Decision Making Skill and Complex Problem Solving in Team Sports

David Stevenson

University of Stirling

Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

School of Sport

University of Stirling

2013

DECLARATION

I declare that this thesis is my own research work carried out in the United Kingdom under the supervision of Professor David Lavallee and Dr Pete Coffee of the University of Stirling, Scotland. This has not been submitted in another institution for the award of another degree. References cited in this work have been fully acknowledged.

David Stevenson David Lavallee Pete Coffee

Abstract

This thesis aimed to enhance understanding of the nature of knowledge bases possessed by elite sports performers which underpin perceptual-cognitive and decision making skills. Two main theories were considered; Active Control of Thought (ACT*) and Representational Redescription (RR). The purpose of Study 1 was to examine the anticipatory ability of elite and non-elite players in football and hockey. The results indicated that elite players in both sports were quicker and more accurate in their expectation of pass destination. Study 2 aimed to understand the extent to which knowledge is transferable. The results indicated that elite players' knowledge is relatively domain specific although some elements of underlying task strategy may transfer. The objective of Study 3 was to explore the means by which elite and non-elite players in football and hockey identify and differentiate between possible decisions. Results showed elite players' rationale was based on deeper theoretical principles whilst non-experts utilised relatively superficial information and naïve theories. Study 4 focussed on problem representations of elite and non-elite football players. Results revealed elite players' representations were more pertinent, connected and articulated in a more effective manner. Overall, the findings from the current thesis provide advanced understanding of the knowledge bases responsible for perceptual-cognitive and decision making skill, and such understanding may assist attempts to enhance athletes' performance and support future research.

Contents **Page**

List of Tables

List of Figures

List of Appendices

Acknowledgements

I would like to thank my previous supervisors at the University of Strathclyde. Thanks to Allan Walker who helped me throughout the whole process.

A key part of the thesis was the players involved in the studies and I am extremely grateful to all those who participated and helped to arrange participants. I would like to thank the various people and organisations I worked with during the PhD and who have supported me along the way. A special thanks to the Scottish FA.

My heartfelt gratitude goes to Professor David Lavallee and Dr Pete Coffee. I couldn't have asked for two better supervisors. I would not be writing this today if it wasn't for both of you and I am eternally grateful for all you have done for me. Thank you to my examiners, Professor Aidan Moran and Dr Calum Arthur.

To my Mum, Dad and Graeme – thank you! Each of you has helped me enormously in your own way whether it be proof reading, brainstorming or simply listening when I needed to talk.

Finally, thanks to my extremely patient wife, Carol for all you had to put up with. This is as much yours as it is mine. I am sorry it took so long and thank you for your love, patience and support.

This is dedicated to Sam and "the bump." Although it was started long before you both arrived, it was always done with you in mind. I hope this helps to make all your dreams come true.

"Nothing in the world is worth having or worth doing unless it means effort, pain, difficulty… "

Theodore Roosevelt

Chapter 1: Overview of the research problem and chapter content

In watching football at the highest level, the apparent effortlessness of the world's top players is clearly evident, even to the untrained eye. The very best players are often exemplified by having "all the time in the world", an ability to "read the game" and an indefinable quality which allows them to "make it look easy." These anecdotal observations of such abilities can be discussed in relation to a subcomponent of psychology, that of perceptual-cognitive skill and it is this aspect which forms the basis of the current research programme.

Perceptual-cognitive skill is colloquially referred to as "game intelligence" and encompasses areas such as visual search behaviour, anticipation and decision making. The importance of these skills and abilities in the make-up of an elite footballer cannot be underestimated as it is reported that the capability to read the game and make appropriate decisions under time pressure are likely to differentiate elite and sub-elite field athletes better than physiological and anthropometric measures (Williams & Reilly, 2000).

Given their significance, it is desirable to have a clearer understanding of these skills. In that vein, empirical research would suggest that these skills are largely attributable to the possession of highly elaborate and extensive task-specific knowledge bases (e.g. Williams & Davids, 1995). If there is a criticism of this postulate, it seems rather descriptive in nature and somewhat sparse with regard to underlying mechanisms by which these bases develop. It is the nature of these underlying knowledge bases which is at the heart of this thesis; specifically, this research will examine the relationship between explicit knowledge (i.e., higher-order, conceptual understanding) and implicit knowledge (i.e., unconscious technical and procedural competences).

Chapter 2 provides an overview of the literature on expertise and perceptual-cognitive skill in sport. A theoretical perspective encompassing Adaptive Control of Thought (ACT) and Representational Redescription (RR) is then presented. This chapter concludes with a description of the unresolved issues.

Chapter 3 outlines some general methodological considerations relevant to the research programme. This chapter outlines the theoretical framework, the nature of participants and the general investigation set-up including methodological approach undertaken.

Chapter 4 presents the first study in the research programme. This study was concerned with the anticipatory performance of players of differing ability levels in a laboratory based task. The study comprises two response time investigations where elite and non-elite players in football and hockey were required to anticipate final pass destination after viewing video sequences from a match in their sport of choice.

Chapter 5 presents the second study in the research programme. Study 2 is concerned with the domain specificity of knowledge. Football players of varying abilities were required to anticipate final pass destination after viewing video sequences from hockey matches.

Chapter 6 presents the third study in the research programme. Study 3 consisted of two investigations where elite and non-elite players in football and hockey were required to generate possible courses of action available to a player in possession of the ball after viewing video sequences from their sport of choice. Furthermore, participants were required to provide verbal explanation for their choices.

Chapter 7 presents the final study in the research programme. The aim of Study 4 was to examine the problem representations of elite and non-elite football players. The investigation in this study required elite and non-elite football players to provide solutions to a series of tactical problems which may be encountered in a match.

Chapter 8 provides a general discussion on the findings of the four studies in this thesis. A number of theoretical, methodological and practical considerations are then outlined before discussing potential future research directions. Finally, the chapter provides general conclusions.

Chapter 2: Literature Review

2.1 Introduction

There is an intuitive appeal for the researcher to wish to study expert performance in any domain. In sport, the esteem in which elite athletes are held makes this quest even more compelling. In high profile sports such as football, the popularity and wide spread availability of the game make the players amongst the most revered experts in the world. By increasing understanding of the development process, and identifying the hallmarks of expertise, it is envisaged that the derived information can guide the development of future experts in football (Haugaasen and Jordet, 2012). The process is one which has been investigated by a number of sport science and related researchers who have sought to ascertain the nature of expertise and the mechanisms underpinning elite performance in sport.

Expertise in sport is an accepted research area, a point underlined by the publication of several special issues on the subject (Tenenbaum, 1999; Williams & Ericsson, 2008). There have also been a number of expertise related textbooks (Starkes & Ericsson, 2003; Farrow, Baker, & McMahon, 2013) and general psychology publications (Coyle, 2009; Syed, 2010) on the issue. Based on such work, it is generally accepted that to attain expert status, a person must engage in the activity for a significant time period over the course of several years.

2.2 Theory of Deliberate Practice

The theory of deliberate practice was proposed by Ericsson and colleagues (Ericsson, Krampe & Tesche-Römer 1993). Deliberate practice is said to have occurred when a person engages in practice activity, typically designed by a teacher or coach, with the primary goal of improving some aspect of performance.

Ericsson et al. (1993) examined the development of expertise in music. They investigated three groups of elite violinists and found a causal relationship between the quantity and quality of practice and the level of performance. Retrospective estimates of practice suggested that the best groups of musicians, at around 20 years of age, had engaged in over 10,000 hours of deliberate practice. These findings were concurrent with the seminal work of Simon and Chase (1973) who suggested that 10 years or 10,000 hours of practice was required to reach elite status in chess.

The application of the theory in sport has recently been subject to review (Baker and Young, in press). Research in sport has largely verified the relationship between accumulated practice hours and level of success in wrestling (Hodges & Starkes, 1996), figure skating (Starkes, Deakin, Allard, Hodges & Hayes, 1996), karate (Hodge & Deakin, 1998) football and hockey (Helsen, Starkes & Hodges, 1998). Figures of practice hours derived from these studies were comparable with those of Ericsson et al., (1993) in relation to 10,000 hours. A more recent development has been to document the practice histories of elite athletes (Côté, Baker & Abernethy, 2007; Ford, Le Gall, Carling & Williams, 2008; Ford et al., 2012). The premise is to examine the profile of participation and link the content of practice hours to skill acquisition and eventual level of performance.

Although the quantity and quality of practice of elite performers has been documented, a more salient point is made by Ericsson and Williams (2007) who suggest that expertise arises as a result of specific adaptations to the constraints of the performance environment. Given that, it is important to gain an understanding of the adaptations and ultimately the hallmarks of expertise.

2.3 Expert Knowledge

Engaging in a high volume of practice results in numerous adaptations, such as improved technical competence and physiological enhancements. In addition, and the main subject of the current research programme, there are a number of cognitive adaptations in relation to perceptual-cognitive skill. The following section will discuss these adaptations beginning with the initial, pioneering work on cognitive expertise.

The research and literature on expertise in a cognitive sense emanates from the classic work of de Groot (1965) and the subsequent work by Chase and Simon (1973) in chess. Chase and Simon (1973) presented players of varying ability levels, ranging from chess masters to novice players, with schematic representations of chess board configurations. These were viewed under two conditions; structured, where the configurations were those commonly found in a game, and an unstructured condition, where the pieces were presented in a random pattern. In both conditions boards were presented for a period of 5 seconds and participants were asked to recall the locations of the pieces. They found that expert players had an advantage of recall in the structured condition but not in the unstructured condition suggesting that experts possess more elaborate domain specific knowledge as opposed to superior memory.

This initial work in chess provided the stimulus for empirical work on the knowledge-based approach in complex problem solving in a number of domains such as physics, mathematics, and medicine. Using the expert – non-expert paradigm, this body of work has identified some commonly held expert characteristics in relation to knowledge.

Larkin (1979) used a think aloud protocol to examine how expert and novice physicists solved physics based problems. Results suggested that novices stored their knowledge as a fragmented set of individual equations whereas experts possessed interconnected solution equations which could be quickly accessed for specific types of problems. This was supported by Chi, Glaser and Rees (1982) who found that physics experts possessed more extensive knowledge than novices, with this knowledge being better organised and retrieved more effectively from memory. The enhanced structure of expert knowledge has also been shown in medicine (Patel & Arocha, 2001).

Larkin (1983) found that novices in physics utilised a naïve theory when solving problems which focused on surface features that are not meaningfully related to underlying concepts of the subject. In contrast, when an expert considered the same problem, they related features of the problem to a physics-based context. Chi, Glaser and Rees (1982) presented similar evidence also in physics. Experts in this study were deemed to solve problems in terms of deeper theoretical principles, whilst novices utilised superficial representations based on surface elements. Rabinowitz and Hogan (2008) elicited similar findings in statistical problem solving.

Chi, Feltovich and Glaser (1981) presented evidence that experts differ in their knowledge of problem types. They employed a sorting task where participants were presented with physics based problems and were required to categorise them in an appropriate manner. Results indicated that although experts and novices were able to categorise problems, they differed in the quality of their categories. Novices used physical features to group problems together whereas experts used deeper underlying concepts such as solution plans and structural similarities. Schoenfeld and Hermann (1982) employed a similar protocol to that of Chi et al., (1981) but in mathematics. This experiment involved the categorisation of mathematics problems and compared maths professors and novices. They found that experts sorted based on similarity of solution methods, whilst novices sorted on the basis of superficial elements. Confirmatory evidence of expert - non-expert differences in marine biology sorting tasks has been provided by Shafto and Coley (2003).

Larkin, McDermott, Simon and Simon (1980) asked expert and novice physicists to solve a variety of physics based problems. A retrospective protocol analysis revealed that experts tended to work forward by starting with information provided in the initial problem and using this to generate an appropriate solution. This was in contrast to novices who worked in a backward fashion starting with the goal. Simon and Simon (1978) found that experts in physics were able to retrieve solutions to problems effortlessly as part of their initial comprehension of the problem, whereas novices identified relevant formulae in a stepwise fashion working backwards from the original question.

These findings of expert – non-expert differences in knowledge types are not exclusively restricted to adult populations. In a classic study Gobbo and Chi (1986) investigated knowledge structure in 7-year old male children in relation to palaeontology. Participants were assigned to either an expert or non-expert group on the basis of a dinosaur knowledge related pre-test. The researchers utilised two tasks; a production task, in which children were asked to identify a picture of a dinosaur and then generate pertinent information in relation to the dinosaur in question; and a sorting task in which the children were asked to categorise pictures of the dinosaurs. From this research, three major conclusions were derived. The first was that non-experts tended to focus on superficial elements whereas experts utilised deeper level concepts. Secondly, it was found that experts' knowledge was more structured; specifically it was deemed to be more integrated and cohesive. Thirdly, it was suggested that experts use their knowledge in more sophisticated and accessible ways. Differences in knowledge within youth populations are salient as perceptual-cognitive differences between elite and non-elite players in sport appear to emerge at a relatively young age (Ward & Williams, 2003).

2.3.1 Common Features of Expert Knowledge

In drawing together all of the evidence presented above, there appear to be some commonalities which are exhibited in a number of different domains. It would seem that experts store knowledge in large units that can be accessed rapidly, relate specific features of a problem to meaningful underlying concepts, discriminate among problem types in a way that allows them to categorise problems based on solution plans, work forward and consider alternatives. Non-experts on the other hand, store their knowledge as a fragmented set of individual pieces of information, utilise naïve theories or weak methods, focus on surface features and work in a backward fashion starting with the goal. Furthermore, there is evidence that differences in knowledge begin to emerge at a relatively young age and there appears to be similarity between child and adult expert knowledge.

2.4 Expertise in Sport

The original work in chess, and the subsequent research on complex problem solving in other domains, was the stimulus for research on expertise in sport. Dynamic sports such as football can be viewed as complex problems and, when further broken down, can be considered as a series of complex problems to be solved rather than one overarching problem. Essentially, a football match comprises recurring situations which have been termed microstates (Vaeyens, Lenoir, Williams, Mazyn & Philippaerts, 2007). These microstates have differing requirements and, therefore, pose a range of problems to be solved.

