to response time across pattern exposures for training session one and two. The coloured lines represent the mean response time for each participant across pattern exposures. The points further display the variability of response time data across participants.

### *5.3.1.2 Session type comparison*

No clear difference was found between groups when comparing response time performance from training sessions to pressure tests. To highlight the mixed results, participants two and three from the explicit group and participants one and five from the no-instruction group increased their response time from the first training session to pressure test one. Comparatively, participant four in the explicit group saw a decrease in response time between the first training session and pressure test one.

All participants saw an increase in response time during pressure test two compared to training session two. Indeed, only one participant (participant 5, no-instruction group) performed significantly differently in the second pressure test compared to the first (see Table 5.2).

Table 5.2. Learning and performance under pressure table, displaying the mean difference in response time between, a) Training session one and pressure test one, b) Training session two and pressure test two c) Pressure test one and two. Notably, the final 20 points from each training session are used for the comparison with the pressure tests. The ‘*’ symbol represents a significant difference in mean response time. T1 = Last 20 points of training one, T2 = Last 20 points of training two, P1 = Pressure test one, P2 = Pressure test two.

| | | **Mean difference in response time (m/s)** | | |
|---|---|---|---|---|
| **Participants** | **Group** | **T1 - P1** | **T2 – P2** | **P1 – P2** |
| **Participant 1** | **No-instruction** | M = 60<br>95% CI [-1.85, 121.85]<br>*p* = .168 | M = 34.67<br>95% CI [-11.01, 80.34]<br>*p* = .260 | M = -6<br>95% CI [-40, 52.51]<br>p = .792 |
| **Participant 2** | **Explicit** | M = 36.67<br>95% CI [ -10.83, 84.16]<br>*p* = .252 | M = 57.82<br>95% CI [19.44, 96.20]<br>*p* = .015 * | M = -3.27<br>95% CI [-61.73, 68.26]<br>*p* = .916 |
| **Participant 3** | **Explicit** | M = 112.12<br>95% CI [65.38, 158.87]<br>*p* < .0001 * | M = 88.44<br>95% CI [59.50, 117.38]<br>*p* < .0001 * | M = -2.5<br>95% CI [-33.82, 38.82]<br>*p* = .889 |
| **Participant 4** | **Explicit** | M = -15.37<br>95% CI [-113.91, 83.16]<br>*p* = 1.0 | M = 52.28<br>95% CI [11.84, 92.72]<br>*p* = .039 * | M = 12.71<br>95% CI [-96.64, 71.20]<br>*p* = 1.0 |
| **Participant 5** | **No-instruction** | M = 7.33<br>95% CI [-35.67, 50.33]<br>*p* = .731 | M = 27.28<br>95% CI [5.68, 48.88]<br>*p* = .045 * | M = -55<br>95% CI [11.19, 98.81]<br>*p* = .044 * |

### 5.3.2 Response accuracy – Seizing the opportunity to hit a winner

#### *5.3.2.1 Pattern exposure comparison*

In the first training session, two out of three participants in the explicit group significantly increased response accuracy, however no such effect was evident in the no-instruction group. Participant two and three in the explicit group significantly increased response accuracy by an average of 78% ($p$ = .0007) and 75% ($p$ = .003) respectively in the first training session. Although there was some evidence of change in response accuracy across pattern exposures in the second training session, it did not reach statistical significance.

#### *5.3.2.2 Session type comparison*

No clear group differences were found between training sessions and pressure tests (see Table 5.3). Specifically, from training session one to pressure test one, the response accuracy of participants two and three in the explicit group significantly declined. However, participants response accuracy did not significantly change from the second training session to the pressure test that followed. All participants were more accurate in the second pressure test compared to the first, except for participant two from the explicit group who was less accurate. Indeed, participant three in the explicit group was significantly more accurate pressure test two.

Table 5.3. Learning and performance under pressure table, showing the mean difference in response accuracy between, a) Training session one and pressure test one, b) Training session two and pressure test two c) Pressure test one and two. Notably, the final 20 points from each training session are used for the comparison between pressure tests. The '*' symbol represents a significant difference in mean response accuracy. T1 = Last 20 points of training one, T2 = Last 20 points of training two, P1 = Pressure test one, P2 = Pressure test two.

|  |  | **Mean difference in response accuracy (%)** |  |  |
|---|---|---|---|---|
| **Participants** | **Group** | **T1 - P1** | **T2 – P2** | **P1 – P2** |
| **Participant 1** | **No-instruction** | 6% ↑<br>(p = 1.0) | 14% ↑<br>(p = 1.0) | 11% ↑<br>(p = 1.0) |
| **Participant 2** | **Explicit** | 37% ↓<br>(p = .009) * | 1% ↓<br>(p = .954) | 17% ↓<br>(p = .428) |
| **Participant 3** | **Explicit** | 67% ↓<br>(p = .0003) * | 7% ↑<br>(p = .542) | 62% ↑<br>(p = .0003) * |
| **Participant 4** | **Explicit** | 11% ↓<br>(p = .425) | 100% accurate | 8% ↑<br>(p = .337) |
| **Participant 5** | **No-instruction** | 18% ↓<br>(p = .318) | 16% ↑<br>(p = .288) | 21% ↑<br>(p = .299) |

### 5.3.3 Steps

#### *5.3.3.1 Session type comparison*

The movement response of both groups was comparable in training sessions and pressure tests (see Table 5.4). However, individual responses were evident, with some participants in the explicit group taking more steps in the test conditions and one participant in the no-instruction group using less steps in the second practice session. Mean differences in the number of steps taken and their 95% confidence intervals are presented in Table 5.4.

Table 5.4. Learning and performance under pressure table, showing the mean difference in the number of steps taken between, a) Training session one and pressure test one, b) Training session two and pressure test two c) Pressure test one and two. Notably, the final 20 points from each training session are used for the comparison between pressure tests. The '*'

symbol represents a significant difference in steps taken. T1 = Last 20 points of training one, T2 = Last 20 points of training two, P1 = Pressure test one, P2 = Pressure test two.

| | | **Mean difference in steps** | | |
|---|---|---|---|---|
| **Participants** | **Group** | **T1 - P1** | **T2 – P2** | **P1 – P2** |
| **Participant 1** | **No-instruction** | M = 0.56<br>95% CI [-0.13, 1.25]<br>*p* = .214 | M = 0.27<br>95% CI [-0.10, 0.46]<br>*p* = .458 | M = - .61<br>95% CI [-0.04, 1.27]<br>*p* = .05 * |
| **Participant 2** | **Explicit** | M = 0.45<br>95% CI [0.11, 0.79]<br>*p* = .03 * | M = -0.1<br>95% CI [-0.48, 0.27]<br>*p* = .10 | M = 0.01<br>95% CI [-0.37, 0.36]<br>*p* = .10 |
| **Participant 3** | **Explicit** | M = -0.51<br>95% CI [-0.01, 1.03]<br>*p* = .162 | M = -0.04<br>95% CI [-0.29, 0.22]<br>*p* = .760 | M = 0.18<br>95% CI[-0.57, 0.20]<br>*p* = .650 |
| **Participant 4** | **Explicit** | M = 0.25<br>95% CI [-0.10, 0.60]<br>*p* = .318 | M = 0.68<br>95% CI [0.36, 0.99]<br>*p* = .0006 * | M = 0.06<br>95% CI[-0.21, 0.08]<br>*p* = .334 |
| **Participant 5** | **No-instruction** | M = -0.09<br>95% CI [-0.46, 0.27]<br>*p* = .10 | M = 0.1<br>95% CI [-0.20, 0.39]<br>*p* = .10 | M = 0.125<br>95% CI [-0.40, 0.15]<br>*p* = .10 |

### 5.3.4 Response type

There were significant differences found between groups from training to pressure tests. Participant one from the no-instruction group, and participants two and three from the explicit group predominantly used topspin during the first training session and pressure test, and did not significantly change response type at any stage. Participant four from the explicit group changed from using slice 88% of the time in the first training session to 63% of the time in the first pressure test (*p* = .061). In the first training session, participant five in the no-instruction group used topspin 41% of the time compared to 72% of the time in the first pressure test (*p* = .098).

Topspin was predominantly used during the second training session and pressure test for participant one from the no-instruction group, and participant two and three from the explicit group. Participant four from the explicit group used slice 100% of the time in training session two and pressure test two, and participant five from the no-instruction group went from using topspin 55% of the time in the second training session, to 31% of the time in pressure test two ($p = .109$).

Participant one from the no-instruction group, and participant two and three from the explicit group predominantly used topspin in both pressure tests. Participant four from the explicit group used topspin 31% more in pressure test one compared to pressure test two ($p = .040$), and participant five in the no-instruction group used topspin 67% more in the first pressure test compared to the second pressure test ($p < .0001$).

### 5.3.5 Verbal reports

#### *5.3.5.1 Pattern feature identification and utilisation*

As participants in the explicit group were informed of the features of the pattern sequence and demonstrated their understanding of each feature before training began, the verbal report analysis is primarily focused on participants in the no-instruction group. Player four from the explicit group is also highlighted in the results as an interesting case study.

*Participant one*

- Identified the third feature of the pattern sequence during the first training session after 20 points had been played (during the second in-match interview).
- During the post-task questionnaire after training session one, participant one demonstrated their explicit knowledge of feature two and three by stating: “When the ball landed wider and more to my forehand, I went down the line to win the point”.

*Participant five*

- Demonstrated they had explicit knowledge of the third pattern feature in the first training session after 30 points had been played (during the third in-match interview).
- Revealed their explicit knowledge of the third feature of the pattern sequence in the post-task questionnaire after training session one by expressing: "I would rally crosscourt with the opponent and go down the line to win the point".

*Participant four*

- The only participant in the explicit group to state how the pattern sequence information they were given was utilised.
- During the post-task questionnaire that proceeded the first training session, participant four demonstrated how information about the first pattern feature was utilised to read the opponents next shot: "When I noticed the short ball, I would make sure to move further over to the deuce side corner, ready for the deep corner ball".

#### *5.3.5.2 Groundstroke control*

In the post task questionnaire, all participants expressed their difficulty in aiming the ball down the line when hitting forehand groundstrokes early during the first training session. However, participants also affirmed in the post task questionnaire that they became more proficient or consistent when performing their forehand down the line groundstroke after approximately 20 points had been played in training session one. Additionally, all participants revealed during the post task questionnaire that the direction of their backhand groundstrokes was easily controlled throughout the entire experiment.

### 5.3.6 Summary

We provide a summary of all key findings across dependent variables for each participant in the table below.

Table 5.5. Summary of key findings from each individual participant.

| | **Response time (RT)** | **Response accuracy (RA)** | **Steps** | **Response type** | **Verbal reports** |
|---|---|---|---|---|---|
| **Participant 1** (No-instruction) | • No significant change to RT during training sessions.<br>• ↑ RT from training to pressure test 1<br>• ↑ RT from training session 2 to pressure test 2. | • No significant change in RA within or between training sessions.<br>• ↑ RA in pressure test 2 compared to pressure test 1. | • No significant change in steps from training sessions to pressure tests.<br>• Significantly ↓ steps in pressure test 1 compared to pressure test 2. | • Predominantly used topspin throughout training and pressure tests. | • Identified pattern feature three in training session 1 during in-match interview after 20 points.<br>• Showed explicit knowledge of pattern features two and three during post-task questionnaire after training session 1. |
| **Participant 2** (Explicit) | • No change to RT within training sessions.<br>• ↑ RT from training session 1 to pressure test 1.<br>• ↑ RT from training session 2 to pressure test 2. | • Significantly ↑ RA in training session 1.<br>• Significantly ↓ RA from training session 1 to pressure test 1.<br>• ↓ RA from pressure test 1 to pressure test 2. | • Significantly ↑ steps in training session 1 compared to pressure test 1. | • Predominantly used topspin throughout training and pressure tests. | |
| **Participant 3** (Explicit) | • Significantly ↓ RT from start to end of training session 1 and 2.<br>• ↑ RT from training session 1 to pressure test 1.<br>• ↑ RT from training session 2 to pressure test 2. | • Significantly ↑ RA in training session 1.<br>• Significantly ↓ RA from training session 1 to pressure test 1.<br>• Significantly ↑ RA in pressure test 2, compared to pressure test 1. | • No significant change in steps from training sessions to pressure tests. | • Predominantly used topspin throughout training and pressure tests. | |
| | • Significantly ↓ RT in training | • No significant change in RA during training | • Significantly ↑ steps in pressure test 1 compared | • Changed from using slice 88% of the | • Demonstrated how they utilised the first pattern |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| **Participant 4** (Explicit) | session 1.<br>• ↑ RT in final 10 exposures of training session 1.<br>• Maintained RT from final 10 exposures of training session 1 to the end of training session 2.<br>• ↓ RT from training session 1 to pressure test 1.<br>• ↑ RT from training session 2 to pressure test 2. | session 1.<br>• ↓ RA from training session 1 to pressure test 1.<br>• 100% accurate in training session 2 and pressure test 2.<br>• ↑ RA from pressure test 1 to pressure test 2. | to training session 1. | time in training session 1, to 63% of the time in pressure test 1.<br>• Used slice 100% of the time in training session 2 and pressure test 2.<br>• Used topspin 31% more in pressure test 1 compared to pressure test 2. | feature to read the opponents next shot after training session 1 in the post-task questionnaire. |
| **Participant 5** (No-instruction) | • No significant change in RT during training session 1.<br>• Significantly ↓ RT after 20 exposures in training session 2.<br>• ↑ RT from training session 1 to pressure test 1.<br>• ↑ RT from training session 2 to pressure test 2.<br>• Significantly ↓ RT from pressure test 1 to pressure test 2. | • No significant change in RA during training session 1 or 2.<br>• ↑ RA from pressure test 1 to pressure test 2. | • No significant change in steps across training sessions and pressure tests. | • Used topspin in training session 1 41% of the time, compared to 72% in pressure test 1.<br>• Used topspin 55% of the time in training session 2, compared to 31% of the time in pressure test 2.<br>• Used topspin 67% more in pressure test 1 compared to pressure test 2. | • Identified third pattern feature in training session 1 after 30 points during in-match interview.<br>• Showed explicit knowledge of third pattern feature in post task questionnaire after training session 1. |

## 5.4 Discussion

The previously mentioned limitations caused by the Covid19 pandemic significantly limited what we could conclude from the results of this study. However, despite these limitations, this study used VR technology with the aim of training skilled junior tennis players to identify patterns of play and utilise this information to enhance anticipation and decision-making performance. In doing so we also compared the effectiveness of explicit instructions versus no-instruction on learning and performance under pressure. We demonstrated that exposure to the pattern sequence coupled with explicit instructions resulted in faster changes to response time and response accuracy performance, compared to when no-instructions were provided. Contrary to our expectations, however, instruction during training did not result in poorer performance under pressure.

Response time was analysed when participants made an initial decisive movement to the left or right between the VR opponent hitting a short ball (first pattern feature) and the opponent implementing the second pattern feature (deuce side corner shot 80% of the time). Moreover, response accuracy related to where participants decided to hit the ball after they received the deuce side corner shot (pattern feature three). In line with our expectations, two out of three participants in the explicit group decreased response time (participant three and four) and increased response accuracy (participant two and three) in training session one, compared to both participants in the no-instruction group who did not change response time or response accuracy. The decrease in response time by participants three and four (explicit group) was seemingly the consequence of identifying when the opponent played a short ball (pattern feature one) and the anticipation of the fast corner shot (pattern feature two). This insinuates that these participants were successfully holding the explicit instructions in mind and, more importantly, using this information to improve anticipation as they continued to experience more exposure to the patterns. Indeed, in doing so, these participants were essentially buying themselves more time to prepare for the execution of their next groundstroke. The increase in response accuracy by participants two and three (explicit group) was seemingly the consequence of exposure to decision-making feedback (losing points when hitting middle or crosscourt, and winning points when hitting down the line). This demonstrated that increased exposure to decision-making feedback coupled with the ability to hold the explicit instructions in mind regarding pattern feature three, resulted in decision-making performance improving from the start until the end of training session one.

Participant four from the explicit group had perhaps the most interesting response time behaviour across training session one. Participant four's response time decreased up until the 80th exposure mark, resulting in an anticipatory response 69 m/s prior to the VR opponent's racquet-ball contact. However, their response time regressed in the final 10 exposures of training session one, resulting in an anticipatory response 51 m/s after the opponent's racquet-ball contact. Indeed, it has been suggested that the most effective time to initiate movements during anticipation tasks is as close as possible to the opponent's racquet-ball contact, whereby all contextual and postural information leading up to their opponent's racquet-ball contact can be processed (van der Kamp, Dicks, Navia & Noël, 2018; Dicks, Button, and Davids, 2010). Therefore, we suggest that participant four realised they could afford to wait for all contextual information and postural cues to be available before initiating a movement response, and still perform an effective shot to win the point.