Having established this, it is important to address how these problems are "solved." In most instances, the solution is in the form of selection (cognitive) and execution (motor) of an appropriate response to a given situation. The process of selecting an appropriate response is also termed decision making. Thus, it is feasible to suggest that problems are solved through decision making.

Elite athletes have to be able to make a number of decisions throughout their chosen activity, often in a time pressure environment (Williams & Ford, 2008). Knapp (1963) referred to decision making as "knowing which technique to use in any given situation" (p.17). Farrow and Raab (2008) describe the process as "the ability of a player to quickly and accurately select the correct option from a variety of alternatives that may appear before the ball is hit or kicked or an opponent moves" (p.137). Taking elements from both definitions, it would seem that decision making involves selecting an appropriate motor technique from a number of alternatives.

Initial models of decision making suggested that the process followed a hierarchical structure. McMorris (1986) suggested that when a football player has the ball, the first option they will consider is to attempt to score. If this option is viable, they will deliberate over which technique to use. If there is no opportunity to score, the player will consider other options in a hierarchical fashion such as passing to a player in a goal scoring position, dribbling forward, passing forward and so on.

When considering this model, it is unlikely a process such as this occurs. For example, if a defender has the ball in the corner of the pitch he is defending, it is unlikely that the first course of action he will consider is to attempt to score. Notwithstanding that the likelihood of beating the goalkeeper from a distance of approximately 100 yards is highly improbable, the player's priority in this situation, particularly if being pressurised by the opposition, is to clear the ball away from their own goal. Aside from the issues raised in the hypothetical example provided, the time constraints imposed by the activity make it unlikely that such an onerous processing task can be undertaken. Thus, this type of model was later discounted, even by those authors who had originally proposed them (McMorris, 2004).

Tenenbaum (2003) posited a multifaceted model which proposes that expert decision making in sport consists of the integration of visual attention mechanisms, anticipatory mechanisms and their elaboration with long-term rooted representation. These long-term representations can also be termed knowledge bases. As has been identified, experts appear to have enhanced knowledge bases which mediate expert performance. Before discussing these knowledge structures in detail, the next section will elaborate on the other constituent parts of Tenenbaum's model and discuss the perceptual-cognitive aspects of visual search and anticipatory mechanisms.

Elite sport performers have an advantage over their less elite counterparts with regard to a more sophisticated visual search strategy, and in relation to anticipatory mechanisms, a greater sensitivity to advance cues, they are more adept at recognising emerging patterns of play and they have a greater knowledge of situational probabilities (Williams & Grant, 1999). These findings have been verified by a meta-analysis conducted by Mann, Williams, Ward and Janelle (2007). The review will firstly focus on visual search.

2.4.1 Visual Search Strategy

Visual search refers to the orientation of visual gaze during performance. At the very outset of the decision making process, visual search is of fundamental importance as it is the mechanism by which information from the environment can be used to make decisions. In sport, visual attention is required to detect, recognize, recall, and select stimuli for higher-level processing.

Roca, Ford, McRobert and Williams (2011) investigated the visual search strategy of elite and non-elite players during a simulated 11v11 football sequence. They found that elite players made more visual fixations of shorter duration and focused on more areas of the display. Furthermore, elite players more often attended to opposition players and areas of space. In contrast, non-elite players spent more time fixating on the player in possession of the ball. This suggests that visual search strategy is a knowledge driven process whereby elite players understand the relative importance of information within the display and how it can be used in decision making (Williams & Ford, 2013).

2.4.2 Anticipation

Anticipation refers to a performer's ability to make predictions prior to an event occurring. Within a sports environment, there are numerous sources of information from which a performer can glean information to utilise for anticipation and subsequent decision making and it would seem that experts are more adept at doing so. The expert's advantage over the non-expert is evidenced in a superior ability to utilise information from the postural orientation of opponents (Savelsbergh, Williams, Van der Kamp & Ward, 2005), a capability to formulate more accurate predictions as to the outcome of a situation (Ward & Williams, 2003; Williams, Bell-Walker, Ward & Ford,

2012) and the capacity to quickly and accurately recognise and recall structured patterns within the activity (North, Ward, Ericsson, & Williams, 2011).

2.4.2.1 Advance Cues

In an area closely related to visual search, advance cue utilisation refers to an athlete's ability to make accurate predictions based on contextual information available early in an action sequence and the specific cues or information utilised to guide behaviour (Abernethy, 1987). One task that is amenable to investigating cue utilisation in football is that of penalty kicks. Savelsbergh, Williams, Van der Kamp and Ward (2002) found that elite goalkeepers focused on areas of the kicking leg, the non-kicking leg and the ball, whereas non-experts focused on the trunk, arms and hips.

Methodologically, researchers have utilised a number of techniques. Time Occlusion techniques involve manipulation of the length of a priori information with which the participant is provided (Abernethy & Russell, 1987). Using event occlusion, different areas of the display are masked off in turn with the underlying principle being that performance will diminish if an important postural cue is not present. If performance does diminish, then the area which has been occluded is inferred to be important (Müller, Abernethy & Farrow, 2006). A more recent development has seen postural orientation presented in the form of point light displays (Abernethy, Zawi & Jackson, 2008).

2.4.2.2 Situational Probabilities

Situational probabilities are expectations of what is likely to happen based on a set of circumstances. Despite their intuitive importance in anticipation, there is a paucity of research but typical methodologies focus on participants assigning a probability of the likely outcomes of different scenarios. Initial work was carried out in racquet sports by Alain and colleagues (Alain & Proteau 1980; Alain, Sarrazin & Lacombe 1986; Alain & Sarrazin 1990). Ward and Williams (2003) investigated situational probabilities in relation to passing options in football. They found that elite players were more accurate than non-elite players in assigning probabilities to players in various positions in terms of threat, and that elite players were more adept at identifying the players in best position to receive the ball.

2.4.2.3 Pattern Recall and Recognition

As previously stated, the impetus for much of the research in sports expertise was the work of de Groot (1965) and Chase and Simon (1973) in chess. The area of perceptual-cognitive literature most associated with this work is that of pattern recall and recognition. Allard and colleagues (Allard & Burnett, 1985; Allard, Graham & Paarsulu, 1980) were the first to use these paradigms in the sports domain. Allard et al., (1980) found that expert basketball players were more accurate than non-expert players in recalling player positions in structured sequences of play. The recognition paradigm is an alternative, and more widely applied, method in which participants are presented with a series of clips or pictures and, after a period of time, are re-exposed to some, but not all, of the clips. Allard et al., (1980), were the first to implement the recognition paradigm in the sports domain. They found that expert basketball players displayed superior performance on this task, as shown by quicker and more accurate recognition of previously viewed sequences. These findings have been found in numerous sports including football (Ward & Williams, 2003; Williams & Davids, 1995) and field hockey (Smeeton, Ward & Williams, 2004).

Experimental footage can also be presented as a point light display. The premise of this approach is that if the expert's advantage is in being able to make meaningful associations between the players, then the advantage should still be evident when the experimental footage is presented in this form. Williams, Hodges, North and Barton (2006) presented skilled and less-skilled players with action sequences in this format. They found that skilled players were more accurate in recognising sequences presented in point-light form.

In summing up pattern recall and recognition paradigms, it would seem that no matter which sport or which presentation method is used, the findings confirm that experts have an advantage over their less elite counterparts (North, Ward, Ericsson & Williams, 2011). Evidence in initial chess studies illustrated that experts possess more elaborate, domain specific knowledge as opposed to superior memory and sports based research would appear to provide corroborating evidence (Williams & North, 2009). The overall implication is the ability to recognise and recall structured patterns of play and the other expert advantages outlined above, are attributable to knowledge bases.

2.5 Adaptive Control of Thought (ACT)

One of the most widely cited theories as a possible framework for learning, skill acquisition and perceptual-cognitive expertise in sport is Adaptive Control of Thought (e.g., Gil, Perla Moreno, & Garcia-Gonzalez, 2012; Helsen & Pauwles, 1993; Paull & Glencross, 1997; Williams & Davids, 1995). ACT-R (Anderson, 1993; Anderson & Lebiere, 1998) is the latest iteration of the ACT theory and builds on the previous version of the model, ACT* (Anderson, 1983). Despite the amendments, the fundamental premise of the theory remains essentially unchanged. As such, it will be referred to as ACT throughout. The following section provides an overview of the theory.

ACT theory suggests that human cognition is based on a series of condition-action links called productions. These productions are responsible for initiating appropriate responses under specific conditions. ACT is the most widely quoted example of a production system and consists of two primary structures; declarative memory and procedural memory. These memories can also be termed as knowledge bases and in the sports domain declarative knowledge is referred to as “what to do” and procedural knowledge is “how to do.”

2.5.1 Declarative Knowledge

Although declarative memory encompasses all facts a person possesses, within the sports domain, it is referred to as knowledge of “what to do.” Williams and Davids (1995) conducted a seminal study to investigate whether declarative knowledge is a component of expertise or a by-product of experience. Experienced high-skill and low-skill football players and physically disabled spectators were tested on pattern recall, recognition, and anticipation ability. The groups were matched for overall exposure but differed in terms of skill level and also the way in which they had accrued their experience, with physically disabled football supporters having accumulated their experience through watching games on television and spectating at live matches. The premise of the study was that skilled football players would exhibit an enhanced declarative knowledge base as the procedural component of performance i.e., doing, facilitates “knowing” i.e., “declarative knowledge”

Results revealed that high-skill players exhibited superior performance in relation to low-skill players, who also outperformed the physically disabled spectators on a pass anticipation test. Tests on recall with structured trials produced similar results with high skill players demonstrating superior performance compared with low-skill players. The low-skill group were also significantly better than the physically disabled group. An expert advantage was also evidenced with regard to the pattern recognition where high-skill players were superior at recognising structured and unstructured sequences of play. Due to superior performance exhibited by the high skill group in all tests, results suggested that high-skill players had a larger and more elaborate declarative knowledge base and the authors concluded that declarative knowledge is a constituent of skill as opposed to being by-product of experience.

2.5.2 Procedural Knowledge

The importance of procedural knowledge in sports performance has been demonstrated. Del Villar, Iglesias, Moreno, Fuentes and Carvello (2004) tested 188 youth basketball players aged 12-13 years. Participants were categorised into three groups; high experienced, low experienced and inexperienced players. The investigators found that the experienced players possessed higher levels of procedural knowledge than the other groups. Furthermore, they found a positive relationship between performance, as denoted by league position, and level of procedural knowledge. This suggests that greater involvement, i.e., experience, in an activity leads to greater accumulation of procedural knowledge and that this then relates to level of performance. Procedural knowledge, therefore, would appear to be fundamental to successful sporting performance. This is further exemplified by a study conducted by French et al., (1996) who investigated decision making skill in youth baseball players. They demonstrated that players will not choose a course of action when a particular skill required to do so cannot be executed. Thus, the existence of procedural knowledge is crucial in regulating decision making ability.

2.5.3 Production Compilation

Despite the fact that the bases are distinct (Rabinowitz & Goldberg 1995), ACT theory posits that there is integration. At the early stages of the process, Anderson (1983) suggests that all information is stored in declarative memory. There is, however, a shift from regulation from declarative knowledge toward regulation by procedural knowledge. Production compilation is the name given to the process by which knowledge is transferred from declarative to procedural memory. Initially instructions on how to perform a given task are stored in a series of steps in declarative memory. With practice, these chunks of declarative knowledge are compiled into rules in procedural memory, also referred to as production rules or simply productions. In essence these productions fulfil the same function as the declarative representations of the instructions but do so automatically and with increasing speed and accuracy. This is a key concept as automaticity of performance is considered to be a hallmark of expertise (Fitts & Posner, 1967; Wadden, Borich & Boyd, 2012).

A salient study on the nature of expertise, memory and automaticity was conducted by Beilock and Carr (2001) which investigated the nature of expertise and memory. Skilled and novice golfers were required to putt toward a goal and then asked to verbally report the procedures they employed to complete the task. In terms of performance, experts were better on the putting task. With regard to verbal report measures, although experts were able to provide either prescriptive information on requirements for subsequent shots or diagnostic feedback on perceived inadequacies with the preceding shot, they were unable provide a verbal account of the procedural steps undertaken to execute the stroke in question. Conversely, it was found that novices were able to verbalise the steps they took in performing their actions. The authors described this phenomenon as "expertise-induced amnesia" which is attributable to automation of procedural knowledge. This so-called expert amnesia results in details of procedures being no longer accessible and are, therefore, implicit in nature.

In addition to automaticity, a further point in relation to the production compilation process is that refinement of these production rules ensures that they will only be applied to instances where it will be successful. These refinements suggest that these productions are goal-directed and relatively context specific. This relates to the other key concept from ACT in terms of decision making; productions initiating appropriate responses under specific conditions. As these productions have a conditional element and an action component they have been termed IF…THEN...DO statements (McPherson & Thomas, 1989). The IF denotes the conditions at that present time and the THEN represents a response for that situation. The DO element is simply an adjunct used to denote the motor execution; a crucial element in sport.

2.5.4 Knowledge Structure

McPherson and colleagues (e.g., French & McPherson, 1999; McPherson & Kernodle, 2003, 2007) have outlined two knowledge structures which are believed to be utilised in decision making. Action plan profiles are memory structures in long-term memory (LTM) which activate general rule-based action responses when matched with certain conditions and this bears an obvious resemblance to ACT and the concept of productions. The current event profiles refer to memory structures which are responsible for merging current information with past, current, and potential future occurrences. They are comprised of tactical scripts and situation examples in LTM. The next section will review research conducted by, amongst others, McPherson and co-workers, on expert knowledge structure.

McPherson and Thomas (1989) used such a verbal protocol to determine the thought processes of high and low skill youth tennis players. The investigation of the knowledge base content centred on the number and quality of concepts provided. They identified three different concepts; condition, action and goal. These concepts have obvious roots in ACT with the condition component relating to the specific circumstances encountered. The action concept refers to the course of action taken in the situation and the goal concept reflected the purpose of the action within the context of the game. Findings revealed that high-skill players generated more condition-action concept links with these concepts being more connected to goal concepts. In addition to findings on knowledge structure, it was found that high-skill players chose more applicable and tactically-based courses of action for the given instance. McPherson and Thomas (1989) concluded that youth tennis experts' tactical problem representations were linked to their superior response selections during competition.

McPherson (1999) examined performance and problem representations of youth and adult tennis players concurrently. Again employing the expert – non-expert paradigm, it was found that experts provided more varied, and sophisticated condition and action concepts than non-experts. In terms of comparison between the two expert groups, adults utilised more sophisticated problem representations than youth, with incorporation of both current event and action plan profiles to guide their decisions. This differed from youth experts who predominantly used action plan profiles to direct their response selections. Novice performers, regardless of age, accessed weak problem representations.

Findings pertaining to knowledge structure in sport are not restricted to tennis. McPherson (1993b) examined the development of conceptual knowledge in baseball, specifically in relation to batting preparation and decision making in a contrived baseball problem solving task. Using a think-aloud protocol, experts were found to use sophisticated condition-action rules with these rules being more tactical, refined, and associated when compared with novices. Aside from differences in condition-action rules, experts also differed from novices in what features were deemed important when solving the problem.

Huber (1997) investigated differences in problem representation between elite and non-elite springboard divers. Verbal reports recorded after diving performance were converted into problem representations. Findings revealed that elite divers provided more production rules than novices. Furthermore, the production rules articulated by elite divers were deemed to be more sophisticated as they contained additional, higher-order concepts.

Schack and Mechsner (2006) investigated the cognitive representations of the tennis serve for high-level tennis experts, low-level players, and novices. The results of their study revealed that in high-level experts, these representational frameworks were organised in a distinctive hierarchical tree-like structure with a similarity displayed between the individuals. In contrast, action representations in low-level players and non-players displayed less hierarchical organisation and more variability was observed amongst individuals. Weigelt, Ahlmeyer, Lex & Schack (2011) provided confirmatory evidence in judo where expert skill representations were organized in a distinctive hierarchical structure, which was matched to the functional and biomechanical demands of the task.

Extracting common themes from this research, it seems that both child and adults experts do provide productions, i.e., condition-action links, but these appear to be augmented in the case of adults with additional, more sophisticated information pertaining to higher-order concepts associated with the domain. Furthermore, expert knowledge in adult populations appears to be more connected and coherent (Weigelt, Ahlmeyer, Lex & Schack, 2011). Research presented earlier in relation to complex problem solving also identified a similarity in the knowledge structure of child and adult experts. However, it would appear that whilst there is a similarity, the child expert's knowledge is not akin to that of an adult expert.

2.6 Representational Redescription

The emergence of explicit knowledge of task-specific, higher-order concepts from child to adult experts can be discussed in relation to learning and development. This perspective is valuable in enhancing understanding of the eventual structure of the adult mind. Karmiloff-Smith's (1992) Representational Redescription (RR) model provides a theoretical framework to account for development of representations from implicit information to explicit knowledge. The transition from implicit to explicit is termed explicit theory change.

Through the process of RR, information stored in one representational format is redescribed into another. At each level of the process, the newly formed representation is a more condensed version of the previous, with each new level becoming progressively more explicit, with knowledge becoming available to self and then communicable to others. Karmiloff-Smith (1992) originally proposed 3 phases of development within the RR model.

Phase 1 is data driven in which information from the external environment plays a key role. Behaviour at this phase is sustained by what Karmiloff-Smith (1992) termed "representational adjunctions." These are stored as context bound procedures designed to respond quickly and effectively to the environment. These procedures are goal-directed and implicit in nature i.e., they are not available to conscious access. The culmination of this phase is behavioural mastery, which is termed consistently successful performance.

Phase 2 is an internally driven phase in which the child no longer focuses on environmental stimuli to the same extent, but instead gives greater precedence to internal data (Karmilloff-Smith & Inhelder, 1974). In this phase children tend to place greater emphasis on their newly generated internal data as opposed to information contained within the environment. This shift, however, can manifest itself in new errors and inflexibilities, as the child will dismiss important elements of the external environment in favour of internal representations and naïve theories. This results in a performance decrement on the behavioural level as observed at Phase 1 (Pine, Lufkin & Messer, 2004). Despite this, representations sustaining this phase of development are deemed to be more cognitively advanced, as information from the insulated procedures is now available to other operators in the cognitive system. This allows for the linkage of common features; the basis of an explicit conceptual network of understanding.

At Phase 3, there is reconciliation between internal representations and the external data. This results in individuals being able to perform a task successfully and have accompanying explicit, conceptual knowledge underpinning behaviour in the task.

Karmiloff-Smith (1992) originally proposed that these developmental phases were linked to four levels of representation; Level-I representations are implicit in nature and underpin behaviour at Phase 1. After behavioural mastery has been attained at Phase 1, the implicit information contained within the Level-I representations is redescribed into more explicit forms. These representations were termed E1 (available to self), E2 (communicable to others but not through verbal report) and E3 (available to other through verbal report).

A key aspect of the process of RR is that, as a result of redescription, there are multiple levels of the same knowledge which are stored in different representational formats. Thus, there is existence in the mind of multiple representations of similar knowledge at different levels of detail and explicitness. For example, after redescription into level E1 format, level-I representations remain intact so that they can be utilised when the demands of a task require that type of response i.e., speed and automaticity.

Support for the process of RR has come from numerous studies in a variety of domains such as language (Critten, Pine & Messer, 2012; Critten, Pine & Steffler, 2007), mathematics (Voustina, 2012; Voustina & Jones, 2000; physics (Pine & Messer 1998, 1999, 2000, 2003; Messer, Pine & Butler (2008) and notation (Barlow, Jolley, White & Galbraith, 2003). However, this work has also identified some refinement to the original model outlined previously.

Pine and Messer (2003) conceptualised their own classification system of behavioural and conceptual characteristics in a physics based balance beam task. It consisted of 7 levels of representation: Implicit (Level I), Implicit transition, Abstraction non-verbal, Abstraction verbal, Explicit transition, Explicit E3, Explicit E4. Three of the levels are akin to what Karmiloff-Smith (1992) originally proposed, Level I, Level E1 (termed as Abstraction non-verbal in this model) and Level E3. The refinements, however, are based on the finding pertaining to a verbalisable level of E1 which had been evidenced in earlier studies (Pine & Messer, 1998). Due to the implication of these findings, E2 has been excluded is it was originally conceptualised to have been communicable to others but not through verbalisation. There is the inclusion of an E4 level which is an extension of the E3 identified by Karmiloff-Smith (1992). Crucially, there is inclusion of two transitional levels which attempt to account for the intermediary steps between the phases of development to which Karmiloff-Smith (1992) referred but did not assign a representational level. This suggests the model is more of a continuum with specific markers indicating location on a representational spectrum.

Although RR was originally proposed to be an endogenous process, there is evidence of an exogenous component which can facilitate or enhance the endogenous process. Another area in which the RR model has been applied is that of children's road safety training. Tolmie, Thomson, Foot, Whelan, Morrison and McLaren (2005) examined the effects of different instructional approaches aimed at improving road safety skills of children. They discovered that children in an adult guidance condition improved significantly more than those exposed to a peer discussion or control condition. The researchers attributed the improvement to the appropriation of E3 level representations from adult dialogue. Furthermore, it was also discovered that progress was further enhanced when adult scaffolding was complemented by peer discussion.

2.6.1 Summary of RR

In sum, representational redescription (RR) is a progressive model of developmental change. It is a re-iterative process in which implicit information embedded in context-bound procedures is gradually redescribed into more accessible and explicit formats. This redescription permits the organisation and linkage of common features, providing a base on which an explicit, coherent network of understanding can be constructed for use within a domain and, in some instances, across domains.

2.7 Summary

In order to attain expert status in any domain, it is clearly evident that an individual must engage in a high volume of practice, accruing around 10,000 hours over a 10 year period with the participation profile of this period changing as goals and objectives are shaped. Due to the constraints of the practice environment in which an individual participates, there are specific adaptations which occur which can be considered to be hallmarks of expertise.

In relation to cognitive expertise in complex problem solving, there are generic, common features of expertise displayed across domains. It would seem that experts store knowledge in large units that can be accessed rapidly, relate specific features of a problem to meaningful underlying concepts, discriminate among problem types in a way that allows them to categorise problems based on solution plans and work forward and consider alternatives. With specific reference to perceptual-cognitive expertise in sport, experts have been shown to have a more sophisticated visual search strategy, make effective use of advance information, whether that is in the form of postural orientation or in an unfolding pattern of play, and are able to generate expectations of what is likely to happen through situational probabilities.

The key aspect of these expert – non-expert differences is that they are believed to be attributable to enhanced, task-specific knowledge bases. Despite these findings, there has been some criticism of this type of research (McPherson 1993a) on the basis that findings have been predominantly descriptive in nature. Whilst they illustrate superior expert performance, studies fail to offer an explanation as to why and how these superior performances are evident. Furthermore, there is a paucity of evidence pertaining to the issue of knowledge bases and how they become more enhanced. The nature of these knowledge bases is the crux of the research programme and of particular interest is why and how these knowledge bases become more extensive and elaborate. In addressing these questions, two theories were postulated; Anderson's ACT theory and Karmilloff-Smith's Representational Redescription (RR) model.

Integration of the theories centres on the fact the description of level-I representations at phase one of development in RR bears an obvious resemblance to a production in ACT. The culmination of phase one is behavioural mastery, defined as consistently successful performance. The RR model provided is lacking in terms of the mechanism by which behavioural mastery is reached. This is, however, succinctly theorised by ACT which suggests that through practice, individuals solve problems with increasing speed and accuracy. This is akin to what Karmiloff-Smith (1992) described. The limitation of ACT theory centres on the subsequent development, something which can be accounted for by the RR model. There are, however, a number of unresolved issues and the following section will outline these and the implications for the current research programme.

2.8 Unresolved Issues

ACT is an applicable model for procedural and declarative knowledge bases possessed by elite athletes. Likewise, the theory is a robust framework for decision making in terms of condition-action links called productions which initiate appropriate responses under specific conditions.

Ostensibly, the concept of a production, or IF…THEN...DO statement (McPherson & Thomas, 1989; McPherson & Kernodle, 2007), is sound in that they respond quickly and effectively to the environment and are applied in an appropriate context in which they will be successful. The productions, therefore, are goal-directed and context specific. As such, productions bear a resemblance to what was termed a Level-I representation in the RR model. Research presented earlier also suggests that experts' knowledge is in the form of productions and this is evidenced in both child and adult expert populations. However, Holyoak (1991) proposed that ACT was an adequate description for what he termed 'routine expertise' but that it could not be used to explain 'adaptive expertise' in which athletes may invent new procedures to respond within unpredictable situations. This echoes an argument by Allard and Starkes (1991) who suggested that rather than the specific condition-action links, it is the flexibility in linking that is more important.

In describing football and hockey as a series of complex problems, reference was made to the term microstates. These are events which typically occur within a match. Whilst the same events continually occur, the vagaries and nuances within these events dictate that the exact same conditions rarely, if ever, occur within the microstates. Therefore, given the uncertain environment, what is the efficacy of routine and automated responses when a degree of flexibility would appear to be advantageous?

Furthermore, in relation to initiation of appropriate responses under specific conditions, it is possible that there may be more than one appropriate production response for the conditions present; essentially more than one THEN per IF. This was noted within the definition of decision making provided by Farrow and Raab (2008) which suggests there is a selection process between possible alternative courses of action. There is evidence that, not only can two responses be concurrently triggered, they can also contend against each other (Coles, Gratton, Bashore, Eriksen & Donchin, 1985; Eriksen, Coles, Morris & O'Hara, 1985). The overall issue in relation to ACT and the current research programme is this; if there is a situation in which two appropriate responses are available, what are the means by which they are differentiated?

McPherson (1991) found that adult experts offer more sophisticated productions in comparison with child experts, with the articulation of additional conceptual information, termed the current event profile, which appears to play a role in guiding deployment of productions. To an extent, this begins to partially provide some explanation for the points raised above but questions remain as to how this is achieved and by which mechanism. It is hypothesised that during the process of production compilation, declarative knowledge becomes embedded within the production in the procedural knowledge base, thus rendering it automatic and implicit. Firstly, if automaticity is considered to be a hallmark of expertise, why is there an emergence of new knowledge which differentiates adult from child experts? Secondly, given that productions are evident in both child and adult experts, if declarative knowledge is compiled into a production via production compilation at an earlier age, what is the mechanism by which more conceptually driven, explicit, verbalisable declarative knowledge emerges in expert adult populations to accompany their productions? Thirdly, it would seem that some elements of expert knowledge are non-verbalisable i.e., implicit, whilst other aspects are verbalisable i.e., explicit; what is the efficacy of such a disparate dichotomy and what purpose does it serve in performance?

The last point relates to a further broader issue, the relationship between the procedural and declarative knowledge bases. Despite the interaction within the production compilation process, it is considered that procedural and declarative knowledge bases are distinct and, therefore, develop independently. It is, however, possible that procedural and declarative knowledge are related in another way.

Evidence presented earlier suggests that greater involvement in an activity leads to greater accumulation of procedural knowledge and that this then relates to level of performance. Furthermore, French et al., (1996) demonstrated that youth baseball players will not choose a course of action when a particular skill required to do so cannot be executed. Thus, procedural knowledge would appear to be fundamental to sporting success and is crucial in regulating decision making ability.

Evidence from a previously reviewed football-based study by Williams and Davids (1995), whilst primarily concerned with the role of declarative knowledge, further emphasises the importance of procedural knowledge but does so in a different way. Salient findings were elicited when comparing the low skill group and the supporters with disabilities. With the exception of pattern recognition, the low skill group exhibited superior performances on all tests undertaken, thus suggesting the low-skill group possesses a higher level of declarative knowledge. Given that the supporters with disabilities have amassed their experience entirely through spectating, and thus have no action-based experience of the game itself, this suggests that participation in any level of the activity, and accumulation of procedural knowledge, has a role in the extensiveness of the declarative knowledge base. Starkes and Deakin (1984) proposed that possession of procedural knowledge provides more “hooks” on to which new knowledge can be added. Evidence provided by Williams and Davids (1995) also suggests that there is some sort of mechanism in which procedural knowledge assists in the acquisition of new declarative knowledge, either through the use of so-called “hooks” or by some other method. ACT offers little by way of mechanism for such a phenomenon but evidence from developmental psychology, would suggest that high level conceptual understanding is derived from implicit knowledge structures.