Participants in the no-instruction group revealed they had explicit knowledge of the second and third pattern features. Therefore, we would expect these participants to display similar performance changes as participants in the explicit group. Instead, however, they showed slower improvements, with one participant (player five) significantly decreasing response time in the initial 20 exposures of training session two. A possible reason for this may be that participant one (no-instruction group) had the least amount of match play experience (6 years), compared to others in this study. Therefore, this may have resulted in a reduced ability to utilise their knowledge of the third pattern feature, resulting in no change to anticipation accuracy. Participant five from the no-instruction group significantly decreased response time after 120 exposures, which is consistent with past research that shows learning skills using more implicit instructional methods results in slower learning rates (for a review see Le Noury et al., 2019). Interestingly, participant five's response time did not continue to decrease in the last 30 pattern exposures of training session two, which we attribute to them identifying they could maintain this response time and still perform a successful groundstroke in response to the deep corner shot.

When comparing performance from training sessions to pressure tests, no differences were found between groups, with all participants increasing response time under pressure conditions (particularly during pressure test two). Moreover, no clear differences were found between groups when comparing the effect of pressure on response accuracy performance or movement behaviour. These results contradict past research that has found significant differences in performance under pressure after training with explicit instructions versus more implicit instructional methods (e.g., Smeeton et al., 2005). However, participants in the no-instruction group may have reinvested their explicit knowledge of the pattern back into performance (Liao & Masters, 2001; Masters, 1992; Maxwell et al., 1999), causing them to revert back to more conscious control strategies, resulting in an increase in response time performance under pressure (Anderson, 1982).

Although the no-instruction learning method used in this study is more implicit in nature, the task goal given to participant's in the no-instruction group likely resulted in them consciously searching and processing information that would help them win points (i.e., information about the opponent's patterns of play). To further reduce explicit processing in the future, researchers could use implicit learning methods that distract participants away from the primary learning goal. Methods used to achieve this in the past have included the use of concurrent secondary tasks (Masters, 1992; Maxwell, Masters, & Eves, 2003), incidental learning strategies typically involving the use of a cover story (Raab, 2003), and distraction tasks whereby an explicit contingency is given and the performer aims to learn a different aspect of the skill (e.g., Farrow & Abernethy, 2002). For example, Farrow and Abernethy's (2002) study led participants in the implicit group to believe their aim was to judge the speed of each serve, when the focus was really on the ability to predict serve direction. Therefore, it was reasoned that participants would form more implicit relationships between serve kinematics and resultant serve direction. We suggest similar implicit strategies that distract participants away from the primary goal to reduce explicit processing should be used in the future when training pattern recognition skill.

Notably, a key limitation of this study was the lack of objective measure to assess whether participants were actually experiencing pressure during the pressure tests. Although VR has been shown to closely represent the performance environment of tennis (Le Noury et al., 2020), it is still unknown whether this simulation or other VR simulations are capable of eliciting representative physiological stress responses to pressure conditions. Therefore, future research should assess whether VR can elicit a pressure response that is representative of the real-world. Indeed, if VR is found to elicit representative pressure responses this would be a unique advantage of VR that could be used to train performance under pressure. Additionally, the Covid19 pandemic meant that no transfer test was included in this study to assess the transfer of learning from the VR environment to real performance setting. To maintain experimental control, particularly when training participants to utilise patterns of play, transfer tests may require the use of highly skilled players or coaches that act as opponents, who have the ability to replicate patterns of play (i.e. shot direction and placement) with the same (or as close as possible) accuracy that can be achieved when using a virtual opponent in the VR training setting.

## 5.5 Conclusion

To our knowledge, this study is the first to train skilled junior tennis players to identify patterns of play and utilise this information to enhance anticipation and decision-making performance using VR technology. This study found that exposure to a pattern sequence coupled with explicit instructions resulted in faster changes to response time and response accuracy performance, compared to when no-instructions were provided. Rejecting our expectations, however, instruction during training did not affect performance under pressure. We suggest future training studies should aim to give participants additional exposure to patterns of play. Furthermore, implicit instructional approaches that further limit rule formation during learning should be used in the future to assess their influence on performance under pressure, compared with more explicit instructional approaches.

# Chapter 6: Key findings and general discussion

## 6.1 Introduction

This thesis emerged out of the central idea that the most reliable way to expand our knowledge of anticipation expertise is to examine these processes within experimental settings that are highly representative of the real performance environment. Chapter 2 illustrated that a significant weakness of past research has been the lack of representativeness of tools used to examine anticipation processes. Indeed many researchers, over the past 15 years in particular, have called for experimental tasks to better adhere to principles advocated by Brunswik's (1956) representative design approach (e.g., Representative Learning Design; Pinder et al., 2011). These approaches capture key insights from ecological dynamics to ensure task constraints are representative of the specific performance context they are intended to generalise (Pinder et al., 2011; Chow, Davids, Hristoviski, Araijo, & Passos, 2011). Although challenging, maintaining highly representative perception-action cycles within experimental tasks is fundamental to adhering to these key principles and enhancing our knowledge of anticipation expertise. The current thesis pursued this challenge by incorporating the use of VR technology that has recently been sighted as having high potential to adhere to the principles of representative learning design within experimental settings (Hadlow et al., 2018), whilst also allowing the researcher sufficient experimental control to selectively manipulate contextual information to gain deeper insights into the processes underpinning players' anticipation skill.

Study one of this thesis aimed to examine the representativeness of a VR tennis environment for simulation of tennis performance, using measures of action fidelity and sense of presence. Given the VR tennis environment was shown to adequately represent real-world tennis performance, shown through simulation of stepping and stance behaviour, this allowed gaps in the perceptual-cognitive skill literature to be tackled in a more representative experimental setting, compared to previous research. Using VR technology, study two and three of this thesis aimed to:

a) Assess the ability of skilled junior tennis players to identify two specific serving patterns related to the opponents action tendencies with a) a wide serve pattern connected to the side of the court the point was played on (advantage side of the court), and b) a tee serve pattern connected to the point score in the game (0-0).

b) Enhance the ability of skilled junior tennis players to identify patterns of play and utilise this information to enhance anticipation and decision-making performance.

c) Compare the effectivness of explicit instructions and no-instruction on learning and performance under pressure.

## 6.2 Summary of key findings

The collective findings presented in this thesis offer new insights into how VR technology can be used within experimental research to assess and train perceptual-cognitive skill. Study one revealed that VR tennis can effectively simulate real-world tennis performance, shown through stepping and stance behaviour, and can elicit a high sense of presence in players. Findings from study one (Chapter 3) therefore validated the use of this VR simulation for assessing pattern recognition skill in study two. Findings from study two (Chapter 4) demonstrated that a wide serve pattern that occurred 100% of the time resulted in players demonstrating more rapid improvements in response time relative to patterns that occurred with less frequency. Additionally, players had more difficulty explicitly identifying serving patterns that were connected to the current score, compared to identifying patterns based on the side of the court the opponent served from. Interestingly, players did not initiate a movement response until after the opponents' racquet-ball contact when returning serve, which implies that participants were waiting for confirmatory ball flight information before actioning a response. Based on these results it was concluded that contextual information needs to occur at a high frequency for skilled junior players to utilise this information to inform anticipation.

Study three (Chapter 5) built on the results from study two and sought to train the ability of skilled junior players to identify and utilise patterns when they occur at a lower frequency (80%), with the aim of enhancing anticipation and decision-making skill. Additionally, the influence of explicit instructions and no instruction on performance under pressure was assessed. Results revealed that exposure to patterns coupled with explicit instructions resulted in faster changes to response time and response accuracy performance, compared to no-instruction learning. Additionally, instruction during training did not affect performance under pressure conditions. Based on these findings, it was concluded that future training studies should continue to utilise VR technology to manipulate the presentation of contextual information that may in turn influence the decision-making performance of interceptive sports performers. Furthermore, implicit instructional approaches that further limit rule formation during learning warrant further investigation in the future to assess their influence on performance under pressure, compared with more explicit instructional approaches.

## 6.3 Methodological contribution

The methods used in this thesis present a unique way of operationalising action fidelity within perceptual-cognitive skill research. A key question within this research domain has been how representative actions can be operationalised and coupled with perceptual information to produce more reliable measures of anticipation expertise within experimental tasks. Previous research examining anticipation skill has required participants to make action responses that are not representative of those performed in the performance setting (e.g.

verbal responses, touching a screen) (e.g., Loffing et al., 2015; Smeeton et al., 2005). Furthermore, these actions have not been coupled with perceptual information seen in the performance environment. Although these decoupled perception-action responses may have provided researchers with more experimental control, they have been criticised for excluding a crucial part of expert performance (Abernethy et al., 1993; van der Kamp et al., 2008). Indeed, because perception and action are interdependent of each other, any separation of the two when measuring anticipation, fails to portray the true essence of expertise (Gibson, 1979). Therefore, the validity of findings incorporating unrepresentative or uncoupled movement responses is questioned.

The experimental task utilised throughout this thesis extends the methods used in past anticipation studies by requiring participants to perform representative movements coupled with representative perceptual information. This included performing realistic movements in response to the opponents incoming serve or groundstroke ball trajectory which were highly representative of ball trajectories seen in the real-world setting. Moreover, participants were required to perform realistic forehand and backhand groundstroke techniques when playing shots during the VR task, which has not been seen in previous research whilst also maintaining strong perception-action loops.

Additionally, previous anticipation studies have measured anticipation responses in isolation, without embedding the response within a complete point or normal series of events typically found during competition (e.g., only measuring the participants return of serve without playing the rest of the point out) (e.g., Farrow and Reid, 2012; Gorman & Farrow, 2005). Study two of this thesis required participants to perform realistic actions in response to the opponents serve, but ultimately required participants to play the entire point out after their return of serve was completed. Additionally, study three of this thesis required participants to focus on motor skill execution and decision-making processes in the lead up to the anticipation response that was being measured. This required participants to couple perceptual information (ball flight information) with contextual information to identify the features of the opponent’s pattern of play, which in turn provided guidance for the most appropriate action for participants to perform in order to win points. This methodology provided another dimension of action fidelity not observed in previous anticipation research, providing a task that was more akin to playing tennis in real competition (e.g., deciding where to direct their return of serve and shots thereafter, and executing groundstrokes with appropriate swing technique, footwork and accuracy). In turn, this provided a more representative measure of players ability to identify and utilise contextual information to facilitate anticipation whilst under representative conditions. Therefore, research using VR technology in the future should allow for the normal series of events that occur after the anticipation response is measured to be played out, in order to give a more representative measure of players anticipation and decision-making behaviours.

In one of the few studies to examine the anticipation behaviour of players in-situ during real competition, Troilet and colleagues (2013) quantified the nature and frequency of anticipation behaviour using video coding of incidents where the time delay between the opponent’s shot and the reaction of the player were recorded. Although this method gave a highly representative measure of anticipation behaviour which successfully quantified the nature and frequency of anticipation responses, the authors were unable to comment on the underpinning processes that drove the behaviour observed. In contrast, study two and three of this thesis were able to measure the underpinning processes of participants decision-making and anticipation behaviours using in-match interviews. Interviewing participants in-match helped to uncover the contextual information participants were using to drive their behaviours, in turn providing a deeper understanding of processes that underpin decision-making and anticipation behaviour in tennis. Moreover, Troilet and colleagues (2013) had no way of controlling the contextual information players were subjected to during the tennis matches analysed in their study, as players competed against multiple opponents who had different strengths, weaknesses and behavioural tendencies or tactics. Indeed, a key advantage of study two and three of this thesis was that the contextual information was tightly controlled through the use of AI and VR technology across all participants. Therefore, it is suggested that VR technology may offer a better alternative for analysing anticipation behaviour compared to in-situ and video-based methods, because it can, a) provide a representative competition environment that couples perception and action (similar to an in-situ task), b) allow for in-match interviews to be easily administered in order to uncover the processes underpinning anticipation and decision-making behaviour (a difficult undertaking during real competition), and importantly, c) allow for contextual information to be tightly controlled and replicated across multiple participants (a key characteristic of video-based tasks, but a difficult undertaking during in-situ tasks).

Furthermore, the methods used in this thesis present a unique way of measuring action fidelity. For example, study one of this thesis assessed action fidelity by measuring the number of steps taken and type of stance used when performing forehand and backhand groundstrokes in the VR and real-world environments. However, to attain a meaningful comparison, the stimuli or ball trajectories that players interacted with needed to be the same in both conditions. Hawkeye technology was used to accomplish this challenge. Hawkeye technology allowed for the same ball trajectories to be used in both VR and real-world conditions, therefore participants were able to react to the same ball trajectories in both conditions. This provided a highly representative way of measuring how participants were responding to the same perceptual information in the real-world and VR environments. Study one of this thesis is the first study to our knowledge that has used this method of measuring action fidelity. Therefore, future research examining action behaviours within the VR environment can utilise the methodology to attain an accurate measure of action fidelity.

Moreover, study two and three of this thesis presented a unique method of manipulating contextual information in the experimental setting. Researchers have previously discussed the benefits that would come from being able to selectively manipulate or control contextual information within a display, both in real time and when predetermined (Williams & Jackson, 2019; Cocks et al., 2016; Gray, 2019). This would allow researchers to better understand the contribution of various information sources on anticipatory performance during context specific situations. Addressing this need, the AI software program developed and imported into the VR system allowed the virtual opponent's actions to be controlled, including the type of shot they had available to hit (forehand, backhand, slice etc.), and the direction and velocity of each shot (including the speed, spin and net clearance height) on a point-by-point basis. The AI software allowed for patterns of play to be embedded into the VR opponent's playing style, including the wide and tee serving patterns in study two, and the three pattern features in study three. The use of AI is recommended for future research that aims to use VR technology to train perceptual-cognitive skill or assess the influence of contextual information on anticipation and decision- making in sport.

The use of VR technology itself in studies two and three of this thesis allowed for perceptual information to be coupled with tennis specific actions. A key finding presented in study two was that players did not decrease their response accuracy as improvements in response time were seen. Therefore, there was no speed-accuracy trade off when performing the VR anticipatory task. An issue with past research has been the existence of a speed-accuracy trade off which can occur in tasks that de-couple perception and action, and that do not include realistic consequences for poorly executed actions or having poor accuracy (Farrow & Reid, 2012; Farrow & Abernethy, 2003; Farrow, Abernethy, & Jackson, 2005). Therefore, it is recommended that VR be used in future research assessing perceptual-cognitive expertise to grasp a more representative understanding of the relationship between anticipation speed and accuracy.

Furthermore, it has been suggested that training tasks that better represent constraints in the competition setting are more likely to elicit skill transfer to competition (Pinder et al., 2011, Hadow et al., 2018; Krause et al., 2018). However, there has not been a simple or efficient method for coaches to assess the representative design of training tasks. Therefore, Krause and colleagues (2018) developed a tool for coaches to efficiently assess practice task design in tennis (i.e., the RPAT). The tool focuses on specific aspects of training task design including, how well the task goal during training reflected the competition setting, and how closely the constraints and perception-action couplings of training represented the performance environment. Therefore, I used this tool to assess the representativeness of the VR tasks used in study two and three of this thesis. The results of the RPAT assessment revealed that both VR tasks recorded a perfect score (35 out of 35) for the task goal of training being relevant to the competition setting. Indeed, the goal during training was to win points against the opponent, which is the goal during real tennis competition. This high score also reflected the ability of the training task to measure performance relating to the task goal, which was done using the same scoring system used in real-world tennis. However, both VR tasks scored 28 out of 35 for how well they reflect the competition setting. The deductions in the representativeness of training tasks compared to the competition setting were due to the wire attached to the VR headset restricting participants movement (this is discussed in more detail in the limitations section of this thesis). In short, this restriction resulted in participants movement and recovery position during points to be different to that seen in the real competition environment, in turn decreasing the representativeness of the VR task. Other aspects of task design that resulted in deductions included the use of a forehand groundstroke by the opponent to start each point (instead of a serve that is seen in competition) and the use of a virtual tennis ball which meant participants had no haptic feedback when making racquet-ball contact as they would in the real-world setting. These aspects of task design should be improved in the future to increase the chance of skill transfer occurring to the performance environment.

Study three (Chapter 5) sought to include a pressure condition within the VR task. Replicating pressure in experimental settings (especially in a lab-based setting) has been a dilemma for researchers over many years. Pressure has typically been applied in the past by filming participants performing the task (Alder et al., 2016; Lawrence, Woodman et al., 2014 experiment 1 and 2; Oudejans & Pijpers, 2009 experiment 1), providing negative performance feedback (Alder et al., 2016), providing monetary awards (Lawrence, Woodman et al., 2014 experiment 1; Nieuwenhuys & Oudejans, 2011) or analysing participants performance compared to their peers (Oudejans & Pijpens, 2009 experiment 1; Smeeton et al., 2005). Study three of this thesis extended past research by using crowd noise to apply pressure on participants. That is, when participants won points the crowd booed, and when participants lost points the crowd cheered. Additionally, prior to the task commencing, participants were present inside the VR environment and listened to the crowd cheering and chanting to increase participants sense of occasion and competition-like atmosphere within the virtual stadium. This method of applying pressure was also coupled with previously used methods including informing players that their performance would be analysed by their coach and they would be ranked compared to other members in their tennis squad (e.g., Smeeton et al., 2005). While the results of the current thesis were equivocal, it was evident that VR may be able to generate a greater sense of meaning behind performance through its ability to immerse players in an environment that is highly representative of real-world conditions.