In sum, there are a number of unresolved issues to consider; differentiation between possible courses of action, perceived rigidity of condition-action links, the emergence of verbally communicable declarative knowledge, the relationship between procedural and declarative knowledge, and, finally, the path of expertise development**.** In addressing these issues, the perspective offered by developmental theory is useful. The overall premise of this approach was not to examine development in children per se, but rather to investigate the eventual structure of the adult mind. Given this, there are a number of resultant implications for the current research. Karmiloff-Smith (1992) suggests that "development and learning, then, seem to take two complementary directions. On the one hand, they involve the gradual process of proceduralisation (that is, rendering behaviour more automatic and less accessible). On the other hand, they involve a process of "explicitation" and increasing accessibility (that is, representing explicitly information that is implicit in the procedural representations sustaining the structure of behaviour)" (p.17).

The focus of the thesis is the relationship between implicit and explicit knowledge and, based on theoretical underpinning, it is proposed that there is co-ordination between ACT and the RR model. The proposition is that ACT provides an account of the first phase of development in the RR model and the development of the productions, or in an RR sense, level-I representations. The culmination of this phase, behavioural mastery, rather than being the end point of expertise, is the starting point of another process in the journey toward expertise. It is hypothesised that the procedural knowledge base developed through the ACT, is redescribed through the process of Representational Redescription, to generate new declarative knowledge. Through this process, knowledge becomes more connected, more explicit i.e., communicable to others, and the individual gains a deeper conceptual understanding of the task. Furthermore, this process will result in the existence of multiple representations of knowledge which can be used according to the demands of the situation.

Considering the above, the main integration of the two theories in terms of complex problem solving is that the process of redescription into more explicit forms facilitates the linkage and organisation of previously context-specific, implicitly grasped, responses. In addition to permitting generalisation of actions to novel contexts, this coordination provides the foundation for a rich network of perceived possible responses to a given situation, and the means of selecting between these, according to an understanding of relative consequences. This framework bears an obvious relationship to ACT, but extends it with the addition of a layer of conscious choice between options.

Taking all of this into account, the proposed co-ordination between ACT and RR yields a testable hypothesis: expert knowledge is organised as IF… THEN… DO...BECAUSE propositions. The literature suggests that the representational redescription does occur in children, however, it is unclear whether the process occurs in sophisticated adult skills, of which sporting performance is an exemplary example. The central proposition of the thesis is that in a sophisticated adult skill such as sport, there is a similar progression from implicit information to explicit knowledge, as has been found in children.

To test these hypotheses, and the other aspects pertaining to problem representation, a series of investigations have been designed. The next chapter will outline a framework for investigating expertise in sport, discuss some of the issues associated with the approach undertaken and provide a description of the general investigation set up.

Chapter 3: General Methods

3.1 Introduction

If it is the case that high levels of procedural competence (implicit knowledge), lead to higher levels of conceptual understanding (explicit knowledge), this can be tested in a sports context by selecting groups of elite performers and comparing them with less elite performers. The premise of the approach is that the more extensive and higher-level playing experience of the expert players provides a wider range of implicit knowledge on which to build a network of explicit knowledge and enhanced conceptual understanding. This research programme investigates the degree of conceptual understanding possessed by the participant groups within the context of two sports; football and field hockey. These sports were chosen as they are examples of adversarial complex problems which incorporate strategic decision making.

3.2 Expert – Non-expert paradigm

All subsequent investigations employed the expert v non-expert paradigm. Although widely utilised, this method has been criticised. Sternberg (1995) posited that overuse of the paradigm appeared to constrain the nature of the findings to a series of observations stating experts possessed more knowledge than novices. The first point to consider is the term "novice" as this definition implies that the participants have little or no experience of the task in question and their contribution to the investigation and subsequent findings is limited. The more appropriate way of designing this methodology is to recruit non-experts. These are individuals who engage in the activity and are competent players, but have not attained elite status. The overriding aim of the paradigm is not to demonstrate that experts know more but rather to identify what experts do differently in comparison with non-experts. For example, Tenenbaum, Sar-

El & Bar-Eli (2000) have shown an expert advantage over non-experts in approximately 50% of tennis strokes, therefore, the assumption is that the aspects which only experts exhibit are important facets of expertise and this is the efficacy of the paradigm.

3.3 Participants

There is conjecture as to what constitutes an expert (Bar-Eli, Plessner & Raab, 2011; Chi, 2006b; Swann, Moran & Piggot, under review). In this programme of research participants were categorised on the level of play which they had attained. All participants in the studies were male. Elite football players were recruited from the under 19 squads of three Scottish Premier League teams. Elite hockey players were recruited from the Scottish National squads and from Durham University's National League side. The non-elite players were recruited from the University's student population.

3.4 Inclusion of Two Team Sports

In this research programme, football is included in Studies 1 – 4 and hockey is included in Studies 1 and 3. The rationale for including these sports is twofold. Firstly, both sports have a degree of similarity in terms of structure as they are played with 22 players (11 in each side), share many of the same concepts in terms of attacking and defending and display similar physiological movement patterns. Therefore, if the rationale for the research programme is correct, comparable results should be elicited in both sports, thus making the findings more robust. Secondly, although the two sports are structurally similar, the main difference lies in the tactics employed within the respective games. This difference allows for the possibility of using the hockey based investigations as a transfer task to investigate the level of domain specificity of expert knowledge.

3.5 Expertise Approach

An applicable framework for studying perceptual-cognitive expertise in sport is the expertise approach (Ericsson & Smith, 1991; Williams & Ericsson, 2005). The approach comprises three stages:

1) Identify a representative task from the domain of expertise that is replicable under standardised laboratory conditions
2) Analyse the stable characteristics of expert performance through the use of verbal report technique and /or representative task manipulation
3) Attempt to detail the adaptive learning and explicit acquisition processes relevant to expertise.

The first stage of the model concerns capturing expert performance. This refers to the methodology employed in investigating perceptual-cognitive expertise and examples of such tasks include "pattern recall and recognition," "anticipation based paradigms" and "response time protocols". The second stage relates to identifying the perceptual-cognitive mechanisms that mediate expert performance. This may include information derived from visual search data, film occlusion and point light displays, biomechanical profiling, psychobiological measures and verbal protocol analysis. The rationale for the third stage is to attempt to document the nature of, and the processes involved in, the development of expertise. Typical methodologies employed in this stage are documentation of practice histories and examination of the effectiveness of interventions aimed at improving perceptual cognitive skill.

Although the framework proposed is comprehensive, there has been criticism of the expertise approach (Davids, 2000; Abernethy, Farrow & Berry, 2003). This would suggest that the expertise approach is a useful framework on which to base, rather than follow step by step, a research programme. Furthermore, even when drawing upon the framework provided by Ericsson and Smith (1991), the design of representative experimental tasks in sport is challenging due to its dynamic nature. One of the conditions associated with the expertise approach is that experimental task replicates, to the greatest extent possible, the demands of the real world activity. Additionally, in order to elicit findings that provide information on expert performance, it is important to have a task which requires experts to use their expert knowledge. Taking this into account, four studies utilising video and other media from football and hockey were designed.

3.5.1 Study 1

Study 1 comprises video based response time tests in both football and hockey. Participants were asked to anticipate an opponent's intentions, specifically passing destination. Study one is concerned with an individual's unarticulated knowledge and associated representations. In reference to the expertise approach, the first stage of the model concerns capturing expert performance and response time paradigms were identified as a suitable methodology.

3.5.2 Study 2

Study 2 was designed to examine the extent to which knowledge in one domain transfers to another. It consists of a transfer task where participants in one sport were asked to make judgements in another activity. In this case, football players were asked to anticipate pass destination in hockey. In comparison with the other two stages, the description of the third stage of the expertise approach is relatively sparse and somewhat ambiguous. Its rationale is to attempt to document the nature of and the processes involved in development of expertise. Based on the objectives of this research programme, this step will be investigated in terms of domain specificity of expert knowledge.

3.5.3 Study 3

Study 3 consists of video based decision making test in football and hockey. Participants were asked to identify possible courses available to a player and provide rationale for their choices. Data collected in this investigation were in the form of verbal report and this is an appropriate methodological approach for the second stage of the expertise approach which involves identifying the perceptual-cognitive mechanisms that mediate expert performance.

3.5.4 Study 4

Study 4 is a football based, tactical test where participants were asked to suggest various tactical responses which can be applied in specific circumstances within a match. Data collected in this investigation were in the form of verbal report and is, therefore, a further example of stage two of the expertise approach. This study relates to the concept of explicitness i.e., the level of information provided, and the articulation of higher-order concepts associated with the domain.

3.6 Verbal reports

The approach adopted to examine the second part of the expertise approach, investigation of the mediating processes underlying expertise, is verbal report and this method has been used in studies two and three. Given the premise of information becoming explicit i.e,. verbalisable, the use of verbal reports is appropriate. Verbal reports have been used extensively in the study of expert knowledge in sport (McPherson & Kernodle, 2007; McRobert, Ward, Eccles, & Williams, 2011; Roca, Ford, McRobert & Williams, 2013). Ericsson and colleagues (Ericsson, 2006; Ericsson

& Simon, 1993) have outlined the conditions in which participants could provide a verbal report; a think-aloud methodology whilst performing the task, or retrospectively after completion of the task. In this research programme, the approach taken is for a think-aloud methodology whilst performing the task using a semi-structured interview format. Moreover, an attempt has been made to quantify participants' verbal reports using the principles of performance analysis (PA).

3.7 Performance Analysis (PA)

The premise of PA is founded on the fact that, for a number of reasons, individuals are unable to recall all events which occur within an activity. For example, Franks and Miller (1991) found that International level soccer coaches recalled only 42% of the key factors that determined successful performance. Given this, performance analysis is an effective way of recording performance so that key elements of that performance can be quantified in a valid and consistent manner. In order to do so, the process of performance analysis is reliant on the principles of systematic observation. Systematic observation permits a trained observer to use a set of guidelines and procedures to observe, record and analyse events and behaviours with the assumption that other observers, using the same observation instrument and viewing the same sequence of events, would agree with the recorded data (Hughes & Franks, 2007). In addition to coding a sporting event, the process is useful in coding verbal responses and this type of protocol has been used before in relation to coaching behaviour (Ford, Yates & Williams, 2010).

Analysis is carried out using what is termed a category set. A category set is an observation tool which is used to provide pertinent information on performance. It is consists of categories and subcategories pertinent to the questions that the designer wishes to answer. A key part of this process is that the events identified as being part of the activity are clearly defined so that systematic observation can occur. When these pre-defined events occur in the activity, they are coded using the notation system employed. The category sets used in this research programme were created using Focus X2 software (Performance Innovation, Scotland). The software is shown in Figure 3.1.

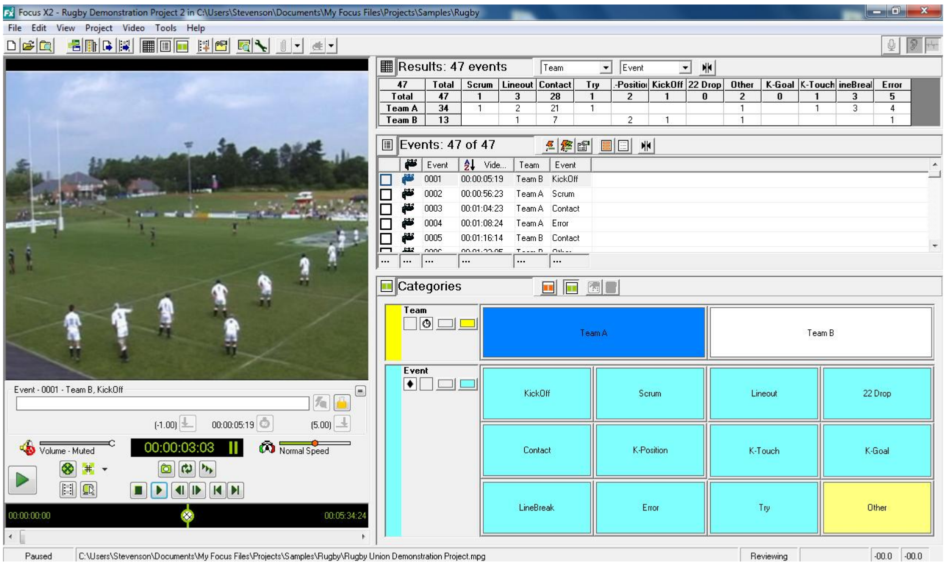


Figure 3.1 Screen shot of Focus X2 Software (Performance Innovation, Scotland).

The Focus X2 software is a sophisticated notational analysis tool used in performance analysis in a variety of sports, including football and field hockey. This system is used in conjunction with video of the activity and events within that activity are then coded. The process of coding involves assigning a timestamp on the video as to when an event occurs. This time-stamped event is then augmented with additional descriptors on that event. To provide an example of a coded event in football:

1.25 – Team A, Corner Kick, Left.

The above notation denotes that at 1 min 25 seconds, Team A had a Corner Kick from the Left Hand Side. As the activity continues, a database of events is generated which provides a list of when events occur within the match and a description for each. This event list is then used to formulate some statistical output, for example, the number of corners Team A had in the match. The main benefit of this software in an academic sense is the creation of numeric databases which can then be used for subsequent inferential statistical analysis.

3.8 Investigation Materials

Each of the studies involves presentation of sport-based test stimuli. Studies 1, 2 and 3 utilise dynamic video sequences from matches. Studies 1 and 3 incorporate both football and hockey footage. Study 2 uses hockey footage only. An extensive library of footage involving elite players (Men's and Women's) for both hockey and football was compiled from TV broadcasts and internal video analysis footage. If not originally in digital format, footage was captured (converted to digital format) using a laptop with firewire from either recordable media or directly from a digital satellite box using a video camera as a DV bridge. The footage was captured in AVI (audio-video interleave) format. The footage was extensively analysed to identify suitable clips for each of the investigations. Study 4 comprised a PowerPoint presentation illustrating diagrams of football-based microstates.