## 6.4 Practical implications

Despite the abundance of research showing the expert advantage in perceptual-cognitive skill, many coaches still do not prioritise this area of development within their training programs. This is particularly evident in many junior tennis programs, where the focus tends to be on motor skill development and physical fitness (notwithstanding, these elements are also important components of tennis performance). This was evident in study two of this thesis, whereby junior skilled tennis players were shown to identify a serving pattern only when it occurred at a 100% frequency (and not a 90%, 80% or 70% frequency) and very regularly during the match (wide serve on every point played on the advantage side of the court). Given study three (and study two) showed that the ability to identify and utilise a pattern of play can significantly decrease response time and increase response accuracy leading to improved anticipation and decision-making performance, this information should encourage coaches to dedicate more time to training pattern recognition skill within their junior development programs.

However, as identified by Abernethy (2013), there has been a lack of research assessing how expertise develops with age and experience level. Consequently, it is relatively unknown whether specific attributes of expertise are more or less important at a particular age or stage of development. This information is important for coaches in order to appropriately guide their design of training programs to progress the development of athletes appropriately. For example, as an athletes fundamental or basic skills progress, other aspects of expertise including anticipation and decision-making become more relevant due to higher temporal demands and increased exposure to competitive environments (Loffing et al., 2017). Consequently, “it may be that more strategic considerations, such as anticipation and decision-making, should be left until intermediate stages of learning” (Williams & Ward, 2003, p. 247). Therefore, implementation of perceptual-cognitive skill training programs targeted at younger or more novice players may require coaches to first diagnose the individual players basic skill level before deciding to start such an intervention (Loffing et al., 2017). Perhaps an effective time to start introducing concepts relating to the identification of opponents strengths, weaknesses and behavioural tendencies to assist anticipation is when players are being introduced to competitive match play? This may help players develop tactical skills and help prepare them for greater temporal constraints later in their tennis careers. However, further research is needed to understand whether there are optimal windows or time periods for perceptual-cognitive skill learning to occur. These findings would provide coaches with critical knowledge to help inform the design of training programs for individual players (Farrow et al., 2018; see also Anderson, Magill, & Thouvarecq, 2012).

### 6.4.1 Perceptual-cognitive skill training

Coaches may be unclear as to the most effective method to use when implementing a perceptual-cognitive skills program. Therefore, we suggest coaches consider three key aspects when designing their perceptual-cognitive skills program; (1) the representative design of the training task (Krause et al., 2018), (2) the instructional approach used to elicit learning (see Le Noury et al., 2019), and (3) the amount of exposure players are given to stimuli that can elicit learning.

The typical approach used by coaches is to adopt 2D video-based occlusion techniques when training perceptual-cognitive skill, however as articulated in the literature review and other sections of this thesis, there are many issues associated with occlusion techniques that limit the likelihood of skill transferring to the real performance environment. Theories and frameworks within the perceptual-cognitive skill literature (e.g., Hadlow et al., 2018; Pinder et al., 2011) have advocated for the use of representative learning design, and more specifically the use of highly representative perception-action couplings when conducting training, to increase the likelihood of skill transfer occurring to the performance setting. Indeed, the results of study one in this thesis present evidence that a tennis VR simulation can represent the perception-action couplings of a real-world tennis environment (as well as high immersive qualities), and therefore has high potential for transferring skills learnt in VR to the real performance setting. Therefore, coaches should consider adopting VR technology over 2D video-based occlusion techniques, when training perceptual-cognitive skill in the future.

The most common instructional approach used with perceptual-cognitive and motor skill training programmes is the use of explicit instructions or if-then rules which essentially tell players what to do in various situations. Given explicit instructional methods have been found to be effective in improving response time and accuracy performance (e.g., Abernethy et al., 1999; Singer et al., 1994; Farrow et al., 1998), the key question for coaches is why they would choose to employ more implicit modes of learning within perceptual-cognitive training programmes. One reason to move away from more explicit approaches is that this method has been found to result in the development of declarative knowledge, causing performers to reinvest in this consciously acquired information, resulting in poorer performance under pressure (Abernethy et al., 2012; Smeeton et al., 2005; Masters, 1992). In contrast, more implicit approaches that aim to facilitate learning without players accruing explicit knowledge (e.g. Farrow & Abernethy, 2002, Gorman & Farrow, 2008) have been shown to result in more stable performance under pressure (Abernethy et al., 2012), albeit when coupled with longer learning periods (Green & Flowers, 1991).

However, in contrast to findings from past research, the results from study three of this thesis revealed no clear difference in performance under pressure between participants in the explicit group and no-instruction group. This may have occurred because participants in the no-instruction group formed explicit knowledge or if-then rules associated with patterns of play the opponent was implementing during the task. Although no-instruction learning reduced the number of if-then rules formed by participants compared to the explicit group (explicit knowledge of two pattern features for participants in the no-instruction group, compared to the explicit group who had explicit knowledge of all three pattern features) the if-then rules formed by the no-instruction group may have caused participants to reinvest this explicit knowledge back into performance (Liao & Masters, 2001; Masters, 1992; Maxwell et al., 1999), causing them to revert back to more conscious control strategies, resulting in a decrease in performance under pressure (Anderson, 1982).

Notably, both learning groups in study three were given the same primary goal which was to win as many points as possible during the task. This task goal likely resulted in the no-instruction group consciously searching and processing information that would help them win points (i.e., information about the opponent’s patterns of play). To reduce explicit processing, coaches could focus on implicit learning methods that further distract participants away from the primary learning goal. Methods used to achieve this in the past have included the use of concurrent secondary tasks (Masters, 1992; Maxwell, Masters, & Eves, 2003), incidental learning strategies typically involving the use of a cover story (Raab, 2003), and distraction tasks whereby an explicit contingency is given and the performer aims to learn a different aspect of the skill (e.g., Farrow & Abernethy, 2002). For example, Farrow and Abernethy's (2002) study led participants in the implicit group to believe their primary task was to judge the speed of each serve, when the focus was actually on the ability to predict serve direction. Therefore, it was reasoned that participants would form more implicit relationships between serve kinematics and resultant serve direction. Similar implicit strategies that distract participants away from the primary goal to reduce explicit processing could be incorporated when training pattern recognition skill. This may involve giving participants the aim of detecting the speed of the opponents ground strokes, rather than the directional patterns of groundstrokes, or focusing performers attention on improving aspects of movement (e.g., footwork or type of stance used) when performing groundstrokes whilst giving exposure to patterns of play to induce a learning effect.

Another consideration coaches should make when implementing perceptual-cognitive skill training is the amount of exposure performers have to stimuli that can elicit a learning effect. This is particularly relevant in the context of training the ability of players to utilise patterns of play to enhance anticipation and decision-making performance. Past pattern recognition training has given participants up to 120 exposures to patterns and showed improvements in learning (e.g., North et al., 2017; Gorman & Farrow 2009), however no significant learning effect compared to placebo and control groups. Study three in this thesis supports these findings, demonstrating that 150 exposures to an opponent's pattern of play was sufficient for two out of three players in explicit instructions to decrease response time, and one out of two players in the no-instruction group decreased response time. Admittedly, these results are inconclusive given the small sample size and lack of comparison with control and placebo groups.

It has also been suggested that perceiving patterns of play (e.g., relating to an opponent's groundstroke or serve tactics) may represent a higher order and more strategic skill compared to perceiving postural cues, which represent a lower-order process (North et al., 2017). Therefore, higher-order skills being trained using implicit instructional methods may require extended training periods with prolonged pattern exposure, compared to the intervention seen in study three of this thesis (150 pattern exposures across two training sessions), to induce similar performance improvements observed when training the ability to perceive postural cues (e.g. Hagemann & Memmert, 2006; Savelsbergh et al., 2010). Therefore, it is recommended that when coaches use more implicit instructional approaches during training, they should consider giving players 250 + exposures to patterns over a training period of at least six weeks. Players currently build knowledge of patterns during on-court training sessions by playing points and matches against opponents. Although players will get exposure to patterns and tactics through this training and match play, VR technology can be extremely helpful here by providing additional repetitions of specific patterns to help fast track players expertise in this area. Additionally, players can do this VR training without the need for another player or even coach being present which is another district advantage of VR training.

## 6.5 Limitations

The studies presented in this thesis have their limitations which need to be addressed. For example, study two and three included a measure of response time when returning serve and anticipating the opponents ground stroke pattern sequence. To attain this data, players movements were recorded in the real-world using a video camera and in the virtual environment via a screen recording, and this footage was then synced together to create a single video file. Although this method was effective for attaining response time data, the process of syncing the vision of players performing in the real-world and virtual environments decreased the framerate of the final video file which was used for analysis. This resulted in the precision of response time values to be diminished (e.g. precision value of ± 33 m/s in study two of this thesis). Although this precision value was improved in study three of this thesis to ± 17 m/s using framerate converter software, to improve the precision of values when measuring response time in the VR setting, it is recommended that researchers and computer engineers collaborate to develop a combination of AI and wearable sensor devices that are capable of detecting players decisive upper and lower body movements when responding to stimuli. This data could be transferred automatically after each VR session is complete, which would improve the efficiency of the data collection and analysis process.

A key limitation of the VR tasks seen in study two and three of this thesis was that a wire was attached to the VR headset restricting participants movement. This constraint meant that participants could only move around in the half of the court the point started from (e.g., in study two if the opponent served from the deuce side, the participant could only move on the deuce side half of the court throughout the point), and participants were restricted to moving up to 2 metres inside and behind the baseline. As participants are able to move around the entire court during real match play, players often recover back to the middle of the court after each shot they perform during points in order to prepare for the upcoming shot. However, the restricted movement in the VR tasks of study two and three of this thesis meant that players did not need to recover back to the middle of the court, they could simply recover back to the middle of the half of the court the point was being played on. In turn, this changed the participants movement patterns during the VR tasks compared to real competition setting (Krause et al., 2018). However, the limitations associated with the wire on the VR headset can be addressed in the future by using a wireless VR headsets which are now available. This will mean participants movements will only be restricted by the capacity of the VR system to track the headset in space (typically a 10 x 10 metres square playing area).

A further limitation of both VR tasks used in study two and three of this thesis was that participants were not able to serve or start the point themselves, therefore the VR opponent always started the point. This is inconsistent with what occurs during real competition and reduced the representativeness of both VR tasks (Krause et al., 2018). Key to solving this issue is to develop haptic feedback gloves which allow performers to hold a virtual tennis ball in their non-hitting hand. This would allow players to perform a ball toss action in order to hit a serve to start points within the VR setting. This would lend itself to further assessment of how skilled performers implement their own serving tactics in response to an opponent’s strengths and weaknesses when returning serve.

Moreover, verbal report data presented in study three showed that participants had trouble aiming forehand groundstrokes down the line within the first 20 points of the task, however could effectively aim their shots when performing backhand groundstrokes. Although participants were able to successfully aim their forehand groundstrokes after approximately 20 points had been played, this may be a sign of a deficiency in action fidelity with the VR task. Therefore, research is warranted to compare participant’s motor skill execution performance in the VR and real-world environments. A further measure that should be used to address action fidelity is to compare the shot accuracy performance of expert relative to novice players. Virtual reality environments would be considered highly representative if they can show differences in expertise.

A key limitation of study three of this thesis was the lack of objective and subjective measures to assess whether participants were actually experiencing pressure during the pressure tests. Although VR has been shown to closely represent the performance environment of tennis (Le Noury et al., 2020), it is still unknown whether this simulation or other VR simulations are capable of eliciting representative physiological stress responses to pressure conditions. Therefore, future research should assess whether VR can elicit a pressure response that is representative of the real-world. Indeed, if VR is found to elicit representative pressure responses this would be a unique advantage of VR that could be used to train performance under pressure.

The temporal constraints placed on performers in study two and three also needs to be considered. The temporal constraints placed on players meant they could wait for ball flight information before initiating their responses. Future research training pattern recognition should therefore look to increase the temporal constraints placed on players to gain further insight into their ability to utilise patterns of play to inform anticipation and decision-making behaviors in competition. Although, higher temporal constraints may be more consistent with tennis played at more advanced senior levels, exposing junior players to these demands may fast track their learning and better prepare them for future matches whereby the temporal demands are higher than their current level.

## 6.6 Future directions for perceptual-cognitive skill research

The key findings of this thesis give rise to a number of interesting research questions that could be addressed in the future. I have outlined eight suggestions for future research which are listed below.

1. **Further assess action fidelity within VR environments.**

Findings from study one revealed that VR tennis adequately represented the action behaviours seen in real-world tennis, as well as eliciting a high sense of presence. Although these findings are promising, future research is needed to further assess the representativeness of VR technology for simulating real-world performance. Specifically, action fidelity should be further assessed by comparing players swing biomechanics in the VR setting compared to the real-world setting. This is an important measure for ensuring the VR environment is not causing any unwanted changes to movement or swing technique that may transfer to the real performance setting. This could be done using motion analysis software such as Vicon.

2. **Whether VR environments can elicit representative pressure responses should be explored.**

Given study three of this thesis did not measure whether participants actually felt pressure during the task, future research should use a combination of physiological and subjective measures to assess the ability of VR environments to create pressure responses that are representative of real-world pressure responses. Additionally, the specific forms of contextual information that need to be present in the environment (e.g. crowd noise, scoreboard pressure etc.) to elicit pressure responses need further investigation. Once this is resolved, these conditions should be simulated in the VR environment and assessed for their ability to induce the same pressure responses as the real-world environment. It is recommended that future studies use VR’s ability to manipulate any form of contextual information (e.g. crowd noise) to create a sense of occasion or championship atmosphere within the VR environment, coupled with storytelling that emphasises pressure situations (e.g., Liao & Masters, 2001) to create a representative pressure response.

3. **Training interventions should explore the use of VR for improving players resilience to pressure conditions.**

If VR is successfully shown to elicit representative stress responses, this opens up further research for training players resilience under pressure conditions and assessing whether this training transfers to improvements under pressure in the real performance environment. Results from past research have shown that VR environments coupled with arousal reduction strategies (e.g. desensitization through exposure to stressful situations, relaxation techniques and biofeedback techniques) can effectively increase resilience to stress (Bosse et al., 2012; Morie et al., 2011; Stetz et al., 2011). Therefore, further research is warranted to assess whether stress resilience training can be effective in sport scenarios.

### 4. Explore how knowledge of patterns is integrated with the ability to read postural cues during anticipation.

Compared to the use of postural cues there has been an under representation of research assessing and training pattern recognition skill in sport. Specifically, more research is needed to increase our knowledge of how patterns of play are integrated with players ability to *read* postural cues. Earlier studies have shown that performers integrate contextual priors and postural cues by weighing up which information source is more reliable (Gredin et al., 2018). Similar to the findings of study two of this thesis, the reliability of contextual information (e.g., patterns of play occurring 100% of the time) significantly influencers whether performers will use this information during anticipation or wait for further arising postural cues or ball flight information before initiating a response (Gray and Canal-Bruland, 2018, Gredin et al., 2018; Helm et al., 2020). Additionally, it has been suggested that contextual information may be more influential in changing anticipatory behaviour when the predicted outcome from contextual information conflicts with the arising postural cue information (Helm et al., 2020). Future research in tennis should therefore explore the contribution of patterns of play on the anticipation behaviour of skilled players when the postural cues of an opponents service action are manipulated (e.g., movements are disguised) but the contextual information remains constant (e.g. the wide serve pattern that occurred 100% of the time in study two of this thesis).

5. **Identify the factors that influence players ability to identify and utilize specific contextual information to enhance anticipation.**

Aside from the reliability of contextual information, what other factors influence whether players use contextual priors to enhance anticipation performance? It may be that patterns of play are more difficult to identify and/or utilise when other distracting contextual information is present in the performance setting. Impeding contextual information may include; 1) the absence or presence of a crowd and their reactions, which distract players or elicit a sense of pressure, 2) the opponent may have a specific strength to their game (e.g. powerful forehand groundstroke down the line) that players focus on or are worried about, thereby distracting them away from a serving pattern of play that is concurrently being used, and 3) physical or mental fatigue that decreases the capacity for players to detect patterns of play, or reduces their capacity to utilise knowledge of patterns. Greater knowledge around how these specific sources of contextual information (and others) affect the anticipation processes of players will help inform the design of future training settings. The use of better process tracing measures, such as recording changes to gaze behaviour (e.g., Gredin et al., 2018) and conducting in-match interviews (as seen in study two and three of this thesis) will also help identify the underlying anticipation processes of players when studying these issues.

6. **Explore how indirect instructional approaches, compared to explicit approaches, can be used to train pattern recognition skill within VR settings is needed.**

Indirect instructional approaches can be more easily developed in VR environments (e.g. implicit presentation of recurrent patterns of play) allowing researchers to continue to expand on the prospect and limits of such training. Although study three found that no-instructions resulted in only one out of two players decreasing response time, it is recommended that a greater amount of exposure to patterns is given to players learning more implicitly (250 + exposures). Researchers are encouraged to continue to compare different instructional methods for training pattern recognition skill in the future.