3.9 General Investigation Setup

Each of the studies employed a similar design. All investigations involved media displayed on a large screen via a computer and a projection system. Participants sat in a chair positioned approximately three metres from the screen. Participants were provided with a laser pen in order to intimate which elements on the screen they were identifying.

Laser traces and verbal responses were recorded using a video camera onto a DV tape. Verbal responses were recorded using the camera's built-in microphone. The video camera was placed on a tripod and positioned behind the participant, slightly above head height. The participant's image did not appear on any footage. All footage was subsequently converted into a digital video file (AVI) by capturing the recorded video from the DV tape onto a laptop computer.

Having discussed relevant general methodological issues, the next chapter will present the first study in the research programme.

Chapter 4: Study 1

4.1 Introduction

When researching the relationship between implicit and explicit knowledge, it is important to design tasks which require and utilise the different levels of representation which underpin each of the phases of development in RR. According to Karmilloff-Smith (1992), in tasks where individuals are not required to verbalise what they are doing or why they are doing, they will first of all call upon their level-I representations and, in some instances, utilise E1 representations. According to the theory, these representations are used to respond quickly and accurately to complex problems presented within the environment. The aim of this study is to investigate these particular representations in expert and non-expert performers and, therefore, the investigation has to incorporate unarticulated performance measures.

The first step of the expertise approach is to capture expert performance in the laboratory setting. A possible approach is to adopt the widely employed pattern recognition methodologies. These paradigms are thought to be amongst the most reliable predictors of expertise in sport (Williams & Davids, 1995) and can be considered to have unarticulated performance measures. A time measure will be derived in terms of how quickly a pattern is recognised and an accuracy score will be allocated should this be carried out successfully. Despite this, a question has to be raised as to the ecological validity of these protocols which undermines their suitability to investigate underlying representations. The skills of recall and recognition are not part of the real world activity *per se*, as within a football match players are not required to recall if they have previously seen the sequence but rather respond in an effective manner to the unfolding pattern of play. As a result, any investigation should incorporate a task that occurs within the activity on which it is based. Furthermore, in relation to ACT and RR, pattern recall and recognition tests do not provide IF...THEN scenarios and, therefore, lack a problem solving and decision making context in which to investigate the theories.

Also identified within the first stage of the expertise approach, a possible alternative methodological approach is that of response time paradigms. Response time paradigms have been used successfully in football (Helsen & Pauwels, 1993; Williams & Davids, 1998). This methodology is appealing as a key aspect of decision making in a match context is that players are required to make effective decisions in a time pressure environment. Furthermore, this approach can be integrated within a task associated with a particular activity. For example, Mori, Ohtani and Imanaka (2002) investigated response time in karate. There were two tasks; a choice reaction time (i.e., a response time) and a simple reaction time. They presented karate athletes and novices with video clips of an opponent's offensive actions. In the choice reaction time protocol, participants were required to intimate as quickly as possible if the opponent's actions would be aimed at the upper, middle or lower part of the body. For the simple reaction time test, athletes had to react to the initiation of the opponent's movement from their ready stance or when a dot appeared on the display. Significant differences were found between the karate athletes and the novices in the choice reaction time protocol but not in the simple reaction time protocol. This implies that there is a knowledge-based component associated with response time as opposed to a general skill of reaction time.

In field-based team sports such as football and hockey, a frequently occurring event which lends itself to experimental manipulation is anticipation of pass destination. An example of a response time protocol incorporating pass anticipation in football is provided by Williams and colleagues (Williams, Davids, Burwitz & Williams,1993; Williams & Davids, 1995). Groups of elite and non-elite players were presented with clips of a football match which were filmed from a position high behind the goal. Located on the attacking third of the pitch was a grid of ten numbered boxes. For the duration of the video sequence, the player who would play the pass which had to be anticipated, was surrounded by a black square. Participants were asked to verbally indicate the number of the box into which the pass would be played. The resultant measures were response time and response accuracy. Results indicated that experts were both quicker and more accurate but significant differences were only found with response time.

There are two main implications from this experiment. Firstly, the experiment of Williams and Davids (1995) highlights a potential issue with response time protocols; designing a task which adequately elicits performance measures whilst maintaining fidelity. The experiment included elements in the video sequences which aided the process of anticipation. That is the participants knew which player would play the final pass and knew into which area of the pitch the ball would be played; both of which would not be available in the real world task. Any investigation, therefore, should aspire to provide as little additional *a priori* information as possible, whilst maintaining an ability to elicit appropriate performance measures.

Secondly, the findings corroborate an observation by Grehaigne, Godbout and Bouthier (2001) who suggest that research examining decision making in sport illustrates that experts can make effective decisions in time restricted environments but tend to have speed as opposed to accuracy. Speed of decision is of fundamental importance in team sports as it is an open, ever-changing environment. It is precisely this latter characteristic which may explain this apparent lack of accuracy displayed by experts. As the environment changes both rapidly and frequently, an accuracy measure derived solely from the particular moment at which the answer is provided, is rather arbitrary given that many applicable courses of action may be presented at varying times. As such, there is a need to re-evaluate the two widely utilised measures of response time and response accuracy. Specifically, it is crucial that these measures are not viewed independently from one another.

The following investigation is a pass anticipation test which has attempted to incorporate all the aspects discussed above. According to ACT theory and RR, as a result of practice, individuals solve problems with increasing speed and accuracy. Within RR, this is considered to be underpinned by level-I representations. In line with the theory, and given that elite players have engaged in more extensive practice, it is hypothesised that elite players will make faster and more accurate decisions in anticipating where a pass will be played. Furthermore, given that successful anticipatory performance in the real world activity requires both speed and accuracy, it is also hypothesised that the expert players will exhibit superior ability when these two aspects are considered concurrently.

4.2 Method

This study consists of two separate investigations involving football and hockey. In both investigations, elite and non-elite participants in each sport were required to view a video sequence and identify the destination of the next pass after a stimulus appeared. The efficacy of using an anticipation test i.e., reading someone else's intentions, is that it provides a suitable measure in terms of accuracy of judgement as the pass destination is matter of fact as opposed to an interpretative and subjective answer based on opinion.

The dependent variables were response time, response accuracy, total response accuracy and combined score of response time and response accuracy. Response time, the time that participants require to make their judgments, is the time taken from appearance of the stimulus to the laser being pointed on the player whom the participant thought would receive the ball. Response accuracy, accuracy of judgment, is the proportion of correct responses i.e., number of correctly identified pass destinations with an initial response. Total response accuracy was measured as the total proportion including instances where the participant had altered their initial response. Combined score was derived by dividing a participant's mean response accuracy by their mean response time. The independent variable was level of play.

4.2.1 Participants

Participants for each investigation were recruited from the participant pools outlined in the general methods chapter.

In investigation 1a, groups of elite football players (n=20), non –elite football players (n=20) participated in the study. Elite players were aged between 16 years and 19 years (M = 17.45 years) and non-elite players were aged between 17 years and 20 years (M = 18.65 years).

In investigation 1b, groups of elite hockey players (n=15) and non-elite hockey players (n=15) participated in the study. Elite players were aged between 17 years and 22 years (M = 18.80 years) and the non-elite players were aged between 18 years and 22 years (M = 20.40 years).

4.2.2 Materials

The stimuli were developed from full matches involving elite players in each sport. Digital video data for the investigation was obtained using the procedure outlined in the general methods chapter. The tests utilised footage from a vantage point high behind the goal. Using Focus X2 software, a total of 8 games in football and 6 games in hockey were analysed by the investigator to find appropriate test stimuli. Appropriate stimuli involved a passage of play within the activity in which a player making a pass was presented with more than one viable passing option.

Passes within these passages of play originated from, and were played to, different areas of the pitch. Passes were played by players in different positions i.e., some were played by central defenders, some from midfielders etc., and differed in terms of type and distance. This ensured that the investigation was more representative of the game.

Suitable passages of play were coded using Focus X2's bookmaking facility, with the pass of interest being time-stamped. Finalised video clip sequences of 20 seconds were exported as an AVI file for subsequent editing. Video editing was conducted using Windows Movie Maker.

Each finalised video clip was preceded by a 3 second countdown. Clips were not a standardised length. After a period of build up play, a red hash appeared in the bottom left corner of the screen when the player who would play the pass of interest, i.e., the pass to be anticipated, would receive the ball. Due to the nature of the activity, the length of time between inception of the clip and appearance of the red hash was not standardised. The red hash appeared in the period when the ball was in transit from the preceding pass to the player who would play the pass of interest. The red hash stimulus had no other role than to provide an indication that the next pass would be the pass of interest and thus was required to be anticipated. The appearance of the red hash did not signify, however, that the player about to receive the ball would immediately play the pass, only that they would be in possession of the ball. The period between the appearance of the red hash and release of the ball was not standardised. The red hash remained on screen until the end of the clip. The clip froze at the point of contact between the player's foot or stick and the ball. A freeze image of that frame remained on screen until an answer was provided. This is shown in Figure 4.1.

Figure 4.1 – An example of the final frame image in the football task

Results were obtained by coding a digital video of the test protocol in Focus X2 using a pre-defined category set. This category set was designed to measure response time and accuracy and is shown in Appendix A. The coding was conducted manually by the investigator. The software's bookmarking facility was used to time-stamp the time at which the red hash appeared on screen and the time at which the laser pen settled on the player deemed by the participant to be the recipient of the pass. Response time was calculated by determining the difference between timestamps for each clip.

Response accuracy was based on the outcome of the clip and a correct response was deemed to be identification of the player who was the eventual recipient of the ball in the actual game. The initial answer provided by the participant was coded as to whether it was correct or incorrect. Total response accuracy was derived in a similar fashion with an additional attempt coded as to whether it was correct or incorrect.

When events had been coded, Focus X2 created a database of events which was exported to Microsoft Excel where further analyses were conducted. A calculation was performed to ascertain a participant's combination score. This was calculated by dividing response accuracy i.e., proportion of correct answers, by mean response time. Once completed, the data were exported to SPPS statistical software where subsequent analysis was performed. Independent t-tests were used to compare the performance of the elite and non-elite groups in each sport for each of the four dependent variables.

4.2.3 Procedure

The general investigation set-up was as outlined in Chapter 3, pages 50-51.

Prior to the test, participants underwent a laser familiarisation procedure. This involved pointing a laser pen on a black square on a white background, which appeared on the large screen. In the first instance the square followed a curved path of 3 second intervals. There were 10 squares in total. The second part of the familiarisation period involved the square being presented in 10 random locations and at random time intervals.

Participants were provided with a verbal account of the testing procedure and a series of instructions. Participants were informed prior to the test protocol as to what the red hash signified. Furthermore, they were explicitly told that the red hash did not denote that the player about to receive the ball would immediately play the pass. Participants were asked to answer as quickly and accurately as possible when they thought they knew which player would receive the pass. No emphasis was placed on either speed or accuracy of the response. Furthermore, participants were told to answer based on what they had seen in the clip as opposed to what they felt was theoretically or personally the most likely pass destination. At no point were participants told that they were able to alter their initial answer. Participants were informed that they did not have to wait for the freeze, but they could not answer until the red hash appeared. When the hash appeared, participants were free to identify the pass destination by pointing the laser directly on the player thought to be the intended recipient. Participants were asked to point the laser on the player regardless if the pass in question was played to the player directly or if it was intended to be played into an area for the player to run onto.

Before the main test, three practice clips were administered. This was followed by 15 test clips. Each clip was preceded by a 3 second countdown and during this time, participants were informed as to the area of the screen in which the ball would be located at the onset of the game footage. A similar procedure was employed by Roca et al., (2011). Clips ran in a continuous fashion with separation facilitated by the 3 second count down.

4.3 Results

4.3.1 Investigation 1a

As noted in Table 4.1, no statistically significant difference was observed between the response time of elite football players and the non-elite football players (M = 3.57, SD = 1.54 and M = 4.36, SD = 2.52 respectively), $t(38) = -1.20$, $p > 0.11$.

No statistically significant difference was observed in the response accuracy between elite football players than non-elite players (M = 0.48, SD = 0.15 and M = 0.43, SD = 0.21 respectively), $t\ (38) = 0.86$, $p > 0.19$.

As noted in Table 4.1, elite football players were more accurate than non-elite players when altering their initial expectation and had higher scores for total response accuracy (M = 0.56, SD = 0.10 and M = 0.46, SD = 0.20 respectively). An independent t-test showed the difference between the groups was significant *t* (28.56) = 1.921, $p < 0.05$, *d* = 0.67.

Elite football players exhibited higher scores for the combination measure than the non-elite players (M = 0.16, SD = 0.09 and M = 0.11, SD = 0.04 respectively). This is shown in Table 4.1. An independent t-test showed that the difference between the two groups was significant *t* (27.44) = 2.202, $p<0.05$, *d* = 0.77.

Table 4.1 – Investigation 1a Results

	Elite	**Non-elite**	***p***
Response time (secs)	3.57 (1.54)	4.36 (2.52)	0.24
Response Accuracy	0.48 (0.15)	0.43 (0.21)	0.39
Total Response Accuracy	0.56 (0.10)	0.46 (0.20)	0.03
Combination score	0.16 (0.09)	0.11 (0.04)	0.02

4.3.2 Investigation 1b

As noted in Table 4.2, no statistically significant difference was observed between the response time of elite hockey non-elite players (M = 4.07, SD = 1.97, M = 4.48, SD = 1.94 respectively), in relation to response time, *t* (28) = -0.570, $p > 0.281$.

As noted in Table 4.2, no statistically significant difference was observed between elite hockey players and their non-elite counterparts in relation to response accuracy (M = 0.42, SD = 0.21, M = 0.31, SD = 0.17 respectively), *t* (28) = 1.503, $p > 0.07$.

Elite hockey players were more accurate than non-elite players when altering their initial expectation and had higher scores for total response accuracy (M = 0.53, SD = 0.17, M = 0.33, SD = 0.17). This is noted in Table 4.2. An independent t-test showed the difference between the groups was statistically significant t (28) = 3.228, $p < 0.01$, d = 1.18.

Elite hockey players showed higher score for the combination measure than the non-elite players (M = 0.10, SD = 0.03, M = 0.07, SD = 0.03 respectively). This is noted in Table 4.2. An independent t-test revealed that the difference between the two groups was statistically significant t (28) = 2.742, $p < 0.01$, d = 1.

Table 4.2 – Investigation 1b Results

	Elite	**Non-Elite**	***p***
Response time (secs)	4.07 (1.97)	4.48 (1.94)	0.57
Response Accuracy	0.42 (0.21)	0.31 (0.17)	0.14
Total Response Accuracy	0.53 (0.17)	0.33 (0.17)	0.0015
Combination score	0.10 (0.03)	0.07 (0.03)	0.0055

4.4 Discussion

The aim of this study was to examine the anticipatory performance of elite football and hockey players on a pass destination anticipation test. In doing so, the underlying theoretical aim was to investigate the representations from the RR model utilised in an unarticulated performance task. Four dependent variables were measured; response time, response accuracy, total response accuracy and combination score. In both investigations, significant differences were observed for two dependent variables; total response accuracy and combination score.

Although there were four dependent variables, the nature of the real-world task dictates they are inextricably linked as successful performance requires both speed and accuracy. This point is best exemplified by the response time and response accuracy measures. These are the traditional measures for an investigation of this ilk but the proposition in this research programme was that they could not be considered independently for the reason that successful performance requires both facets.

A further point raised in relation to accuracy was that, in an ever changing environment such as a football or hockey match, deriving a measure of accuracy based solely on the answer provided at that particular moment is not appropriate. Discussing accuracy initially, in effect participants create a situational probability; an expectation of what will happen in the situation. The issue for accuracy, however, is that this probability is formulated for that particular moment in the game and this may change as the play evolves.

It was highlighted that the possession of interest, i.e., the possession of the ball where the pass would be anticipated, was not a standardised length. As a result, participants were required to make a judgment as to when the pass would be played. If a probability is formulated for a pass but the player does not release the ball, then the participant's accuracy measure will be affected. For this reason, it is suggested that accuracy measures of this type are slightly arbitrary in nature. In terms of the interrelated nature of the dependent variables, this is more likely to occur if an expectation is formulated near the beginning of the sequence when there is scope for subsequent change in the game picture.

A feature of the investigation was the inclusion of a so-called freeze; a still image presented on screen at the point of contact between the ball and the player's foot or stick. The freeze served two main purposes; to control feedback and to ensure participants were not forced to provide an answer when they were not ready to do so. In relation to the latter, this was so that it would not bias response time data. In doing so, however, it is feasible to suggest that the response accuracy data was biased. The issue discussed above with regard to an early expectation being deemed wrong is negated if a participant waits until the video freezes. This is due to the fact that there is more time to scan the display and this task is also easier as the picture is static. Additionally, the freeze provides supplementary postural information, i.e., the direction of the player's body, which is largely informative as to eventual pass destination. Overall, the implication of answering after the freeze is that response accuracy is increased.

There is a further issue with the freeze; it represents the last opportunity for anticipation and thus, any decision made after this point is re-active in nature i.e., the event will have occurred without a player having a prior expectation of what may happen. Thus, in order to increase accuracy, there is a decrement in speed which is ineffective and detrimental to performance in the real-world task. This relates to the point made in the introduction to this study; the concept of a quick wrong answer and a slow right answer. In this regard, and given the point made above, there is an argument to be made that a slow right answer is less appropriate and speed of response is perhaps more desirable. Given this, the next part of the discussion will examine response time.

Although the expert – non-expert differences in response time were not statistically significant in either task, the differences are theoretically significant. Empirical evidence would suggest that the ability to make decisions quickly is paramount in elite sport. For example, Steel, Adams and Canning (2007) reported that water-polo players and swimmers were able to confidently identify team mates when presented with randomised video clips of less than one second. In both investigations in the current study, the differences between experts and non-experts was greater than a half a second, which based on this swimming research, is a feasible time in which to extract and process pertinent information.

Focusing on football, in a physiological context, there has been a recent emphasis on the high intensity element of the game. It has been postulated that this facet is the best determinant or the most appropriate measure of high level performers (Gregson, Drust, Atkinson & Di Salvo, 2010). This has implications for cognition and perception as, if the game is played at a high tempo in the upper echelons of the game, then both speed of thought and action have to be quick to be able to perform effectively. Secondly, if the game is played at such intensity, then the technical skills possessed by the player have to be able to cope with the demands of such a tempo.

Given the discussion above on the importance of speed and time pressure at the upper echelons of elite football, it is perhaps advantageous to favour speed of response. However, as has been stated, speed and accuracy have to be considered concurrently. It is relatively straightforward to offer a quick response without regard to accuracy of said response. The key issue, therefore, is how quickly one can be accurate. This concept is the basis of the combination measure.

The test was designed so that participants were not forced to offer a quick response if they felt they were unable to do so. Likewise, an opportunity was afforded if the participant could provide a quick response. The instructions given to the participants - answer when you think you know and as quickly and accurately as possible, are testament to this philosophy.

The combination measure was an attempt to cater for these differing approaches and address the concept of quick wrong and slow right. If a participant is accurate but slow or, alternatively, quick but inaccurate, one should be off-set by the other thus providing a more representative indication of anticipation. Thus, as this measure is more reflective of the real-world activity, it is not surprising that there were statistically significant differences in both investigations. In addition, the combination measure was an attempt to address the perceived speed-accuracy trade-off highlighted above. Given the nature of the task, it is more complex than a simple speed-accuracy trade-off in the sense that, a speed-accuracy trade-off, implies that the quicker one is, the less accurate one becomes. Examination of the response time and accuracy data, as well as the resultant combination measure, would suggest that elite players are more accurate in their expectations and crucially, formulate these expectations in a shorter time. When non-elite players attempt to answer quickly, their accuracy is less than the elite players. This is more evident in the hockey task as, although the recreational hockey players exhibit quick response times, their low accuracy suggests that they are unable to accompany the speed with the requisite accuracy. Therefore, the expert advantage is to formulate an accurate expectation early on in the sequence.

Relating back to the ACT – RR framework, the premise of using unarticulated performance measures was to investigate Level-I and E1 representations. It was suggested as part of the hypothesis that, as a result of the processes involved in ACT theory, problems are solved with increased speed and accuracy. The extensive practice undertaken by the elite players should, therefore, be exhibited by faster and more accurate expectations of pass destination**.** This is evidenced by the statistically significant differences for the combination measure of speed and accuracy. The results for the combination measure would suggest that the expert players have more extensive and developed representations at Level-I.

Whilst its efficacy is not in question and the premise is conceptually sound, there is an issue with the combination measure. As it is derived from a measure, response accuracy, which has been deemed rather arbitrary in nature, the discussion on this point relates to the instance at which the initial expectation was formulated and how this may change as the game situation changes. The nature of the game means that decisions have to be made quickly. However, as accuracy is just as important, the study elicited further evidence of a strategy employed by expert players.

Evidence from this study tends to suggest that the elite players are more adept at altering their initial expectation as the game picture changes. This was evidenced by the statistically significant differences in total response accuracy in both investigations. Furthermore, in addition to the significant differences observed in both investigations, a salient point is the change between response accuracy and total response accuracy. In the football task, the elite players changed from 0.48 to 0.56; an increase of 0.08. The non-elite players changed from 0.43 to 0.46, an increase of 0.03. In hockey, the enhancement is even more marked; the elite players changed from 0.42 to 0.53, an increase of 0.11. The non-elite players changed from 0.31 to 0.33 an increase of 0.02.

These differences are germane and point toward a strategy employed by the elite players in both sports.

As was outlined previously, the participants effectively create a situational probability; an expectation of what is likely to happen in the situation. This expectation is, however, dependent on a number of factors. These factors then impact on the unfolding sequence of play and in some instances necessitate a response alteration. Tenenbaum (2003) suggests that this ability is a skill which develops as a result of practice and experience in a domain. As such, it is considered to be more apparent with expert performers. Furthermore, Tenenbaum (2003) argues that "the enhanced knowledge base and structure of experts enable them to apply more frequently a continual-type of processing. This strategy enables them to make faster responses, and at the same time, it increases their readiness to make changes if necessary." (p.205). The salient point from Tenenbaum's argument is that the enhanced knowledge base is the crucial factor in the application of continual-type of processing. The ability to alter one's response illustrates a level of conceptual understanding. The relative consequence of an initial expectation being no longer viable is that an alternative course of action is now more probable. A degree of understanding is required to assess the current situation and form another expectation as to how the game will now unfurl. Results within this study are suggestive of an expert advantage whereby several possibilities are formulated and then as the play develops, and the probability of a course of action increases or decreases, the experts are better at recalibrating these probabilities and altering their responses accordingly. This may be due to more connected knowledge attributable to the process of RR.

Results suggest that this effect is more marked in hockey. A possible reason is that hockey players in the test clips held onto the ball for longer time periods than was evident in football. Thus, there is a longer window of opportunity in which to answer, but significantly in relation to total response accuracy, there is a greater likelihood that the player in the clip will have an opportunity to make a pass but elect not to do so. As such, the number of opportunities to answer increases, and the ability to make judgment as to time of release is taxed. There are more opportunities for participants to alter their initial response as the situation evolves. Speculatively, it is possible that the hockey stick may also be utilised as an effective tool to dummy or deceive intended pass destination. Thus, if a participant "buys" the deception, their initial expectation will be wrong. The utilisation of a response alteration measure allows for this occurrence and takes this expert ability into account.

There is, however, a cautionary undercurrent to these particular results. As participants were not explicitly informed that they were able to do so, it may well be that the participant did not change their mind as they felt they were not permitted to do so. It is, however, curious that a number of participants did so without an explicit instruction and that this phenomenon occurred in both investigations. Although the protocol catered for the possibility, no explicit instruction was provided to avoid priming participants. Nonetheless, it does provide an interesting finding that can be related back to the real world activity.

4.4.1 Summary

It would seem that the inclusion of the two additional performance measures has provided an enhanced understanding of the decision making process. Significant differences between the elite and non-elite players in both sports were found in relation to the combination score and total response accuracy. Conforming to the premise of using the expert – non-expert paradigm, the results from Study 1 appear to reveal a strategy employed by experts in anticipating an opponent's intentions. It has been established that successful performance requires both speed and accuracy. In discussing the dependent variables measured in this study, it is difficult to do so in isolation. It would appear that neither speed nor accuracy takes precedence and, furthermore, they do not work in isolation. However, the nature of the game dictates that it is perhaps more prudent to offer a quick response. The advantage that the experts in both sports possess is the ability to quickly formulate a reasonably accurate expectation of what is likely to happen. There is a caveat to their quick response; a capability to alter their response should the play evolve in a different way to what was initially expected using continual-type processing.

Given that the same ability has been evidenced in elite players in both sports, it is pertinent to ask whether this ability to quickly and accurately make and modify decisions is a domain general feature of expertise. Alternatively, is the advantage evidenced by elite players a result of their task-specific knowledge. Furthermore, the issue of transfer is germane from a theoretical stance. The RR model posits that progression along the continuum results in knowledge being available in other domains. The next study will investigate the issue of domain specificity by means of a transfer task where players in one sport will be asked to make judgements in an unfamiliar activity.

Chapter 5: Study 2

5.1 Introduction

There is a similarity between football at the highest level and chess. This analogy is not exclusively restricted to football and a variety of other sports, such as field hockey, can be equated to chess. Evidence suggests that experts in chess possess a similar ability to experts in football, and other sports, with regard to pattern recall and recognition (Gorman, Abernethy & Farrow, 2012).

Despite the fact that experts in both domains posses a similar ability, given that chess and football are fundamentally different, transfer between the two activities would seem to be unlikely. However, is it possible to suggest that there is transfer between tasks which do display similarities? The issue of transfer is germane; does expertise in one sport transfer to another or is it domain specific? If there is evidence of transfer, which elements transfer?

Transfer is also salient from a theoretical standpoint. The RR model posits that in addition to facilitating intra-domain connections, the process of redescription and the explicitation of knowledge may, in certain circumstances, result in inter-domain connectivity, and thus transfer to other contexts. Despite this hypothesis, research to date would suggest that knowledge is relatively domain specific and thus cross-domain transfer is at best limited.

Carraher, Carraher and Schliemann (1985) reported extensive differences between the performance of child street vendors in Brazil on money calculations and similar classroom mathematics problems. In science education, Howe, Tolmie, Anderson and MacKenzie (1992) found that although undergraduate students had a comprehension of how to calculate average speed from the context of driving a car, they were often unable to identify how this information could be utilised in physics based problems.

In sport, Kioumourtzoglou, Kourtessis, Michalopoulo and Derri (1998) provided evidence that perceptual skills are task-specific and depend greatly on the nature of the task. They investigated expertise in three different sports with participants recruited from the Greek national teams in basketball, volleyball and water-polo. Groups of physical education students were recruited as non-expert participants. They found that basketball players were better on prediction and selective attention, volleyball players performed better on perceptual speed, focused attention, prediction, and estimation of speed and direction of a moving object. Water-polo players had significantly better scores than novices in decision making, visual reaction time, and spatial orientation. The authors concluded that the nature of each sport influences the way perceptual abilities differentiate elite athletes from novices. Thus, the implication in terms of transfer is that perceptual skill is specific to the particular domain.

There is, however, some evidence of transfer in sport, but where it does occur, it appears to be somewhat limited. Smeeton, Ward and Williams (2004) investigated transfer of pattern recognition skills. Participants from football, hockey and volleyball took part in pattern recognition tests in all three sports. Results indicated that the ability to recognise patterns by skilled athletes in other sports was most prevalent between football and hockey but more difficult in relation to volleyball. Therefore, this study suggests there may be some evidence of transfer but it does appear to have constraints. Similarly, Abernethy, Côté and Baker (2002) discovered that skilled players in basketball and netball were better able to recognise patterns in different sports than less-skilled players in their own particular sport i.e., expert netball players were more adept at recognising basketball patterns than less-skilled basketball players.