### 7. Use AI to manipulate any form of contextual information and create specific scenarios.

Virtual technology coupled with AI software allows researchers to manipulate any aspect of contextual information in the VR environment. Therefore, this creates opportunities for researchers to train players perceptual-cognitive skill in specific scenarios that may commonly or uncommonly occur in competition. Research may look to give players more repetitions or opportunities to train in situations they may otherwise not experience in their regular training schedules and assess whether additionally VR training in common or uncommon situations enhances performance in the competition setting when those situations occur. Additionally, VR environments can be designed to look like any real-world environment. This grants an opportunity for researchers to give players exposure to new environments they may face during future competition, particularly settings which may cause additionally performance anxiety (e.g., Olympic games or world championships). Given coaches and athletes often know what the competition environment will look like months leading into an event such as the Olympic games, researchers could design a VR environment that replicates the exact surroundings of the competition environment and assess whether giving athletes exposure to performing in this environment improves performance at the actual event. Perhaps simply allowing athletes to become familiar with the competition surroundings without necessarily performing in the simulation may also help to reduce performance anxiety and therefore improve performance in competition.

8. **Include transfer tests, placebo and control groups when training anticipation and decision-making skill.**

A key issue with past research remains the lack of transfer tests that assess whether perceptual-cognitive skill training elicits improvements to performance in the competition setting (Broadbent et al., 2015). Additionally, the majority of past research has failed to include adequate placebo and control groups, appropriate training intervention periods and retention tests that assess whether performance improvements are maintained over time (days, weeks, months) (Abernethy et al., 2012; Williams & Jackson, 2019; Zentgraf et al., 2017). Unfortunately, many researchers have requested this issue to be resolved in the past, however the majority of published studies still fail to address these issues in experimental design. Therefore, stricter parameters around the design of studies may need to be enforced by journals in this field if researchers wish to have their work published. At the very least, perhaps studies need to include a control and transfer test? Future studies should aim to include all of the abovementioned parameters where possible in future training interventions to enhance our understanding of the relative effectiveness of perceptual-cognitive skill training.

## 6.7 Concluding remarks

The aim of this thesis was to increase our understanding of how VR technology can be applied to assess and train pattern recognition and decision-making skill in sport, specifically the sport of tennis. Moreover, this thesis aimed to build on the recently growing body of research concentrating on how contextual information is identified and utilised by skilled performers to enhance anticipation performance, and whether this skill can be trained using VR technology.

This thesis extends the perceptual-cognitive skill literature through its use of VR technology, AI, and methods of assessing task representativeness. Moreover, this thesis helps guide the design of future perceptual-cognitive skill research through the manipulation of contextual information in the VR environment and use of more implicit and explicit instructional methods to train anticipation and decision-making performance. It is hoped that key sporting bodies and coaches around the world will be excited by the potential of VR technology to have a positive impact on the performance of athletes. It is hypothesised that we will see a proliferation of research assessing the use of VR in sport over the next decade, which will likely disclose what the true benefits of VR really are for athletes at all levels of performance.

# Chapter 7: References and Appendix

(APA reference style)

## 7.1 References

Abernethy, B. (2013). Research: Informed practice. In D. Farrow, J. Baker, & C. MacMahon (Eds.), Developing sport expertise: Researchers and coaches put theory into practice. *Routledge 2*, 249– 255.

Abernethy, B., & Russell, D. G. (1984). Advance cue utilisation by skilled cricket batsmen. *Australian Journal of Science and Medicine in sport*, *16*(2), 2-10.

Abernethy, B., & Russell, D. G. (1987). Expert-novice differences in an applied selective attention task. *Journal of Sport and Exercise Psychology*, *9*(4), 326-345.

Abernethy, B., & Russell, D. G. (1987). The relationship between expertise and visual search strategy in a racquet sport. *Human movement science*, *6*(4), 283-319.

Abernethy, B., & Wood, J. M. (2001). Do generalized visual training programmes for sport really work? An experimental investigation. *Journal of sports sciences*, *19*(3), 203-222.

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.

Abernethy, B., Schorer, J., Jackson, R. C., & Hagemann, N. (2012). Perceptual training methods compared: The relative efficacy of different approaches to enhancing sport-specific anticipation. *Journal of Experimental Psychology: Applied, 18*, 143-153.

Abernethy, B., Thomas, K.T. and Thomas, J.T. (1993). Strategies for improving understanding of motor expertise (or mistakes we have made and things we have learned!!). In *Cognitive Issues in Motor Expertise*. 317- 356.

Abernethy, B., Wood, J. M., & Parks, S. (1999). Can the anticipatory skills of experts be learned by novices? *Research Quarterly for Exercise and Sport*, *70*(3), 313-318.

Alain, C. & Proteau, L. (1978). Etude de variables relatives au traitement de l'information en sports de raquette. *Canadian Journal of Applied Sport Sciences, 3*, 27-33.

Alain, C. and Proteau, L. (1980). Decision making in sport. *Psychology of Motor Behavior and Sport*, 465- 477.

Alder, D., Ford, P. R., Causer, J., & Williams, A. M. (2014). The coupling between gaze behavior and opponent kinematics during anticipation of badminton shots. *Human movement science*, *37*, 167-179.

Alder, D., Ford, P. R., Causer, J., & Williams, A. M. (2016). The effects of high-and low-anxiety training on the anticipation judgments of elite performers. *Journal of Sport and Exercise Psychology*, *38*(1), 93-104.

Allard, F., & Starkes, J. L. (1980). Perception in sport: Volleyball. *Journal of sport and exercise psychology*, *2*(1), 22-33.

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological review*, *89*(4), 369-406.

Anderson, D. I., Magill, R. A., & Thouvarecq, R. (2012). Critical periods, sensitive periods, and readiness in motor skill learning. In N. J. Hodges & A. M. Williams (Eds.), Skill acquisition in sport: Research, theory and practice, 2nd ed., pp. 211–228). New York: Routledge.

Anson, G., Elliot, D., & Davids, K. (2005). Information processing and constraints-based views of skill acquisition: Divergent or complementary? *Motor Control, 9*, 217–241.

Araujo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of sport and exercise*, *7*(6), 653-676.

Araujo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: Comment on. *Ecological Psychology*, *19*(1), 69-78.

Baddeley, A. D., Hitch, G. J., & Bower, G. H. (1974). The psychology of learning and motivation. *The psychology of learning and motivation*, *8*, 47-90.

Baker, J., & Young, B. (2014). 20 years later: deliberate practice and the development of expertise in sport. *International Review of Sport and Exercise Psychology*, *7*(1), 135-157.

Banister, H., & Blackburn, J. M. (1931). An eye factor affecting proficiency at ball games. *British Journal of Psychology*, *21*(4), 382-384.

Baños, R. M., Botella, C., Garcia-Palacios, A., Villa, H., Perpiñá, C., & Alcaniz, M. (2000). Presence and reality judgment in virtual environments: a unitary construct?. *CyberPsychology & Behavior,* 3 (3), 327-335.

Barton, H., Jackson, R. C., & Bishop, D. (2013). Knowledge of player tendencies: The effect on anticipation skill and susceptibility to deception. In *Journal of Sport & Exercise Psychology,* 35, 18-18.

Bates, D., Maechler, M., Bolker, B., Walker, S., Christensen, R. H. B., Singmann, H., & Bolker, M. B. (2015). Package 'lme4'. *Convergence*, *12*(1), 32-38.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure?. *Journal of Experimental Psychology: General*, *130*(4), 701-725.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied, 8(1),* 6-16.

Bideau, B., Kulpa, R., Vignais, N., Brault, S., Multon, F., & Craig, C. (2010). Using virtual reality to analyze sports performance. *IEEE Computer Graphics and Applications, 30*, 14-21.

Blundell, N. L. (1985) The contribution of vision to the learning and performance of sports skills: Part 1. The role of selected parameters. *The Australian Journal of Science and Medicine in Sport*, 17, 3-11.

Bosse T, Gerritsen C, de Man J, Treur J. (2012) Measuring stress-reducing effects of virtual training based on subjective response. In: Huang T, Zeng Z, Li C, Leung CS, editors. Neural information processing. New York (NY): Springer. 322–330.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European journal of sport science*, *15*(4), 322-331.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments*. Berkeley: University of California Press.

Cañal-Bruland, R., & Mann, D. L. (2015). Time to broaden the scope of research on anticipatory behav- ior: A case for the role of probabilistic information. Frontiers in Psychology, 6, 63.

Casey GW. (2011). Comprehensive soldier fitness: A vision for psychological resilience in the U.S. Army. Am Psychol. 66 (1). 1–3.

Causer J, Smeeton NJ, Williams AM, Sampaio J. (2017). Expertise differences in anticipatory judgements during a temporally and spatially occluded task. *Plos One.* 12(2). 1–12

Chase, W.G., & Simon, H. A. (1973) 'Perception in chess', Cognititve psychology, 4: 55-81.

Chow, J. Y., Davids, K., Hristovski, R., Araújo, D., & Passos, P. (2011). Nonlinear pedagogy: Learning design for self-organizing neurobiological systems. *New Ideas in Psychology*, *29*(2), 189-200.

Cocks, A. J., Jackson, R. C., Bishop, D. T., & Williams, A. M. (2016). Anxiety, anticipation and contextual information: A test of attentional control theory. *Cognition and Emotion*, *30*(6), 1037-1048.

Craig, C. (2013). Understanding perception and action in sport: how can virtual reality technology help?. *Sports Technology*, *6*(4), 161-169.

Craig, C., & Watson, G. (2011). An affordance based approach to decision making in sport: discussing a novel methodological framework. *Revista de psicología del deporte*, *20*(2), 689-708.

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.

Davids, K. (2008). Designing representative task constraints for studying visual anticipation in fast ball sports: what we can learn from past and contemporary insights in neurobiology and psychology. *International Journal of Sport Psychology*, *39*(2), 166-177.

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

Dessing, J. C., & Craig, C. M. (2010). Bending it like Beckham: how to visually fool the goalkeeper. *PLoS One*, *5*(10), e13161.

Dicks, M., Araújo, D., & van der Kamp, J. (2019). Perception-action for the study of anticipation and decision making. In *Anticipation and decision making in sport*. Routledge, 181-199.

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

Dicks, M., Button, C., & Davids, K. (2010). 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.

Drowatzky, J. N., & Zuccato, F. C. (1967). Interrelationships between selected measures of static and dynamic balance. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *38*(3), 509-510.

Düking, P., Holmberg, H. C., & Sperlich, B. (2018). The potential usefulness of virtual reality systems for athletes: a short SWOT analysis. *Frontiers in Physiology*, *9*, 128.

Erickson, G. (2007). Sports vision: Vision care for the enhancement of sports performance. St. Louis, MO: Butterworth Heineman Elsevier.

Ericsson, K. A., Krampe, R. Th., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100,* 363-406.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition & emotion*, *6*(6), 409-434.

Fadde, P. J., & Zaichkowsky, L. (2018). Training perceptual-cognitive skills in sports using technology. *Journal of Sport Psychology in Action*, *9*(4), 239-248

Farrow, D., & Abernethy, B. (2002). Can anticipatory skills be learned through implicit video based perceptual training?. *Journal of sports sciences*, *20*(6), 471-485.

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., & Fournier, J. (2005). Training perceptual skill in basketball: Does it benefit the highly skilled? Paper presented at the Promoting Health and Performance for Life; Proceedings of the ISSP 11th World Congress of Sport Psychology, August 15 – 19, Sydney.

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.

Farrow, D., & Reid, M. (2012). The contribution of situational probability information to anticipatory skill. *Journal of Science and Medicine in Sport*, *15*(4), 368-373.

Farrow, D., Baker, J., & MacMahon, C. (2013). Developing sport expertise: Researchers and coaches put theory into practice. Abingdon: Routledge.

Farrow, D., Chivers, P., Hardingham, C., & Sachse, S. (1998). The effect of video-based perceptual training on the tennis return of serve. *International Journal of Sport Psychology, 23*, 231 – 242.

Faure, C., Limballe, A., Bideau, B., & Kulpa, R. (2020). Virtual reality to assess and train team ball sports performance: A scoping review. *Journal of Sports Sciences*, *38*(2), 192-205.

Gabbett, T., Rubinoff, M., Thorburn, L., & Farrow, D. (2007). Testing and training anticipation skills in softball fielders. *International Journal of Sports Science & Coaching*, *2*(1), 15-24.

Galton, F. (1869). *Hereditary Genius.* Macmillan, London. Reprinted 1979, Friedmann, London.

Galton, F. (1874a). *English Men of Science: Their Nature and Nurture.* Macmillan, London. Reprinted 1970, Cass, London.

Galton, F. (1874b). On a proposed statistical scale. *Nature* 9**,** 342–343.

Galton, F. (1883) *Inquiries into Human Faculty and Its Development.* 2nd edn. Dent, London (Everyman).

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

Goldin, S. E. (1978). Effects of orienting tasks on recognition of chess positions. *The American Journal of Psychology*, 659-671.

Goldin, S. E. (1979). Recognition memory for chess positions: Some preliminary research. *The American Journal of Psychology*, 19-31.

Gorman, A. D., & Farrow, D. (2009). Perceptual training using explicit and implicit instructional techniques: Does it benefit skilled performers?. *International Journal of Sports Science & Coaching*, *4*(2), 193-208.

Gorman, A. D., Abernethy, B., & Farrow, D. (2012). Classical pattern recall tests and the prospective nature of expert performance. *Quarterly Journal of Experimental Psychology*, *65*(6), 1151-1160.

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. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking, and slumps. *Journal of Experimental Psychology: Applied, 10,* 42–54.

Gray, R. (2015). Differences in Attentional Focus Associated With Recovery From Sports Injury: Does Injury Induce an Internal Focus?, Journal of Sport and Exercise Psychology, 37(6), 607-616.

Gray, R. (2017). Transfer of training from virtual to real baseball batting. Frontiers in psychology, 8, 2183-2189.

Gray, R. (2019). Virtual environments and their role in developing perceptual-cognitive skills in sports. *Anticipation and Decision Making in Sport*. Routledge, 342-358.

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

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*, *24*(4), 509.

Green, & Flowers, (1991). Implicit versus explicit learning processes in a probabilistic, continuous fine- motor catching task. *Journal of Motor Behavior,* 23, 293- 300.

Hadlow, S. M., Panchuk, D., Mann, D. L., Portus, M. R., & Abernethy, B. (2018). Modified perceptual training in sport: a new classification framework. *Journal of Science and Medicine in Sport*, *21*(9), 950-958.

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., Schorer, J., Bruland, R. C., Lotz, S., & Strauss, B. (2010). Visual information pick-up in fencing: An analysis combining eye movements, the occlusion paradigm, and cueing. *Attention, Perception & Psychophysics*, *72*, 2204-2214.

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.

Harris, D. J., Bird, J. M., Smart, A. P., Wilson, M. R., & Vine, S. J. (2020). A framework for the testing and validation of simulated environments in experimentation and training. *Frontiers in Psychology*, *11*, 605.

Harris, D. J., Buckingham, G., Wilson, M. R., & Vine, S. J. (2019). Virtually the same? How impaired sensory information in virtual reality may disrupt vision for action. *Experimental brain research*, *237*(11), 2761-2766.

Harris, D., Buckingham, G., Wilson, M., Brookes, J., Mushtaq, F., Mon-Williams, M., et al. (2019a). Testing the fidelity and validity of a virtual reality golf putting simulator. PsyarXiv [Preprint].

Held, R. M., & Durlach, N. I. (1992). Telepresence. *Presence: Teleoperators & Virtual Environments*, *1*(1), 109-112.

Helm, F., Cañal-Bruland, R., Mann, D. L., Troje, N. F., & Munzert, J. (2020). Integrating situational probability and kinematic information when anticipating disguised movements. *Psychology of Sport and Exercise*, *46*, 101607.

Helsen, W. F., & Starkes, J. L. (1999). A multidimensional approach to skilled perception and performance in sport. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *13*(1), 1-27.

Hourani, L. L., Kizakevich, P. N., Hubal, R., Spira, J., Strange, L. B., Holiday, D. B., & McLean, A. N. (2011). Predeployment stress inoculation training for primary prevention of combat-related stress disorders. *Journal of cybertherapy & rehabilitation*, *4*(1), 101-116.

Jackson, R. C., & Farrow, D. (2005). Implicit perceptual training: How, when, and why?. *Human Movement Science, 24*(3), 308-325.

Jacobs, D. M., & Michaels, C. F. (2002). On the apparent paradox of learning and realism. *Ecological Psychology*, *14*(3), 127-139.

Jacobs, D. M., & Michaels, C. F. (2002). On the apparent paradox of learning and realism. *Ecological Psychology*, *14*(3), 127-139.

James, N., & Bradley, C. (2004). Disguising ones intentions: The availability of visual cues and situational probabilities when playing against an international level squash player. In A. Lees, J.-F. Kahn, & I.W. Maynard (Eds.), Science and Racket Sports III, Abingdon, Oxfordshire: Routledge, 247-252.

James, W. (1890) *Principles of psychology*, New York: Holt.

Klostermann, A., Vater, C., Kredel, R., & Hossner, E. J. (2015). Perceptual training in beach volleyball defence: different effects of gaze-path cueing on gaze and decision-making. *Frontiers in psychology*, *6*, 1834.

Kovalchik, S. A., & Reid, M. (2017). Comparing matchplay characteristics and physical demands of junior and professional tennis athletes in the era of big data. *Journal of sports science & medicine*, *16*(4), 489-490.

Krause, L., Farrow, D., Buszard, T., Pinder, R., & Reid, M. (2019). Application of representative learning design for assessment of common practice tasks in tennis. *Psychology of Sport and Exercise*, *41*, 36-45.

Lawrence, G. P., Cassell, V. E., Beattie, S., Woodman, T., Khan, M. A., Hardy, L., & Gottwald, V. M. (2014). Practice with anxiety improves performance, but only when anxious: evidence for the specificity of practice hypothesis. *Psychological Research, 78*(5), 634-650.

Le Noury, P., Buszard, T., Reid, M., & Farrow, D. (2020). Examining the representativeness of a virtual reality environment for simulation of tennis performance. *Journal of Sports Sciences*, 1-9.

Le Noury, P., Farrow, D., Buszard, T., & Reid, M. (2019). Instructional approaches for developing anticipation and decision making in sport. In *Anticipation and decision making in sport*. Routledge, 306-326.

Lee, T. D., & Swinnen, S. P. (1993). 'Three legacies of Bryan and Harter: Automaticity, variability and change in skilled performance'. In J. L. Starkes & F. Allard (Eds.), *Cognitive issues in motor expertise***,** Amsterdam: North Holland, 295-316.

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2001). A cross-media presence questionnaire: The ITC-Sense of Presence Inventory. *Presence: Teleoperators & Virtual Environments*, *10*(3), 282-297.

Liao, C. M., & Masters, R. S. (2001). Analogy learning: A means to implicit motor learning. *Journal of sports sciences*, *19*(5), 307-319.

Loffing, F., & Hagemann, N. (2014). On-court position influences skilled tennis players' anticipation of shot outcome. *Journal of Sport and Exercise Psychology*, *36*(1), 14-26

Loffing, F., & Hagemann, N. (2014). Skill differences in visual anticipation of type of throw in team-handball penalties. *Psychology of Sport and Exercise*, *15*(3), 260-267.

Loffing, F., Stern, R., & Hagemann, N. (2015). Pattern-induced expectation bias in visual anticipation of action outcomes. *Acta psychologica*, *161*, 45-53.

Loffing, F., Hagemann, N., & Farrow, D. (2017). The next piece of the puzzle. *Routledge handbook of talent identification and development in sport*, 205-218.

Mann, D. L., Abernethy, B., & Farrow, D. (2010). Visual information underpinning skilled anticipation: The effect of blur on a coupled and uncoupled in situ anticipatory response. *Attention, Perception, & Psychophysics*, *72*(5), 1317-1326.

Mann, D. L., Schaefers, T., & Cañal-Bruland, R. (2014). Action preferences and the anticipation of action outcomes. *Acta psychologica*, *152*, 1-9.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *29*(4), 457-478.

Marteniuk, R. G. (1976). Cognitive information processes in motor short-term memory and movement production. *Motor control, Academic Press*. 175-186.

Masters, R. S. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British journal of psychology*, *83*(3), 343-358.

Masters, R.S.W., Poolton, J.M., & Maxwell, J.P. (2008). Stable implicit motor processes despite aerobic locomotor fatigue. *Consciousness & Cognition*, *17*, 1, 335-338.

Maybery, M., & O'Brien-Malone, A. (1998). Implicit and automatic processes in cognitive development. *Implicit and Explicit Mental Processes*, 149-170.

McGreevy, M. W. (1992). The presence of field geologists in Mars-like terrain. *Presence: Teleoperators & Virtual Environments*, *1*(4), 375-403.

McMenemy, K., & Ferguson, S. (2007). A Hitchhiker's guide to virtual reality. Wellesley, MA: Peters, Limited.

McMorris, & Hauxwell, (1997). Improving anticipation of soccer goalkeepers using video observation. *Science and football III*, 290-294

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.

Meehan, M., Insko, B., Whitton, M., & Brooks, F. P., Jr. (2002). Physiological Measures of Presence in 538 Stressful Virtual Environments. *Proceedings of the 29th Annual Conference on Computer* 539 *Graphics and Interactive Techniques*, 645–652.

Milazzo, N., Farrow, D., Ruffault, A., & Fournier, J. F. (2016). Do karate fighters use situational probability information to improve decision-making performance during on-mat tasks?. *Journal of Sports Sciences*, *34*(16), 1547-1556.

Milner, A.D. & Goodale, M.A. (1995). The visual brain in action. Oxford: Oxford University press.

Millward, R. B., & Reber, A. S. (1972). Probability learning: Contingent-event schedules with lags. *The American Journal of Psychology*, 81-98.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive psychology*, *19*(1), 1-32.

Mitroff, S. R., Friesen, P., Bennett, D., Yoo, H., & Reichow, A. W. (2013). Enhancing ice hockey skills through stroboscopic visual training: a pilot study. *Athletic Training and Sports Health Care*, *5*(6), 261-264.

Moran, A. (2009). Attention in sport. *Advances in applied sport psychology: A review*, 195-220.

Morie, J., Chance, E., & Buckwalter, J. G. (2011). Report on a preliminary study using breath control and a virtual jogging scenario as biofeedback for resilience training. Proceedings of the Human Computer Interaction International Conference. Springer, Berlin, Germany. 474-480.

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. (2014). An expertise approach to training anticipation using temporal occlusion in a natural skill setting. *Technology, Instruction, Cognition, and Learning*, *9*, 295-312.

Murphy, C. P., Jackson, R. C., & Williams, A. M. (2018). The role of contextual information during skilled anticipation. *Quarterly Journal of Experimental Psychology*, *71*(10), 2070-2087.

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, 43-58.

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.

Neumann, D. L., Moffitt, R. L., Thomas, P. R., Loveday, K., Watling, D. P., Lombard, C. L., & Tremeer, M. A. (2018). A systematic review of the application of interactive virtual reality to sport. *Virtual Reality, 22*(3), 183-198.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. *Cognitive skills and their acquisition*, *1*, 1-55.

Nieuwenhuys, A., & Oudejans, R. R. (2011). Training with anxiety: short-and long-term effects on police officers' shooting behavior under pressure. *Cognitive processing*, *12*(3), 277-288.

North, J. S., Hope, E., & Williams, A. M. (2017). Identifying the micro-relations underpinning familiarity detection in dynamic displays containing multiple objects. *Frontiers in psychology*, *8*, 963.

North, J. S., Hope, E., & Williams, A. M. (2017). The role of verbal instruction and visual guidance in training pattern recognition. *Frontiers in psychology*, *8*, 1473.

North, J. S., Ward, P., Ericsson, A., & Williams, A. M. (2011). Mechanisms underlying skilled anticipation and recognition in a dynamic and temporally constrained domain. *Memory*, *19*(2), 155-168.

North, J. S., Williams, A. M., Hodges, N., Ward, P., & Ericsson, K. A. (2009). Perceiving patterns in dynamic action sequences: Investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *23*(6), 878-894.

Oudejans, R. R., Heubers, S., Ruitenbeek, J. R. J., & Janssen, T. W. (2012). Training visual control in wheelchair basketball shooting. *Research Quarterly for Exercise and Sport*, *83*(3), 464-469.

Oudejans, R. R., & Pijpers, J. R. (2009). Training with anxiety has a positive effect on expert perceptual–motor performance under pressure. *Quarterly Journal of Experimental Psychology*, *62*(8), 1631-1647.

Oudejans, R. R., Michaels, C. F., Bakker, F. C., & Dolne, M. A. (1996). The relevance of action in perceiving affordances: Perception of catchableness of fly balls. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(4), 879-891.

Oudejans, R. R., Michaels, C. F., Van Dort, B., & Frissen, E. J. (1996). To cross or not to cross: The effect of locomotion on street-crossing behavior. *Ecological psychology*, *8*(3), 259-267.

Pagé, C., Bernier, P. M., & Trempe, M. (2019). Using video simulations and virtual reality to improve decision-making skills in basketball. *Journal of sports sciences*, *37*(21), 2403-2410.

Pallavicini, F., Argenton, L., Toniazzi, N., Aceti, L., & Mantovani, F. (2016). Virtual reality applications for stress management training in the military. *Aerospace medicine and human performance*, *87*(12), 1021-1030.

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.

Perfect, P., Timson, E., White, M. D., Padfield, G. D., Erdos, R., & Gubbels, A. W. (2014). A rating scale 565 for the subjective assessment of simulation fidelity. *The Aeronautical Journal*, *118*(1206), 953– 974.

Pinder, R. A., Davids, K., Renshaw, I., & Ara.jo, D. (2011). Representative learning design and functionality of research and practice in sport. Journal of Sport & Exercise Psychology, 33(1), 146–155.

Pinder, R. A., Renshaw, I., & Davids, K. (2009). Information–movement coupling in developing cricketers under changing ecological practice constraints. *Human Movement Science*, *28*(4), 468-479.

Pinker, S (2002) *The blank slate: The modern denial of human nature,* New York, Viking.

Poulter, D. R., Jackson, R. C., Wann, J. P., & Berry, D. C. (2005). The effect of learning condition on perceptual anticipation, awareness, and visual search. *Human Movement Science*, *24*(3), 345-361.

Raab, M. (2003). Decision making in sports: influence of complexity on implicit and explicit learning. *International Journal of Sport and Exercise Psychology*, *1*(4), 315-433.

Renshaw, I., & Gorman, A. D. (2015). Challenges to capturing expertise in field settings. *Routledge handbook of sport expertise*, 282-294.

Rizzo, A. S., Buckwalter, J. G., Forbell, E., Reist, C., Difede, J., Rothbaum, B. O., ... & Talbot, T. (2013). Virtual reality applications to address the wounds of war. *Psychiatric Annals*, *43*(3), 123-138.

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.

Savelsbergh, G. J. P., Van Gastel, P. J., & Van Kampen, P. M. (2010). Anticipation of penalty kicking direction can be improved by directing attention through perceptual learning. *International Journal of Sport Psychology, 41*, 24-41.

Savelsbergh, G. J., Williams, A. M., Kamp, J. V. D., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of sports sciences*, *20*(3), 279-287.

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*, 60-73.

Schorer, J., Cañal-Bruland, R., & Cobley, S. (2010). Frequency of knowledge of results does not influence perceptual learning and retention in novices. *International Journal of Sport Psychology, 41*, 107-117.

Schorer, J., Loffing, F., Hagemann, N., & Baker, J. (2012). Human handedness in interactive situations: Negative perceptual frequency effects can be reversed! *Journal of Sports Sciences, 30*, 507-513.

Schwab, S., & Memmert, D. (2012). The impact of a sports vision training program in youth field hockey players. *Journal of sports science & medicine, 11*(4), 624-631.

Sherman, W. R., and A. B. Craig. (2003) Understanding Virtual Reality- Interface, Application, and Design. *Presence: Teleoperators and Virtual Environments*, *12* (4), 441–442.

Shim, J., Carlton, L. G., Chow, J. W., & Chae, W. S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *Journal of motor behavior*, *37*(2), 164-175.

Singer, R.N., Cauraugh, J.H, Chen, D., Steinberg, G.M., Frehlich, S.G., & Wang, L. (1994). Training mental quickness in beginning/intermediate tennis players. *The Sports Psychologist, 8*, 305-318.

Slater M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual 598 environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 599 *364*(1535), 3549–3557.

Slater, M. and Usoh, M. (1993) Presence in Immersive Virtual Environments, IEEE Virtual Reality Annual International Symposium (VRAIS), September 18-22, Seattle, Washington, 90-96.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, *6*(6), 603-616.

Slater, M., Antley, A., Davison, A., Swapp, D., Guger, C., Barker, C. et al., (2006). A virtual reprise of the Stanley Milgram obedience experiments. *PLoSONE 1*(1): e39.

Smeeton, N. J., Huys, R., & Jacobs, D. M. (2013). When less is more: Reduced usefulness training for the learning of anticipation skill in tennis. *PLoS One*, *8*(11), e79811.

Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of various instructional approaches in developing anticipation skill. *Journal of Experimental Psychology: Applied*, *11*(2), 98-110.

Spearman, C. (1904). General intelligence, objectively determined and measured. *American Journal of Psychology* 15, 201-293.

Squires, S. D., Macdonald, S. N., Culham, J. C., & Snow, J. C. (2016). Priming tool actions: Are real objects more effective primes than pictures?. *Experimental Brain Research*, *234*(4), 963-976.

Starkes, J.L. and Allard, F. (eds.) (1993). Cognitive Issues in Motor Expertise. Amsterdam: Elsevier.

Starkes JL, Allard F, Lindley S, O'Reilly K. (1994). Abilities and skill in basketball. *Int. J. Sport Psychol.* 25, 249–265.

Starkes, J. L. (1987). Skill in field hockey: The nature of the cognitive advantage. *Journal of Sport and Exercise Psychology*, *9*(2), 146-160.

Starkes, J. L., & Deakin, J. (1984). Perception in sport: A cognitive approach to skilled performance. *Cognitive sport psychology*, 115-128.

Stetz MC, Kaloi-Chen JY, Turner DD, Bouchard S, Riva G, Wiederhold bk. (2011). The effectiveness of technology-enhanced relaxation techniques for military medical warriors. 176 (9), 1065-1070.

Stetz MC, Long CP, Schober WV, Cardillo CG, Wildzunas RM (2007). Stress assessment and management while medics take care of the VR wounded. Annu Rev Cybertherapy Med. 5, 191-204.

Stinson, C., & Bowman, D. A. (2014). Feasibility of training athletes for high-pressure situations using virtual reality. *IEEE transactions on visualization and computer graphics*, *20*(4), 606-615.

Stoffregen, T. A., Bardy, B. G., Smart, L. J., & Pagulayan, R. J. (2003). On the nature and evaluation of fidelity in virtual environments. *Virtual and adaptive environments: Applications, implications, and human performance issues*, 111-128.

Stone, J. A., Strafford, B. W., North, J. S., Toner, C., & Davids, K. (2018). Effectiveness and efficiency of virtual reality designs to enhance athlete development: an ecological dynamics perspective. *Movement & Sport Sciences-Science & Motricité*, (102), 51-60.

Tarr, M. J., & Warren, W. H. (2002). Virtual reality in behavioral neuroscience and beyond. *nature neuroscience*, *5*(11), 1089-1092.

Terman, L. (1925) *Genetic studies of genius, Standford:* Standford University Press.

Terman, L. M., & Oden M. H. (1947) *The gifted child grows up*, Standford: Standford University Press.

Terman, L. M., & Oden M. H. (1959) *The gifted group at mid-life*, Standford: Standford University Press.

Tirp, J., Steingröver, C., Wattie, N., Baker, J., & Schorer, J. (2015). Virtual realities as optimal learning environments in sport-A transfer study of virtual and real dart throwing. *Psychological Test and Assessment Modeling*, *57*(1), 57-64.

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., Dicks, M., Navia, J. A., & Noël, B. (2018). Goalkeeping in the soccer penalty kick. *German Journal of Exercise and Sport Research*, *48*(2), 169-175.

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), 100-130.

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), 100-130.

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

Vilar, L., Araújo, D., Davids, K., & Renshaw, I. (2012). The need for ‘representative task design’ in evaluating efficacy of skills tests in sport: A comment on Russell, Benton and Kingsley (2010). *Journal of sports sciences*, *30* (16), 1727-1730.

Vine, S. J., Moore, L. J., & Wilson, M. R. (2014). Quiet eye training: The acquisition, refinement and resilient performance of targeting skills. *European journal of sport science*, *14*. 235-242.

Watson, J. B. (1924) *Behaviourism*, New York: Norton.

Williams, A. M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of sports sciences*, *18*(9), 737-750.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human movement science*, *24*(3), 283-307.

Williams, A. M., & Ford, P. R. (2008). Expertise and expert performance in sport. *International Review of Sport and Exercise Psychology*, *1*(1), 4-18.

Williams, A. M., & Jackson, R. C. (2019). Anticipation in sport: Fifty years on, what have we learned and what research still needs to be undertaken?. *Psychology of Sport and Exercise*, *42*, 16-24.

Williams, A. M., & Ward, P. (2003). Perceptual expertise: Development in sport. In J. L. Starkes & K. A. Ericsson (Eds.), *Expert performance in sports: advances in research on sport expertise* (pp. 219-249). Champaign, IL: Human Kinetics.

Williams, A. M., & Ward, P. (2007). Anticipation and decision making: Exploring new horizons, 203-223.

Williams, A. M., Herron, K., Ward, P., & Smeeton, N. J. (2008). Using situational probabilities to train perceptual and cognitive skill in novice soccer players. *Routledge,* 348-351.

Williams, A. M., Vickers, J., & Rodrigues, S. (2002). The effects of anxiety on visual search, movement kinematics, and performance in table tennis: A test of Eysenck and Calvo’s processing efficiency theory. *Journal of Sport and Exercise Psychology*, *24*(4), 438-455.

Williams, A. M., Ward, P., & Chapman, C. (2003). Training perceptual skill in field hockey: Is there transfer from the laboratory to the field? *Research Quarterly for Exercise and Sport, 74,* 98-103.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. (2002). Anticipation skill in a real-world task: Measurement, training, and transfer in tennis. *Journal of Experimental Psychology: Applied*, *8*, 259–270.