A possible explanation for the transfer between football and hockey exhibited by Smeeton et al., (2004), and between netball and basketball illustrated by Abernethy et al., (2002), stems from the analogy literature. A study by Gick and Holyoak (1980) suggested that performance on a problem solving task was enhanced when an analogy was provided, and this effect was increased when the analogy was accompanied by a hint. Subsequent studies advocated the use of analogies (Holyoak & Koh, 1987; Keane, 1989) but suggested that the closer the base story is to the target, the more likely the transfer. Despite this assertion, evidence would suggest that proximity of the base and target is insufficient. Anolli, Antonietti, Crisafulli and Cantoia (2001) discovered that retrieval of a remote analogy was futile in itself without provision of a hint i.e., inclusion of a pertinent clue to the solution.

It would seem that that the closer the analogy is to the base, the possibility of transfer is increased. As stated, football and hockey share similar structural and physiological patterns and, as such, hockey can be considered as an analogy for football and vice versa. This is also the case with basketball and netball. To investigate the nature of transfer and the extent to which high level conceptual understanding in one sport may generalise to others, both elite and non-elite football players, as well as non-players, will be asked to make judgements in the area of hockey.

The theoretical rationale for this approach relates to the fact that in the absence of domain specific knowledge, it is posited that experts fall back on so-called weak methods. Anderson's (1983) ACT* theory predicts that when domain knowledge is lacking, experts should fall back on general strategies. Schraagen (1993) suggests that when knowledge is absent, that there may be skills of intermediate generality that do transfer. With specific reference to RR, the use of weak methods is thought to be related to the existence of multiple levels of knowledge. When explicit knowledge in a domain is not present, it is hypothesised that another level of representation is utilised. As such, just as has been illustrated with the studies pertaining to pattern recognition, transfer has to be investigated with unarticulated performance measures. Therefore, the most applicable test for this study is the hockey response time protocol employed in Study 1.

Given the premise of transfer to a novel context, football is less applicable as a transfer task due to its widespread availability, exposure and popularity. Therefore, this investigation will focus solely on hockey, as it does not have the same exposure and so can be considered to be more of a novel context, thus making it more applicable to the theoretical underpinning. Furthermore, the blinkered development of the elite footballers is advantageous for studying RR in the purest sense. There is negligible contribution from other sports and this would then suggest that if there is to be any transfer, it would be almost entirely as a result of the process of representational redescription as opposed to contribution of any other sport (Ford & Williams, 2012).

Hockey is one of the most applicable sports in which to investigate possible transfer from football, primarily due to the argument presented in regard to analogies. Both sports are structurally comparable in terms of number of players and physiological movement patterns, thus conforming to the concept referred to above in terms of similarity between an analogy and a base story. These similarities would suggest that there is some possibility of transfer. Despite the similarities, there are some key differences which make them sufficiently dissimilar. For instance, the fundamental difference is that contact with the ball is with a stick rather than a body part. Also, the physical dimensions of the playing area differ, with a hockey pitch being smaller. Along with the use of the stick, there are salient rule deviations; attempts on goal are only permitted from inside the circle and secondly there is no offside. These rules are significant as there are implications for the overall shape and structure of the game.

As such, there is a change in the participant pool as this study includes a group of non-players. In the previous study, a group such as this was not required as a non-player group serves little purpose when the aim of the research is to ascertain the differences between those that play professionally and those who play recreationally. In this case of transfer, that rationale does not apply. As a result, it is constructive to have this group as the participants do not engage in either sport. Thus, if participants in this group perform at a similar level to those who have played football, it provides an indication of the degree of transfer i.e., if all groups perform at the same level, then participation in another sport does not assist in transfer as, in essence, all of the participants can be considered as hockey non-experts. If, however, the two groups of football players perform better than the non-player group, there are grounds to suggest that playing another sport assists in transfer to some degree. If the elite group’s performance is superior in comparison with the other groups, then there are further implications in terms of the RR model and transfer.

The purpose of this investigation is to examine the nature of transfer and to establish if playing at a high level in one sport transfers to another. Elite players have a greater reservoir of explicit, task-specific knowledge; a consequence is the existence of underlying levels of knowledge, akin to E1and Level-I in the RR model. Thus, if presented with a novel situation, experts can fall back on said knowledge. Referring back to the analogy section and in terms of the RR model, one way in which this may manifest itself is that the deeper network of understanding and generalised knowledge of the elite players will provide a hint of sorts and this will provide a notion of how football relates to hockey i.e., an explicit understanding of the structural similarities. Thus, in line with the theory, and given the apparent transfer in unarticulated performance measures in similar sports, it is hypothesised that, in spite of low level understanding of the game, the elite football players will exhibit superior performance in comparison with the other two groups.

5.2 Method

The investigation utilised the hockey based protocol used in Study1, investigation 1b. In this investigation, elite, non-elite and non-playing participants were required to view a hockey based video sequence and identify the destination of the next pass after a stimulus appeared. The dependent variables were response time, response accuracy, total response accuracy and combined score of response time and response accuracy. Response time, the time that participants require to make their judgments, is the time taken from appearance of the stimulus to the laser being pointed on the player whom the participant thought would receive the ball. Response accuracy, accuracy of judgment, is the proportion of correct responses i.e., number of correctly identified pass destinations with an initial response. Total response accuracy was measured as the total proportion including instances where the participant had altered their initial response. Combined score was derived by dividing a participant's mean response accuracy by their mean response time. The independent variable was level of play.

5.2.1 Participants

Groups of elite football players (n=18), non –elite football players (n=18) and non-players (n=18) participated in the study. Participants for each investigation were recruited from the participant pools outlined in the general methods chapter. In addition, the non-players were recruited from the University's student population. Elite players were aged between 16 years and 19 years (M = 17.17 years) and the non-elite players were aged between 17 years and 20 years (M = 18.89 years). Non players were aged between 17 and 22 (M = 19.61).

5.2.2 Materials

The stimuli were developed from full matches involving elite players in hockey. Digital video data for the investigation were obtained using the procedure outlined in the general methods chapter. The tests utilised footage from a vantage point high behind the goal. Using Focus X2 software, a total of 6 games in hockey were analysed by the investigator to find appropriate test stimuli. Appropriate stimuli involved a passage of play within the activity in which a player making a pass was presented with more than one viable passing option.

Passes within these passages of play originated from, and were played to, different areas of the pitch. Passes were played by players in different positions i.e., some were played by central defenders, some from midfielders etc., and differed in terms of type and distance. This ensured that the investigation was more representative of the game.

Suitable passages of play were coded using Focus X2's bookmaking facility, with the pass of interest being time-stamped. Finalised video clip sequences of 20 seconds were exported as an AVI file for subsequent editing. Video editing was conducted using Windows Movie Maker.

Each finalised video clip was preceded by a 3 second countdown. Clips were not a standardised length. After a period of build up play, a red hash appeared in the bottom left corner of the screen when the player who would play the pass of interest, i.e., the pass to be anticipated, would receive the ball. Due to the nature of the activity, the length of time between inception of the clip and appearance of the red hash was not standardised. The red hash appeared in the period when the ball was in transit from the preceding pass to the player who would play the pass of interest. The red hash stimulus had no other role than to provide an indication that the next pass would be the pass of interest and thus was required to be anticipated. The appearance of the red hash did not signify, however, that the player about to receive the ball would immediately play the pass, only that they would be in possession of the ball. The period between the appearance of the red hash and release of the ball was not standardised. The red hash remained on screen until the end of the clip. The clip froze at the point of contact between the player's stick and the ball. A freeze image of that frame remained on screen until an answer was provided. This is shown in Figure 5.1.

Figure 5.1 – An example of the final frame in a hockey clip

Results were obtained by coding a digital video of the test protocol in Focus X2 using a pre-defined category set. This category set was designed to measure response time and accuracy and is shown in Appendix A. The coding was conducted manually by the investigator. The software's bookmarking facility was used to time-stamp the time at which the red hash appeared on screen and the time at which the laser pen settled on the player deemed by the participant to be the recipient of the pass. Response time was calculated by determining the difference between timestamps for each clip.

Response accuracy was based on the outcome of the clip and a correct response was deemed to be identification of the player who was the eventual recipient of the ball in the actual game. The initial answer provided by the participant was coded as to whether it was correct or incorrect. Total response accuracy was derived in a similar fashion with an additional attempt coded as to whether it was correct or incorrect.

When events had been coded, Focus X2 created a database of events which was exported to Microsoft Excel where further analyses were conducted. A calculation was performed to ascertain a participant's combination score. This was calculated by dividing response accuracy i.e., proportion of correct answers, by mean response time. Once completed, the data were exported to SPPS statistical software where subsequent analysis was performed. Four, one-way ANOVA's were conducted for each of the four dependent variables. These were followed up with post hoc Tukey HSD tests.

5.2.3 Procedure

The general investigation set-up was as outlined in Chapter 3, pages 50-51.

Prior to the test, participants underwent a laser familiarisation procedure. As in Study 1 this involved the pointing a laser pen on a black square on a white background, which appeared on the large screen. In the first instance the square followed a curved path of 3 second intervals. There were 10 squares in total. The second part of the familiarisation period involved the square being presented in 10 random locations and at random time intervals.

Participants were provided with a verbal account of the testing procedure and a series of instructions. Participants were informed prior to the test protocol as to what the red hash signified. Furthermore, they were explicitly told that the red hash did not denote that the player about to receive the ball would immediately play the pass. Participants were asked to answer as quickly and accurately as possible when they thought they knew which player would receive the pass. No emphasis was placed on either speed or accuracy of the response. Furthermore, participants were told to answer based on what they had seen in the clip as opposed to what they felt was theoretically or personally the most likely pass destination. At no point were participants told that they were able to alter their initial answer. Participants were informed that they did not have to wait for the freeze, but they could not answer until the red hash appeared. When the hash appeared, participants were free to identify the pass destination by pointing the laser directly on the player thought to be the intended recipient. Participants were asked to point the laser on the player regardless if the pass in question was played to the player directly or if it was intended to be played into an area for the player to run onto.

Before the main test, three practice clips were administered. This was followed by 15 test clips. Each clip was preceded by a 3 second countdown and during this time, participants were informed as to the area of the screen in which the ball would be located at the onset of the game footage. A similar procedure was employed by Roca, Ford, McRobert and Williams (2011). Clips ran in a continuous fashion with separation facilitated by the 3 second count down.

5.3 Results

As noted in Table 5.1, there was no significant difference between the groups in relation to response time. $F(2,51) = 2.637$, $p>0.08$.

In relation to response accuracy, as noted in Table 5.1, there was a statistically significant effect for group $F(2,51) = 3.70$, $p<0.05$, $\eta^2 = 0.13$. Tukey HSD revealed that the mean response accuracy for the non-elite footballers was significantly different to the non-players. There was no significant difference between the non-elite footballers and the elite players nor between the elite players and the non-players.

Given their higher initial response accuracy, the non-elite players exhibited the highest total response accuracy across the groups (M=0.41, SD=0.14, M=0.36, SD=0.16 and M=0.28, SD=0.09 respectively). This is noted in Table 5.1. There was a statistically significant effect for group. $F(2,51) = 4.51$, $p < 0.05$, partial $\eta^2 = 0.15$. Post hoc analysis using Tukey HSD revealed that the mean score for non-elite players was significantly different to the non-player group but did not differ significantly from the elite players.

As noted in table 5.1, ANOVA revealed a statistically significant effect for groups in relation to the combination measure. $F(2,51) = 3.44$, $p<0.05$, $\eta^2 = 0.12$. However, Tukey HSD post hoc analysis did not reveal any significant differences between the groups. This result is most likely attributable to the fact that the initial difference is marginally significant ($p = 0.4$) and there is not enough statistical power to undertake the subsequent post hoc comparisons.

Table 5.1 – Study 2 Results

	Elite	Non-Elite	Non-players	*p*
Response time (secs)	4.21(1.72)	5.72 (2.53)	5.62 (2.24)	0.081
Response Accuracy	0.32 (0.17)	0.40 (0.16)	0.27 (0.08)	0.032
Total Response Accuracy	0.36 (01.6)	0.41 (0.14)	0.28 (0.09)	0.016
Combination score	0.08 (0.03)	0.08 (0.03)	0.06 (0.03)	0.04

5.4 Discussion

The aim of this investigation was to examine the extent to which knowledge is domain specific or if possession of an enhanced knowledge base in one activity facilitates transfer to another. The anticipatory performance of elite footballers, non-elite footballers and non-footballers on a pass destination anticipation test was examined. Four dependent variables were identified and measured; response time, response accuracy, total response accuracy and combination score.

In discussing these results and investigating the nature of transfer from football, it was suggested that using a hockey-based task was a suitable first step. The rationale was based on the fact that if there was little or no transfer between two similar sports, there is unlikely to be any in a dissimilar activity. As such, the investigation is predominantly concerned with the performance of the elite group and how this compares with the other two groups. Before discussing more general issues relating to transfer and development of sporting expertise, it is necessary to analyse the results obtained and in doing so, there is a need to refer back to the results of a previous study conducted in the research programme. Although the participants in this current study are not entirely the same as those in Study 1, the comparison is both valid and insightful.

It was suggested above that the discussion should focus on the results of the elite players. It is interesting to note, therefore, that the elite football group's results across all four dependent variables are comparable to those of the non-elite hockey group in Study 1. This result alone would suggest that there is a degree of transfer. There is, however, a cautionary undertone to the assumption that football skills transfer to hockey.

In this study, the elite and non-elite groups had the same mean combination score which, in turn, was superior to the non-player group. It is important to note that there were no statistically significant differences between the elite football and the non-elite football groups. Given this, it is unclear which elements of performance actually transfer.

It was suggested that if the two football groups outperformed the non-players groups, as would appear to be the case with the combination measure, then it may be possible to postulate that participation in football does assist in transfer to hockey. The rationale for the inclusion of the non-player group has, therefore, been largely vindicated for the reasons outlined previously. The difficulty in discussing the nature of transfer relates to the lack of a consistent, across the board pattern which was observed in the previous investigation. Results in Study 1 revealed that the elite groups in both sports, i.e., football and hockey, outperformed their less elite counterparts on two dependent variables; total response accuracy and combination measure.