Williams, A. M., Ward, P., Smeeton, N. J., & Allen, D. (2004). Developing anticipation skills in tennis using on-court instruction: Perception versus perception and action. *Journal of Applied Sport Psychology*, *16*(4), 350-360.

Winslow, B., Carroll, M. B., Martin, J. W., Surpris, G., & Chadderdon, G. L. (2015). Identification of resilient individuals and those at risk for performance deficits under stress. *Frontiers in neuroscience*, *9*, 328.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence, 7*(3), 225-240.

Zentgraf, K., Heppe, H., & Fleddermann, M. T. (2017). Training in interactive sports. *German Journal of Exercise and Sport Research*, 1-13.

## 7.2 Appendix

### 7.2.1 Appendix A: Consent form chapters 3 and 4

# CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

**INFORMATION TO PARTICIPANTS:**

We would like to invite your child to be a part of the study titled: “The examination of how well virtual reality tennis compared to real life tennis using subjective and objective measures”. The project will aim to (1) assess how similar virtual reality tennis is compared to real life tennis, (2) identify factors that heighten fidelity in virtual reality tennis, and (3) examine whether patterns of play can be identified in virtual reality. This project requires your child to attend three days of testing.

**CERTIFICATION BY SUBJECT:**

I, ________________________________________ (parent/guardians name)

of ________________________________________ (parent/guardians suburb)

certify that I am at least 18 years old and that I am voluntarily giving my consent for

____________________________________ (participant/child’s name)

to participate in the study titled: “Examining the fidelity of virtual reality tennis using subjective and objective measures” being conducted by Victoria University.

I, ________________________________________ (participant’s name) give assent to be involved in the study.)

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 Peter Le Noury and that I freely consent to my child’s participation involving the below mentioned procedures:

- Three days of testing at Maribyrnong College.
- Participating in 15 minutes of virtual reality tennis using a real tennis racquet and another 15 minutes using a racquet handle device.
- Completing all questionnaires that will assess the level of presence of virtual reality tennis

which will give a reliable measure of fidelity.

- Complete 15 minutes of real life tennis.
- Filming during each virtual reality task and real life tennis condition to allow researchers to assess the anticipation speed, stance and footwork of participants.

I agree with the all of the above procedures to be undertaken during this research project ☐ Yes ☐ No (please tick)

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

I have been informed that the information I and/or my child provide will be kept confidential.

Parent/Guardian Signed: ___________________________________ Date: ________________

Participant Signed: ___________________________________ Date: ________________

Any queries about your adolescent's participation in this project may be directed to Damian Farrow (Chief Investigator), Tim Buszard (Associate Investigator), or Peter Le Noury (Student Investigator).

Student Investigator
Peter Le Noury
peter.lenoury@live.vu.edu.au
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Victoria University

Associate Investigator
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Telephone 9919-4512
Victoria University

Chief Investigator
Damian Farrow
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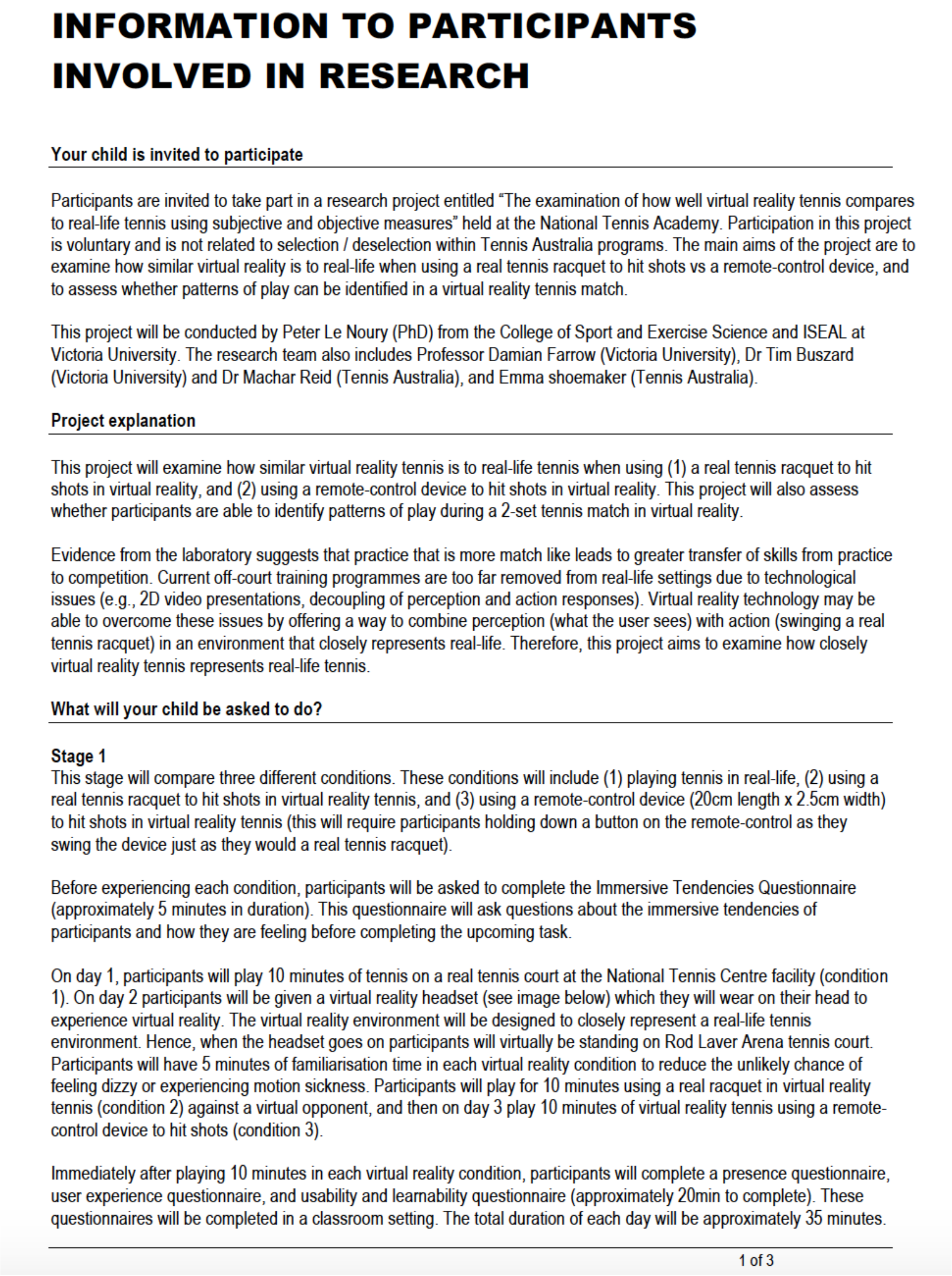
Telephone 9919-4512

### 7.2.2 Appendix B: Information letter chapters 3 and 4



# INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

## Your child is invited to participate

Participants are invited to take part in a research project entitled "The examination of how well virtual reality tennis compares to real-life tennis using subjective and objective measures" held at the National Tennis Academy. Participation in this project is voluntary and is not related to selection / deselection within Tennis Australia programs. The main aims of the project are to examine how similar virtual reality is to real-life when using a real tennis racquet to hit shots vs a remote-control device, and to assess whether patterns of play can be identified in a virtual reality tennis match.

This project will be conducted by Peter Le Noury (PhD) from the College of Sport and Exercise Science and ISEAL at Victoria University. The research team also includes Professor Damian Farrow (Victoria University), Dr Tim Buszard (Victoria University) and Dr Machar Reid (Tennis Australia), and Emma shoemaker (Tennis Australia).

## Project explanation

This project will examine how similar virtual reality tennis is to real-life tennis when using (1) a real tennis racquet to hit shots in virtual reality, and (2) using a remote-control device to hit shots in virtual reality. This project will also assess whether participants are able to identify patterns of play during a 2-set tennis match in virtual reality.

Evidence from the laboratory suggests that practice that is more match like leads to greater transfer of skills from practice to competition. Current off-court training programmes are too far removed from real-life settings due to technological issues (e.g., 2D video presentations, decoupling of perception and action responses). Virtual reality technology may be able to overcome these issues by offering a way to combine perception (what the user sees) with action (swinging a real tennis racquet) in an environment that closely represents real-life. Therefore, this project aims to examine how closely virtual reality tennis represents real-life tennis.

## What will your child be asked to do?

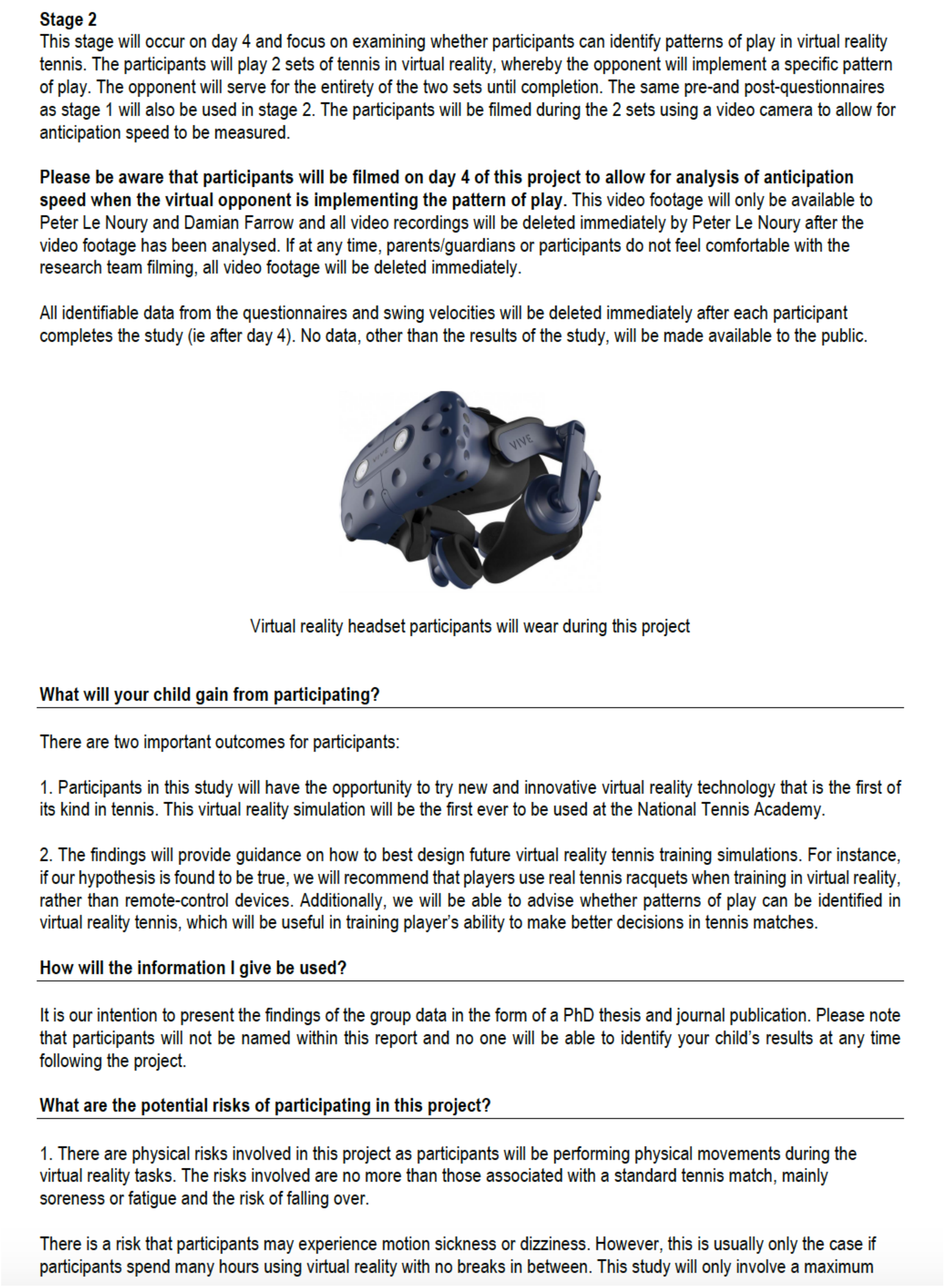
### Stage 1

This stage will compare three different conditions. These conditions will include (1) playing tennis in real-life, (2) using a real tennis racquet to hit shots in virtual reality tennis, and (3) using a remote-control device (20cm length x 2.5cm width) to hit shots in virtual reality tennis (this will require participants holding down a button on the remote-control as they swing the device just as they would a real tennis racquet).

Before experiencing each condition, participants will be asked to complete the Immersive Tendencies Questionnaire (approximately 5 minutes in duration). This questionnaire will ask questions about the immersive tendencies of participants and how they are feeling before completing the upcoming task.

On day 1, participants will play 10 minutes of tennis on a real tennis court at the National Tennis Centre facility (condition 1). On day 2 participants will be given a virtual reality headset (see image below) which they will wear on their head to experience virtual reality. The virtual reality environment will be designed to closely represent a real-life tennis environment. Hence, when the headset goes on participants will virtually be standing on Rod Laver Arena tennis court. Participants will have 5 minutes of familiarisation time in each virtual reality condition to reduce the unlikely chance of feeling dizzy or experiencing motion sickness. Participants will play for 10 minutes using a real racquet in virtual reality tennis (condition 2) against a virtual opponent, and then on day 3 play 10 minutes of virtual reality tennis using a remote-control device to hit shots (condition 3).

Immediately after playing 10 minutes in each virtual reality condition, participants will complete a presence questionnaire, user experience questionnaire, and usability and learnability questionnaire (approximately 20min to complete). These questionnaires will be completed in a classroom setting. The total duration of each day will be approximately 35 minutes.



**Stage 2**

This stage will occur on day 4 and focus on examining whether participants can identify patterns of play in virtual reality tennis. The participants will play 2 sets of tennis in virtual reality, whereby the opponent will implement a specific pattern of play. The opponent will serve for the entirety of the two sets until completion. The same pre-and post-questionnaires as stage 1 will also be used in stage 2. The participants will be filmed during the 2 sets using a video camera to allow for anticipation speed to be measured.

**Please be aware that participants will be filmed on day 4 of this project to allow for analysis of anticipation speed when the virtual opponent is implementing the pattern of play.** This video footage will only be available to Peter Le Noury and Damian Farrow and all video recordings will be deleted immediately by Peter Le Noury after the video footage has been analysed. If at any time, parents/guardians or participants do not feel comfortable with the research team filming, all video footage will be deleted immediately.

All identifiable data from the questionnaires and swing velocities will be deleted immediately after each participant completes the study (ie after day 4). No data, other than the results of the study, will be made available to the public.

Virtual reality headset participants will wear during this project

## What will your child gain from participating?

There are two important outcomes for participants:

1. Participants in this study will have the opportunity to try new and innovative virtual reality technology that is the first of its kind in tennis. This virtual reality simulation will be the first ever to be used at the National Tennis Academy.

2. The findings will provide guidance on how to best design future virtual reality tennis training simulations. For instance, if our hypothesis is found to be true, we will recommend that players use real tennis racquets when training in virtual reality, rather than remote-control devices. Additionally, we will be able to advise whether patterns of play can be identified in virtual reality tennis, which will be useful in training player's ability to make better decisions in tennis matches.

## How will the information I give be used?

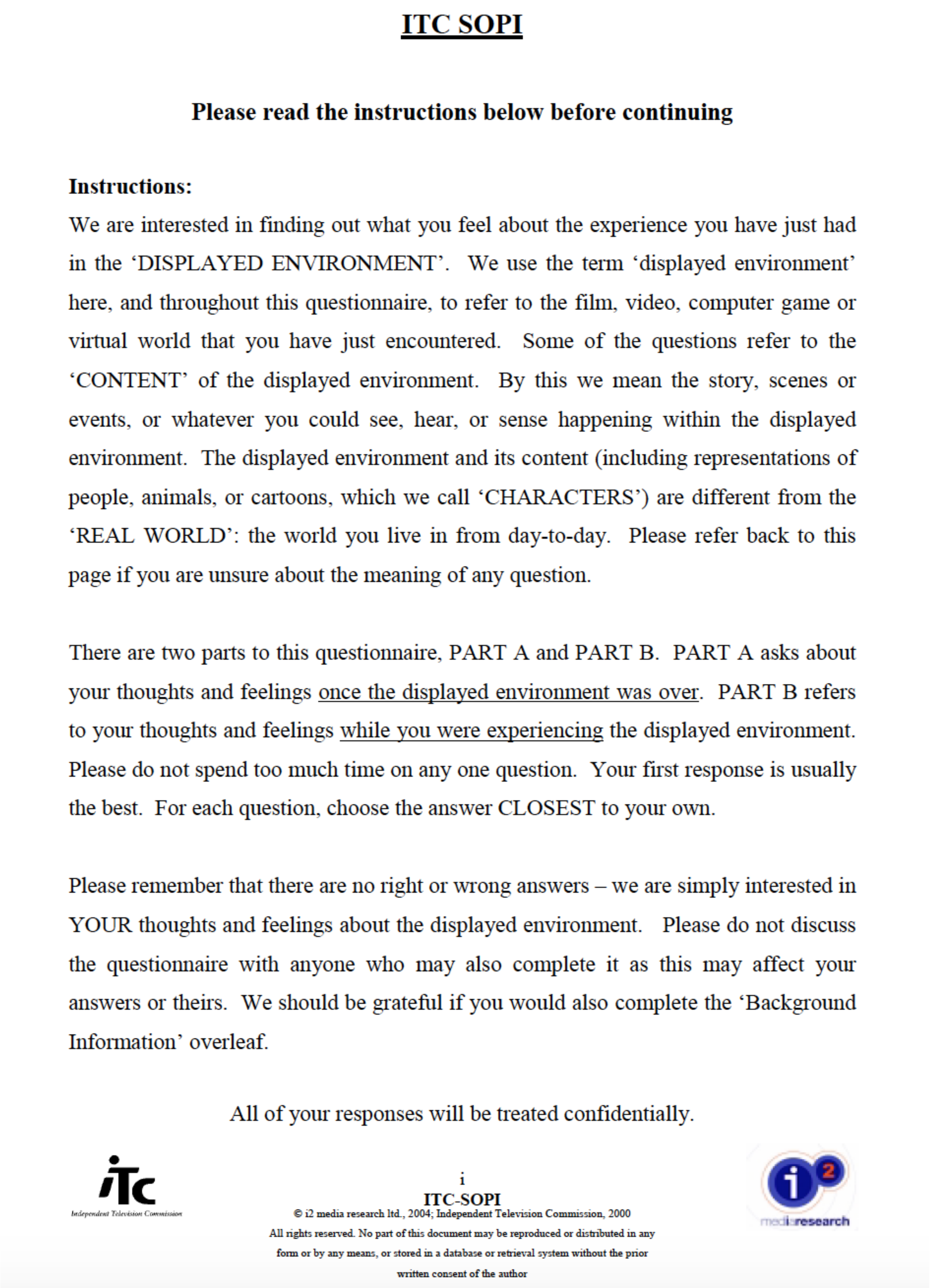
It is our intention to present the findings of the group data in the form of a PhD thesis and journal publication. Please note that participants will not be named within this report and no one will be able to identify your child's results at any time following the project.

## What are the potential risks of participating in this project?

1. There are physical risks involved in this project as participants will be performing physical movements during the virtual reality tasks. The risks involved are no more than those associated with a standard tennis match, mainly soreness or fatigue and the risk of falling over.

There is a risk that participants may experience motion sickness or dizziness. However, this is usually only the case if participants spend many hours using virtual reality with no breaks in between. This study will only involve a maximum

### 7.2.3 Appendix C: Presence Questionnaire chapter 3



## ITC SOPI

**Please read the instructions below before continuing**

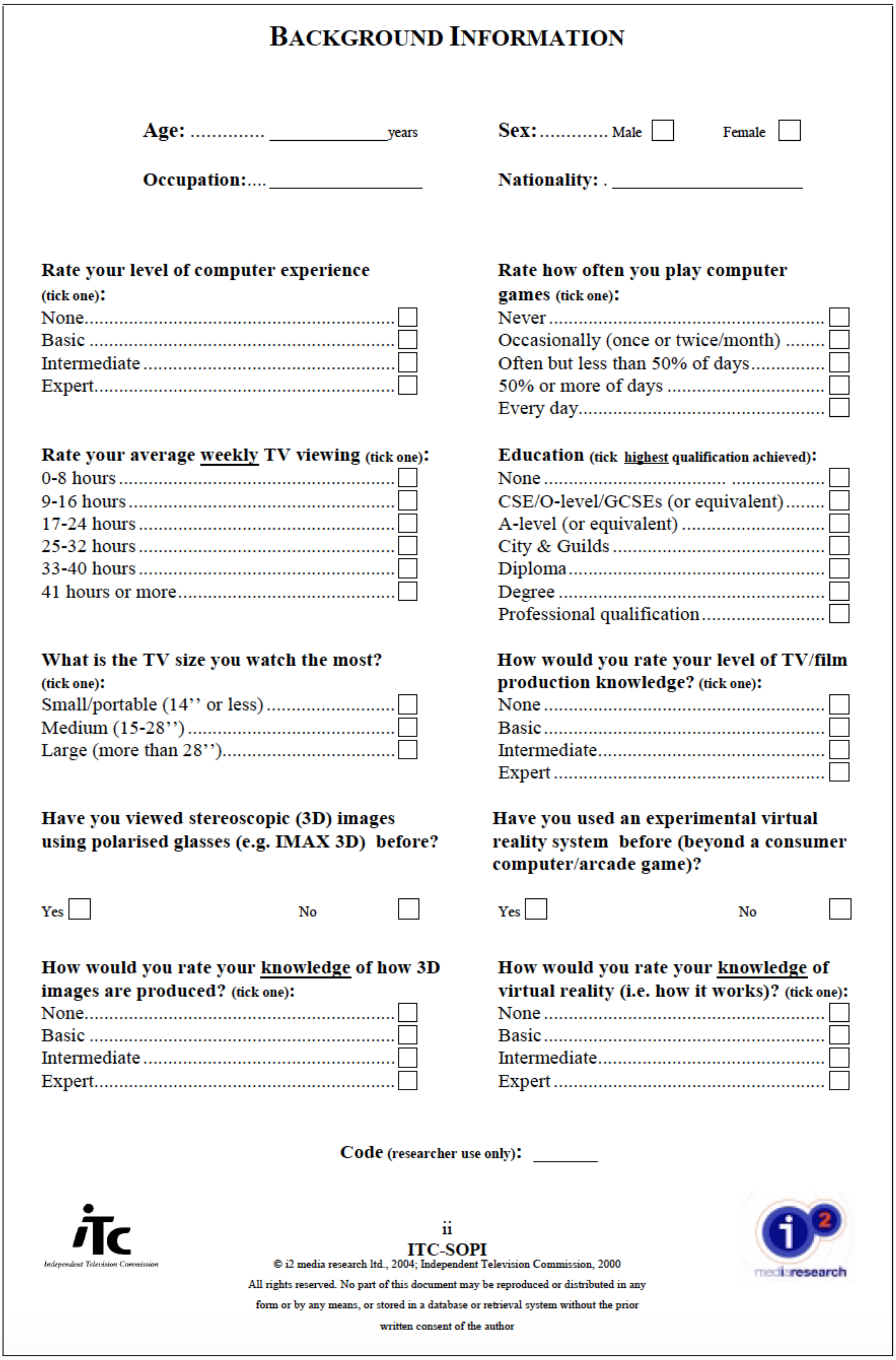
**Instructions:**

We are interested in finding out what you feel about the experience you have just had in the 'DISPLAYED ENVIRONMENT'. We use the term 'displayed environment' here, and throughout this questionnaire, to refer to the film, video, computer game or virtual world that you have just encountered. Some of the questions refer to the 'CONTENT' of the displayed environment. By this we mean the story, scenes or events, or whatever you could see, hear, or sense happening within the displayed environment. The displayed environment and its content (including representations of people, animals, or cartoons, which we call 'CHARACTERS') are different from the 'REAL WORLD': the world you live in from day-to-day. Please refer back to this page if you are unsure about the meaning of any question.

There are two parts to this questionnaire, PART A and PART B. PART A asks about your thoughts and feelings once the displayed environment was over. PART B refers to your thoughts and feelings while you were experiencing the displayed environment. Please do not spend too much time on any one question. Your first response is usually the best. For each question, choose the answer CLOSEST to your own.

Please remember that there are no right or wrong answers – we are simply interested in YOUR thoughts and feelings about the displayed environment. Please do not discuss the questionnaire with anyone who may also complete it as this may affect your answers or theirs. We should be grateful if you would also complete the 'Background Information' overleaf.

All of your responses will be treated confidentially.



## BACKGROUND INFORMATION

**Age:** ............. _____________years

**Sex:**............ Male ☐ Female ☐

**Occupation:**.... ________________

**Nationality:** . __________________

**Rate your level of computer experience (tick one):**
- None................................................................ ☐
- Basic ................................................................ ☐
- Intermediate .................................................. ☐
- Expert............................................................. ☐

**Rate how often you play computer games (tick one):**
- Never ............................................................ ☐
- Occasionally (once or twice/month) ........ ☐
- Often but less than 50% of days.............. ☐
- 50% or more of days ................................ ☐
- Every day.................................................. ☐

**Rate your average <u>weekly</u> TV viewing (tick one):**
- 0-8 hours ........................................................ ☐
- 9-16 hours ...................................................... ☐
- 17-24 hours .................................................... ☐
- 25-32 hours .................................................... ☐
- 33-40 hours .................................................... ☐
- 41 hours or more........................................... ☐

**Education (tick <u>highest</u> qualification achieved):**
- None ............................... ................... ☐
- CSE/O-level/GCSEs (or equivalent)........ ☐
- A-level (or equivalent) ............................ ☐
- City & Guilds ........................................... ☐
- Diploma..................................................... ☐
- Degree ...................................................... ☐
- Professional qualification......................... ☐

**What is the TV size you watch the most? (tick one):**
- Small/portable (14'' or less) ......................... ☐
- Medium (15-28'') ........................................... ☐
- Large (more than 28'').................................... ☐

**How would you rate your level of TV/film production knowledge? (tick one):**
- None ........................................................... ☐
- Basic........................................................... ☐
- Intermediate.............................................. ☐
- Expert ........................................................ ☐

**Have you viewed stereoscopic (3D) images using polarised glasses (e.g. IMAX 3D) before?**

Yes ☐ No ☐

**Have you used an experimental virtual reality system before (beyond a consumer computer/arcade game)?**

Yes ☐ No ☐

**How would you rate your <u>knowledge</u> of how 3D images are produced? (tick one):**
- None................................................................ ☐
- Basic ................................................................ ☐
- Intermediate .................................................. ☐
- Expert............................................................. ☐

**How would you rate your <u>knowledge</u> of virtual reality (i.e. how it works)? (tick one):**
- None ........................................................... ☐
- Basic........................................................... ☐
- Intermediate.............................................. ☐
- Expert ........................................................ ☐

**Code (researcher use only):** _______

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ITC-SOPI

# PART A

**Please indicate HOW MUCH YOU AGREE OR DISAGREE with each of the following statements by circling just ONE of the numbers using the 5-point scale below.**

| (Strongly disagree) | (Disagree) | (Neither agree nor disagree) | (Agree) | (Strongly agree) |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

---

**<u>AFTER</u> MY EXPERIENCE OF THE DISPLAYED ENVIRONMENT…**

1. I felt sad that my experience was over .......................................................1 2 3 4 5
2. I felt disorientated..............................................................................1 2 3 4 5
3. I had a sense that I had returned from a journey........................................1 2 3 4 5
4. I would have liked the experience to continue ...........................................1 2 3 4 5
5. I vividly remember some parts of the experience.......................................1 2 3 4 5
6. I'd recommend the experience to my friends. ............................................1 2 3 4 5

# PART B

**Please indicate HOW MUCH YOU AGREE OR DISAGREE with each of the following statements by circling just ONE of the numbers using the 5-point scale below.**

| **(Strongly disagree)** | **(Disagree)** | **(Neither agree nor disagree)** | **(Agree)** | **(Strongly agree)** |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

---

**<u>DURING</u> MY EXPERIENCE OF THE DISPLAYED ENVIRONMENT…**

1. I felt myself being 'drawn in'. ....................................................................1 2 3 4 5

2. I felt involved (in the displayed environment). ........................................1 2 3 4 5

3. I lost track of time. ........................................................................................1 2 3 4 5

4. I felt I could interact with the displayed environment................................1 2 3 4 5

5. The displayed environment seemed natural. ..............................................1 2 3 4 5

6. It felt like the content was 'live'. ..................................................................1 2 3 4 5

7. I felt that the characters and/or objects could almost touch me.................1 2 3 4 5

8. I enjoyed myself. ............................................................................................1 2 3 4 5

9. I felt I was visiting the places in the displayed environment......................1 2 3 4 5

10. I felt tired. ......................................................................................................1 2 3 4 5

| **(Strongly disagree)** | **(Disagree)** | **(Neither agree nor disagree)** | **(Agree)** | **(Strongly agree)** |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

---

**<u>DURING</u> MY EXPERIENCE OF THE DISPLAYED ENVIRONMENT…**

11. The content seemed believable to me. ........................................................1 2 3 4 5

12. I felt I wasn't *just* watching something. ....................................................1 2 3 4 5

13. I had the sensation that I moved in response to parts of the displayed environment .......................................................................................1 2 3 4 5

14. I felt dizzy. .........................................................................................1 2 3 4 5

15. I felt that the displayed environment was part of the real world. ..............1 2 3 4 5

16. My experience was intense. ..........................................................1 2 3 4 5

17. I paid more attention to the displayed environment than I did to my own thoughts (e.g., personal preoccupations, daydreams etc.). ................1 2 3 4 5

18. I had a sense of being in the scenes displayed...........................................1 2 3 4 5

19. I felt that I could move objects (in the displayed environment). ................1 2 3 4 5

20. The scenes depicted could really occur in the real world..........................1 2 3 4 5

21. I felt I had eyestrain. ...........................................................................1 2 3 4 5

22. I could almost smell different features of the displayed environment. ......1 2 3 4 5

| **(Strongly disagree)** | **(Disagree)** | **(Neither agree nor disagree)** | **(Agree)** | **(Strongly agree)** |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

---

**<u>DURING</u> MY EXPERIENCE OF THE DISPLAYED ENVIRONMENT…**

23. I had the sensation that the characters were aware of me. .......................... 1 2 3 4 5

24. I had a strong sense of sounds coming from different directions within the displayed environment .......................... 1 2 3 4 5

25. I felt surrounded by the displayed environment .......................... 1 2 3 4 5

26. I felt nauseous. .......................... 1 2 3 4 5

27. I had a strong sense that the characters and objects were solid .......................... 1 2 3 4 5

28. I felt I could have reached out and touched things (in the displayed environment). .......................... 1 2 3 4 5

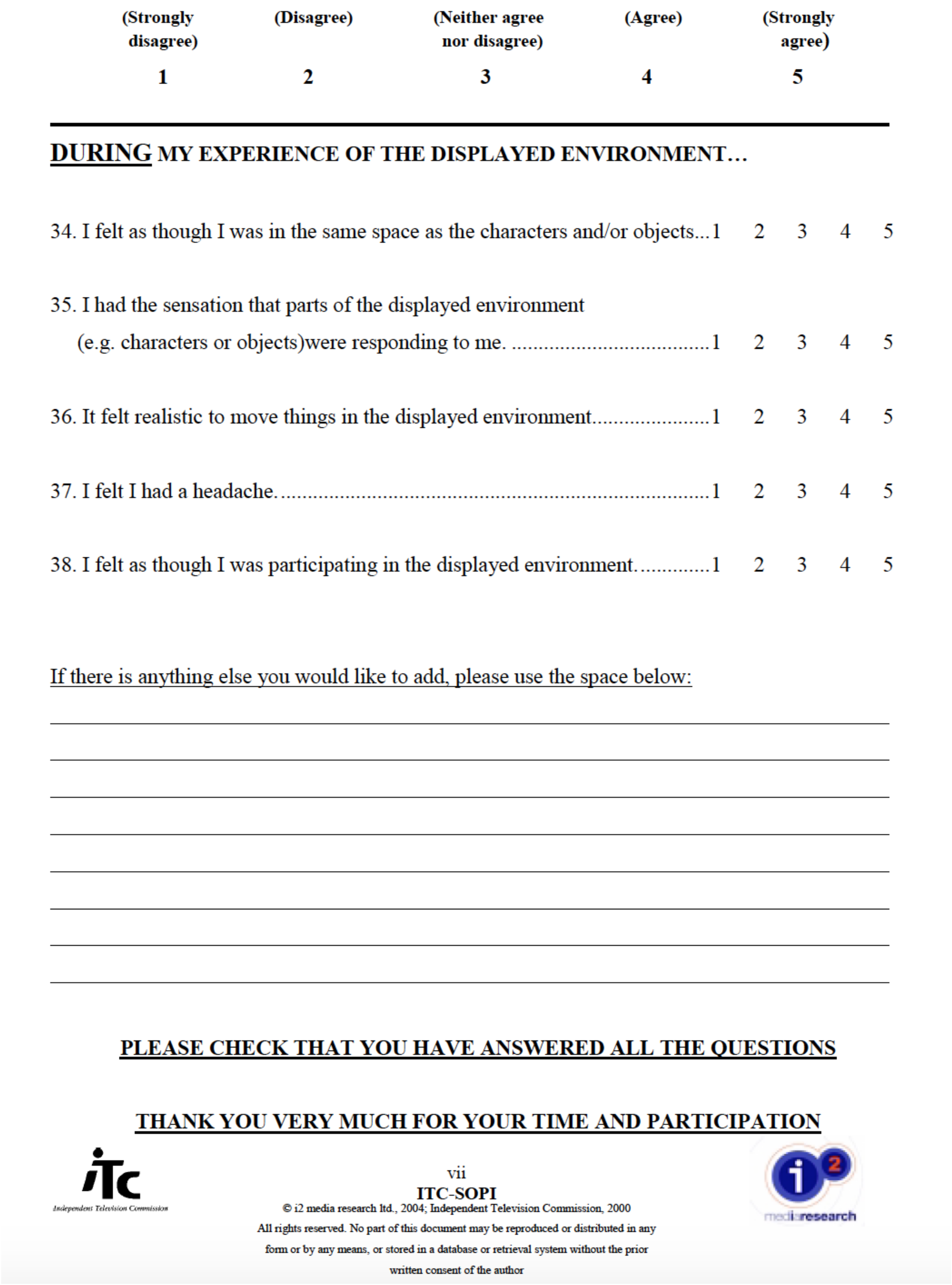
29. I sensed that the temperature changed to match the scenes in the displayed environment. .......................... 1 2 3 4 5

30. I responded emotionally .......................... 1 2 3 4 5

31. I felt that *all* my senses were stimulated at the same time .......................... 1 2 3 4 5

32. The content appealed to me. .......................... 1 2 3 4 5

33. I felt able to change the course of events in the displayed environment. ... 1 2 3 4 5



| | | | | |
|---|---|---|---|---|
| **(Strongly disagree)** | **(Disagree)** | **(Neither agree nor disagree)** | **(Agree)** | **(Strongly agree)** |
| **1** | **2** | **3** | **4** | **5** |

---

**<u>DURING</u> MY EXPERIENCE OF THE DISPLAYED ENVIRONMENT…**

34. I felt as though I was in the same space as the characters and/or objects...1 2 3 4 5

35. I had the sensation that parts of the displayed environment
(e.g. characters or objects)were responding to me. ....................................1 2 3 4 5

36. It felt realistic to move things in the displayed environment.....................1 2 3 4 5

37. I felt I had a headache. ....................................................................1 2 3 4 5

38. I felt as though I was participating in the displayed environment.............1 2 3 4 5

<u>If there is anything else you would like to add, please use the space below:</u>

**<u>PLEASE CHECK THAT YOU HAVE ANSWERED ALL THE QUESTIONS</u>**

**<u>THANK YOU VERY MUCH FOR YOUR TIME AND PARTICIPATION</u>**

**ITC-SOPI**

### 7.2.4 Appendix D: Consent form chapter 5

# CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

**INFORMATION TO PARTICIPANTS:**

We would like to invite your child to be a part of the study titled: "Explicit versus no-instruction learning in a pattern recognition virtual reality tennis task.". The project will aim to examine the effects of explicit instruction, compared with no instruction, on player's ability to learn and utilise a pattern of play sequence in a VR tennis task. Additionally, this project aims to assess participant's performance under pressure conditions. This project requires participants to attend one session of testing at the National Tennis Centre in Melbourne.

**CERTIFICATION BY SUBJECT:**

I, ________________________________________ (parent/guardians name)

of ________________________________________ (parent/guardians suburb)

certify that I am at least 18 years old and that I am voluntarily giving my consent for

____________________________________ (participant/child's name)

to participate in the study titled: Explicit versus no-instruction learning in a pattern recognition virtual reality tennis task.", being conducted by Victoria University and Tennis Australia.

I, ________________________________________ (participant's name) give assent to be involved in the study.)

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 Peter Le Noury and that I freely consent to my child's participation involving the below mentioned procedures:

- One session at the National Tennis Centre in Melbourne.
- Participating in a 40-minute virtual reality tennis task.
- Participating in a virtual reality tennis task that will place external pressure on participants (e.g. crowd booing and cheering).
- Completing all interviews and questionnaires that will assess participant's knowledge of pattern sequences occurring during the virtual reality tennis task.
- Filming participants during the virtual reality tennis task to allow researchers to assess the anticipation speed, shot accuracy and movement of participants, including footwork and type of

stance used, when moving to hit shots in the virtual reality task.

- Audio recording interviews during the virtual reality tennis task to allow researchers to assess participant's knowledge of tactics their opponent is using and any information participants are using to help them win points.

I agree with the all of the above procedures to be undertaken during this research project ☐ Yes ☐ No (please tick)

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

I have been informed that the information I and/or my child provide will be kept confidential.

Parent/Guardian Signed: ___________________________________ Date: _______________

Participant Signed: ___________________________________ Date: _______________

Any queries about your child's participation in this project may be directed to Damian Farrow (Chief Investigator), Tim Buszard (Associate Investigator), or Peter Le Noury (Student Investigator).

Associate Investigator

Tim Buszard
tim.buszard@vu.edu.au
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Student Investigator
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Chief Investigator
Damian Farrow
damian.Farrow@vu.edu.au
Telephone 9919-4512

### 7.2.5 Appendix E: Information letter chapter 5

# INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

## Your child is invited to participate

Participants are invited to take part in a research project entitled “Explicit versus no-instruction learning in a pattern recognition virtual reality tennis task”, held at the National Tennis Academy. Participation in this project is voluntary and is not related to selection / deselection within Tennis Australia programs. The aim of this project is to examine the effects of explicit instruction, compared with no instruction, on player’s ability to learn and utilise a pattern of play sequence in a virtual reality tennis task. Additionally, this project aims to assess participant’s performance under pressure conditions.

This project will be conducted by Peter Le Noury (PhD) from the College of Sport and Exercise Science and ISEAL at Victoria University. The research team also includes Professor Damian Farrow (Victoria University), Dr Tim Buszard (Victoria University) and Dr Machar Reid (Tennis Australia).

## Project explanation

This project will discover whether an explicit instructional approach, compared with no-instruction, influences the ability of participants to identify a pattern sequence that helps them win points during a virtual reality tennis task. Additionally, this project will assess the influence of instructional approach on the ability of participants to utilise and apply a pattern sequence during a virtual reality tennis task and when under pressure conditions. This will be done by participants being allocated to an explicit instructional group who will receive specific instructions about what the pattern sequence is and how to apply it during the task, a no-instruction group who will not be given any instructions about any pattern sequence, or a control group. All groups will play 200 points (40 minutes) against a virtual opponent with the aim of winning as many points as possible. All groups will also play an additional 20 points which will assess performance under pressure conditions.

Past comparisons between explicit and implicit learning (no-instruction), have been shown to be effective in learning pattern sequences, however explicit instructions have been shown to decrease motor skill performance compared to learning implicitly. This is thought to be a result of explicit learners using increased cognitive or mental effort in trying to remember the instruction given to them, and worrying about the application of those instructions. In turn, this detracts from the cognitive resources needed to successfully perform the motor skill. Explicit learning has also been shown to decrease the ability of players to perform skills under pressure conditions, compared to implicit learners who are able to maintain their level of performance under pressure. Therefore, this project will extend past research by using a tennis task involving participants either implicitly or explicitly learning a pattern sequence and applying this sequence using forehand and backhand groundstrokes (motor skill). Additionally, this project will assess the effect of instructional method on performance under pressure conditions. This is the first project to our knowledge that has assessed the ability of skilled tennis players to learn and apply a pattern sequence in a virtual reality tennis task. The findings of this project will inform coaches of the most effective instructional method to use when training pattern recognition skill that reduces the interference with motor skill performance.

### What will your child be asked to do?

---

Participants will be asked to participate in a virtual reality tennis task which will involve playing 200 tennis points against a virtual opponent in a virtual reality environment (40 minutes). Prior to beginning the task, Peter Le Noury will place a VIVE PRO VR headset on participants head which will immerse them in a virtual tennis environment. This virtual environment is designed to replicate a real world tennis stadium, equipped with a hardcourt tennis court surface, large surrounding stand with a crowd of virtual people, a chair umpire, line judges and buildings that can be seen outside of the stadium. The first 5 minutes will be dedicated to ensuring participants feel comfortable in the environment and can successful direct forehand and backhand groundstrokes to different positions on the court. Once participants feel ready, they will begin playing 200 points against the virtual opponent. After every 10th point, the task will be paused and participants will be interviewed about what they are doing to try and win points during the task (1 minute). After the 200 points have been completed, participants will be asked to complete a questionnaire which consists of 5 items asking about what they did to win points and how they thought they performed groundstrokes during the task (2 minutes). Immediately after completing this questionnaire, participants will be asked to play another 20 points which will assess performance under pressure. This will include crowd noise (e.g. booing when players win points and cheering when players lose points) as participants will be told that their scores will be recorded.

**Please be aware that participants will be filmed during the project to allow for analysis of anticipation speed, shot accuracy, number of steps taken, type of stance used and type of groundstroke used during the virtual reality task. Participants will also be interviewed using an audio recorder device during the virtual reality task to assess whether they have identified a pattern sequence.** This video footage and audio files will only be available to Peter Le Noury and Damian Farrow and all recordings will be deleted immediately by Peter Le Noury after the video footage and audio files have been analysed. If at any time, parents/guardians or participants do not feel comfortable with the research team filming or recording audio of their child, all video footage and audio recordings will be deleted immediately.

All identifiable data from the questionnaires will be deleted immediately after each participant completes the study. No data, other than the results of the study, will be made available to the public.

Virtual reality headset participants will wear during this project.

### What will your child gain from participating?

---

There are two important outcomes for participants:

1. Participants in this study will have the opportunity to try new and innovative virtual reality technology that is the first of its kind in tennis. This virtual reality simulation will be the first ever to be used at the National Tennis Academy. Participants will also have the opportunity to be involved in the first project to our knowledge that has assessed the ability of skilled tennis players to learn and apply a pattern sequence in a virtual reality tennis task.

2. The findings of this project will inform coaches of the most effective instructional methods to use when training pattern recognition skill that does not interfere with motor skill performance. Therefore, participants may benefit from using the results from this study to develop their own ability to identify and utilise pattern sequences in the future.

### How will the information I give be used?

It is our intention to present the findings of the group data in the form of a PhD thesis, journal publication and at conferences. Please note that participants will not be named within this report and no one will be able to identify your child's results at any time following the project.

### What are the potential risks of participating in this project?

There are physical risks involved in this project as participants will be performing physical movements during the virtual reality tasks. The risks involved are no more than those associated with a standard tennis match, mainly soreness or fatigue and the risk of falling over.

There is a risk that participants may experience motion sickness or dizziness. However, this is usually only the case if participants spend many hours using virtual reality with no breaks in between. This study will only involve a maximum duration of 40 minutes at one time, therefore the risk of motion sickness is very low.

To minimise these risks the researchers will ensure the tests are done in a safe manner, with the testing area clear of any obstacles that may cause injury. Water will be available for participants during testing. Participants will be exposed to no more than 40 minutes of virtual reality, and they will be encouraged to stop and rest whenever required. Participants will also have 5 minutes of familiarisation before starting each virtual reality condition.

If these physical risks occur, all testing will be held at Melbourne Park – a precinct that includes sports doctors and physiotherapist, thus the participant will be sent to a professional in medicine. The testing will only take place at a time when either a doctor or a physiotherapist is on-site. Indeed, there is almost always a physiotherapist or a doctor on-site at the National Tennis Centre.

Participants may feel concerned that their performance during the virtual reality tasks may highlight any real or perceived physical and/or skill deficiencies, thus leading to potential embarrassment. The researchers will reinforce that all data will remain strictly confidential with their names de-identified using codes.

**Who is conducting the study?**

---

Should you have any questions regarding this project, please contact Peter Le Noury, Tim Buszard or Damian Farrow.

Associate Investigator
Tim Buszard
tim.buszard@vu.edu.au
Telephone 9919-4512
Victoria University

Student Investigator
Peter Le Noury
peter.lenoury@live.vu.edu.au
Telephone 9919-4000
Victoria University

Chief Investigator
Damian Farrow
damian.Farrow@vu.edu.au
Telephone 9919-4512

Any queries about your participation in this project may be directed to the chief investigator associate Investigator or student researcher listed above. If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Regards,

Peter Le Noury (Student Investigator)

### 7.2.6 Appendix F: In-match interview questions chapters 4

## In-match interview questions

1. What are you doing to help you return serve aggressively?

2. Are you doing anything to help you win points more quickly?

3. Are there any other insights you can give me about the match or your opponent so far?

### 7.2.7 Appendix G: Post task questionnaire chapter 4

## Post task Questionnaire

1. Did you use or identify any information that helped you return your opponents serve?

2. Are there any other insights you can give me about the match or your opponent?

### 7.2.8 Appendix H: Task instructions chapter 5

## Task Instructions

Your aim is to win as many points as possible.

Your score will not be shown to anyone.

Use the following information about your opponent to help you win more points during the task:

Your opponent sometimes does not hit through the ball, and so his shots can sometimes **land short in the court** around the service line area.

During this task, your opponent will hit a **short ball** during each point that is played. After he hits a short ball, he likes to hit the next shot he gets to **the corner position** of the court on the deuce side. He will hit to this corner position **<u>80%</u>** of the time after he hits a short ball.

When he hits the corner shot to the deuce side, if you return the ball **down the line** he will be too slow to react and you will **win the point.** However, if you hit the ball towards the middle or cross court you will lose the point by your opponent hitting a winner down the line.

Good luck!

### 7.2.9 Appendix I: Task instructions to the no-instruction group in chapter 5

## Task Instructions

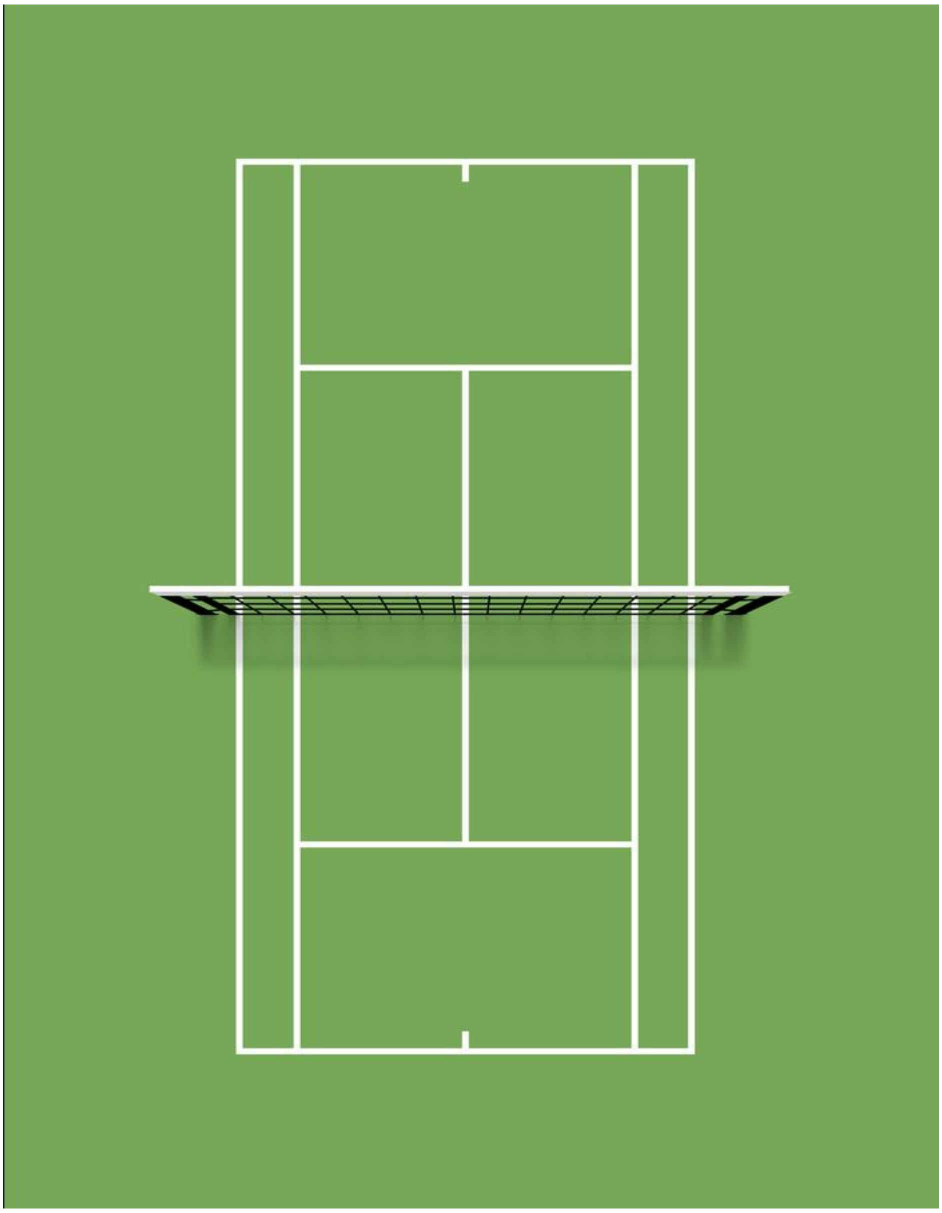
Your aim is to win as many points as possible.

Your score will not be shown to anyone.

You must stay inside the blue box at all times during the task.

Good luck!

### 7.2.10 Appendix J: Image of tennis court used by the explicit group in chapter 5 to explain the opponents pattern features.



### 7.2.11 Appendix K: Post task questionnaire in chapter 5

## Post Task Questionnaire

**Please answer the following items with as much detail as possible.**

1. Did you do anything that helped you win points against the opponent during the virtual reality tennis task?

2. Did you feel like you could control the direction of the ball when hitting forehand ground strokes?

3. Did you feel like you could control the direction of the ball when hitting backhand ground strokes?

4. Please comment on how you think you performed on your ground strokes in the task.

### 7.2.12 Appendix L: In-match interview questions chapter 5

**Interview Question**

1. What are you doing to help you win points against the opponent?