The aforementioned significant differences revealed in Study 1 are the obvious starting point in examining this further. As was identified however, the four measures are inextricably linked to one another. In that vein, it was suggested that the combination measure was the most appropriate measure of successful performance on the task as a combination of both speed and accuracy is required. The importance placed on the combination measure in Study 1 would further suggest that the interpretation of the results in this particular study should be that playing football facilitates transfer to hockey regardless of the of level of play. There is, however, a concern with that assumption, as although there is no numerical difference in the mean combination scores of the elite and non-elite groups, there is a difference in terms of the respective compositions of the measure, i.e., response time and response accuracy.

In the case of the elite players, their score is based predominantly on the mean response time, which is the lowest across all groups. However, this has not been accompanied by a high response accuracy score. Analysis of the non-elite players' constituent measures of accuracy and time reveals that the response time is the lowest across the groups. As was outlined in Study 1 a slower response time can be beneficial to the response accuracy measure and this is evidenced with the non-elite football group whose combination score is largely based on their enhanced accuracy.

The enhanced accuracy score of the non-elite players is then related to the total response accuracy measure. The initial accuracy score is the basis of the total response accuracy measure, as the latter is derived from the initial accuracy measure and then supplemented if the participants successfully alter their initial response when providing an additional answer. The key issue relates to the level of supplementation of the initial response accuracy as opposed to the total response accuracy measure itself. In this study, the change for the non-elite group is 0.01. This is replicated by the non-player group who also exhibit an increase of 0.01, although their initial accuracy is much lower. In regard to the elite players, the increase is 0.04.

In attempting to unravel the nature of transfer, the integrative nature of the dependent variables is key. If uniformity of results had been obtained i.e., elite players outperformed both groups and the non-elite players had outperformed the non-player group then the interpretation would be clearer. Whilst the deeper analysis of the results suggests that the initial observation that participation in football assists in transfer to hockey is inaccurate, it also reveals that there is some evidence of transfer but in a different form to that which was originally hypothesised.

A study by Smeeton et al., (2004) was cited in relation to transfer of pattern recognition skill. The authors discovered that the elite hockey and football players were capable of transferring perceptual information or strategies between their particular sports. In this study, it was suggested that in the absence of domain specific knowledge, experts will fall back on a generalised strategy and there does appear to be evidence of such a phenomenon in this investigation.

In Study 1, the effectiveness of integrating the dependent variables was illustrated as it revealed a strategy utilised by both sets of elite players in their domain of expertise whereby responses were provided quickly and then altered as the situation developed and the initial expectation was incorrect. It would appear that the elite footballers in this study have attempted to employ a similar strategy. In this investigation, however, the participants have been unable to do so as effectively; they have attempted to answer quickly as they would in a game of football, but due to lack of task-specific knowledge, it is not accompanied with response accuracy. It was suggested in Study 1 that this ability to alter one's initial response was linked to a deeper conceptual understanding of the task. As such, further evidence of this lack of task-specific knowledge is provided in this study. It would seem that the elite players do not possesses the level of conceptual understanding required to further alter their responses to the extent which was evidenced in their specialist domain. In drawing these observations together, it would seem that the experts have tried to employ the strategy that was identified in the first investigation but are unable to do so as effectively. It is also apparent that the non-elite players have also adopted a similar strategy as to what was observed in the football-based task in Study 1. Results for response time and accuracy indicate the participants in this group have waited until the clip freezes before offering a response.

Whilst there is commonality with regard to adoption of strategy, there is an issue surrounding this theoretically. The results would suggest that these strategies are examples of weak methods in the hockey task. However, the elite players have a "better" weak strategy in terms of transfer as it is more representative of the real-world activity and the speed of the game.

In sum, results indicate that higher-order concepts in one activity will not transfer to another activity which has different higher-order concepts. However, elements of a strategy do appear to transfer. This suggests that the elite players can perceive the link between the two activities in terms of structure, but lack the task-specific knowledge to accurately respond to the problems posed in hockey which are different to those faced in football. There is, therefore, a need for task-specific knowledge and possession of higher-order concepts in order to execute the strategy they are attempting to employ. Thus, the implication is the elite players have fallen back to use a generalised or weak method which is attempting to treat the hockey task as if it were a football task.

There is a point to be made with regard to the terminology. It is perhaps more appropriate to refer to transfer as generalisation. There are domain general elements which are applicable in football and hockey such as the ability to run 5 metres, which generalise as opposed to transfer. Whilst the example provided is a motor skill, given the structural similarities between the two sports, it is feasible to suggest that there may be perceptual-cognitive skills which are also domain general. An example might be that due to the time pressure of both games, the ability to formulate quick decisions may generalise and there appears to be evidence to that effect in this investigation with the generalisation of strategy. This latter point raises a real-world application with regard to the development of the elite performer.

In Chapter 2, reference was made to the work documenting developmental activities associated with expertise (Côté, Baker & Abernethy, 2007; Ford, Le Gall, Carling & Williams, 2008). In this regard, it would appear that the value of transfer, or perhaps more accurately generalisation, is in terms of ascertaining if diversity of participation is a constituent of expertise, rather than ascertaining if transfer to another domain is a by-product of participation in the specialist domain.

It has been reported that the development pathway of an elite footballer is largely domain-specific (Ford, Ward, Hodges & Williams, 2009; Ford & Williams, 2012). These results are in contrast to those elicited by Côté and colleagues (Côté , 1999; Côté & Hay, 2002; Côté et al., 2001) who postulated that expert performers exhibit a more diverse participation profile and that diversification and participation in deliberate play in the formative stage of an individual's career is not only encouraged but advantageous in the attainment of expert status. These contradictory findings may be explained in terms of methodological approaches and broader issues relating to socio-economic and cultural factors (Ward, Hodges, Williams & Starkes, 2004). However, the ACT-RR model proposed in this thesis may provide a possible explanation.

First of all, in reference to the concept of generalisation, it was stated in the overall rationale section that the ACT-RR co-ordination permits the generalisation of action to novel contexts. It was also suggested that the application of knowledge to different contexts is dependent on having said knowledge made explicit. Results in this study point toward a postulate that participating in similar sports provides a wider implicit base on which to build an explicit, conceptual network of understanding. The caveat to the point above is there have to be explicit links between one sport and another. This then relates to how the skills acquired in one domain can then be strategically deployed in the domain in which one eventually specialises.

5.4.1 Summary

In sum, results in this study suggest that the knowledge possessed by the elite footballers is relatively domain specific. Despite this, there appears to be a small degree of transfer in terms of the strategy employed. However, results also suggest this strategy is not employed effectively due to a lack of domain specific knowledge and absence of higher-order concepts. The transfer of a strategy is salient as it points toward a type of cross-domain generalisation and the most appropriate application of this relates to conflicting reports of expertise development and it is with this particular topic that the concept of transfer, or perhaps more appropriately, generalisation, has the greatest applicability and value. Whilst not providing any supporting evidence to either stance per se, the application of ACT-RR model postulated in this research programme may offer a possible explanation and mechanism for the concept of diversification with the procedural elements gained in the various activities through ACT being connected, organised and generalised through the process of Representational Redescription.

Results in this study are suggestive of a degree of generalisation between structurally similar sports. However, it has also been evidenced that domain specific, higher-order knowledge does not transfer. This suggests that this knowledge is an important component of decision making. The next study will investigate the knowledge underpinning decision making skill in elite and non-elite players in football and hockey in their specialist domain.

Chapter 6: Study 3

6.1 Introduction

Decision making in elite sport is of critical importance. McPherson and MacMahon (2008) report that an expert sport performer is better able to retrieve from their memory a correct decision for what they should do in that situation compared to lesser-skilled players. Whilst this insight is correct, studies which have focused on this task have predominantly measured outcomes, i.e., number of correct decisions made, as opposed to indentifying the underlying mechanisms which allow expert performers to make more appropriate decisions (McMorris & Graydon, 1996; Raab, 2002).

Farrow and Raab (2008) describe decision making as “the ability of a player to quickly and accurately select the correct option from a variety of alternatives that may appear before the ball is hit or kicked or an opponent moves” (p.137). In dynamic activities such as football and hockey, there are situations which require a choice to be made between a number of possible solutions. In relation to ACT, it was suggested previously that there may be more than one appropriate response for the conditions present i.e., more than one THEN per IF. Whilst the definition of Farrow and Raab (2008) intimates that a choice has to be made between alternatives, it neglects to cite the process by which alternative courses of action are differentiated.

As pointed out in the rationale chapter, decision making in real world complex problem solving tasks is not so much a case of identifying a correct course of action but more about the process of selecting between options. In order to do so, Tolmie et al., (2005) argue that “for complex problems where many solutions are possible, the application of knowledge to different contexts depends not just on having it made explicit, but also on the ability to decide which elements of the knowledge to accord the greatest weight in any given instance." (p.4). The second study looks at this process by examining which information sources are important to elite and non-elite players in football and hockey and which elements of knowledge are accorded greatest weight when making a decision.

Data collected earlier in the research programme provided evidence of expert players in football and hockey differentiating between alternatives in relation to response alteration whereby an answer initially deemed correct is then considered to be incorrect as the sequence of play evolves. However, there was no explanation provided as to why the initial choice was made or, where applicable, altered for another option. In an investigation such as the task employed in study one, the RR model would suggest that the participants will call on their level-I representations or E1 representations. The utilisation of Level I (implicit, context bound procedures) would be expected to generate appropriate behaviours in some instances, but without any degree of control or flexibility, or coherence across problems. Whilst the results on total response accuracy in study one illustrate a degree of conceptual understanding, i.e., an ability to accurately alter responses should the situation evolve differently, given the premise of the first investigation, this is likely to be based on the utilisation of E1 type representations which are available to self but not communicable to others. The premise of RR is that attainment of behavioural mastery then triggers subsequent development and the creation of an explicit network of understanding which then drives behaviour. Therefore, there is a need to further investigate the nature of the representations further along the RR continuum.

Decision making in sports such as football and hockey is complex due to the dynamic nature of the activity and the number of moving components. Furthermore, in addition to the environmental constraints, actions within both games are guided by underlying theoretical principles. In a study conducted by Ward and Williams (2003), elite and sub-elite players were asked to allocate probability values to likely courses of action available to a player in the possession of the ball. Results illustrated that the elite players were superior in comparison with sub-elite players in assigning probability values to players in threatening and non-threatening positions. Additionally, the elite players were more adept at identifying players who were in the most advantageous position to receive the ball. The formulation of a decision is partly based on contextual information contained within the display; the study Ward and Williams (2003) illustrates the importance of the position of other players and interpreting that information to formulate an expectation of most likely recipient.

Utilising visual search data obtained from eye-tracking apparatus, it has been reported that certain information sources in the sport environment are more significant than others (Savelsbergh et al., 2002). Evidence suggests there are expert – non-expert differences in terms of information attended and the way in which the display is searched (Roca et al., 2011). Despite the rich information provided, one of the limitations of visual search data is that it is largely inferential in nature. There are pertinent questions which cannot be answered from visual search data alone, specifically why are these information sources important and how are they utilised in the decision making process.

In line with the RR model, if a person possesses E3 representations, it is suggested that there is reconciliation between the information contained within the environment and internal representations possessed by the individual (Karmiloff-Smith, 1992). In regard to the process, in a theoretical observation Tenenbaum (2003) suggested skilled decision making consists of the integration of visual attention mechanisms, anticipatory mechanisms and their elaboration with long-term rooted representation. In drawing all observations together, it would seem that there are important information sources within the display which are then interpreted and elaborated by an individual. Gobbo and Chi (1986) suggest that in the case of experts, once a section of knowledge is triggered by the visual elements, additional, related knowledge can then be activated, assuming knowledge is stored in a connected network.

One of the main facets of the RR model is that the progression of representational change facilitates the linkage and organisation of knowledge. Moreover, further redescription and progression along the RR continuum permits said knowledge to become communicable to others through verbal report. Given the apparent limitations of visual search data, and the important role played by language in RR, another applicable methodological approach to investigate the underlying mechanisms of decision making is verbal report. Two investigations in this chapter involve the selection of, and differentiation between, possible options available to a player in possession of the ball in football and hockey. The purpose of these investigations was to gain an insight into the organisation of the cognitive networks and the degree of conceptual understanding displayed by elite players in comparison with non-elite players. The premise of the study is to investigate the information players of differing skill levels utilise in undertaking the process of decision making. It is hypothesised that the elite players will provide more alternative courses of action. Furthermore, it is hypothesised the elite players will exhibit greater reconciliation between the information in the display and their internal knowledge representations providing a more effective rationale for certain choices of actions.

6.2 Method

Study 3 included two separate investigations involving football and hockey. In both investigations, participants were required to view a video sequence of a passage of play and verbally offer possible courses of action available to the player in possession of the ball. Furthermore, participants were required to provide an explanation for their choices. The task in this investigation is similar to the option generation paradigm (Johnson & Raab, 2003) whereby participants are presented with a situation and required to generate alternatives.

In the alternatives task, the dependent variable was number of alternates and the independent variable was level of play (group). In relation to the explanations provided, the dependent variable was level of play (group) and the independent variables were proportion of references to the Motion, Space, Patterns, Pass and Future Actions categories. These categories are explained in detail below.

6.2.1 Participants

Participants for each investigation were recruited from the participant pools outlined in the general methods chapter.

In investigation 3a, groups of elite football players (n=20), non –elite football players (n=20) participated in the study. Elite players were aged between 16 years and 19 years (M = 17.45 years) and non-elite players were aged between 17 years and 20 years (M = 18.65 years).

In investigation 3b, groups of elite hockey players (n=15) and non-elite hockey players (n=15) participated in the studies. Elite players were aged between 17 years and 22 years (M = 18.80 years) and the non-elite players were aged between 18 years and 22 years (M = 20.40 years).

6.2.2 Materials

The test stimuli for each investigation were developed from full matches involving elite players in each sport. Digital video data for the investigation were obtained using the procedure outlined in the general methods section. The tests utilised footage from a standard camera one position of a high, side-on location at the halfway line. This is the vantage point typically provided for TV broadcasts of both sports. A total of 5 games in football and 5 games in hockey were analysed, using Focus X2 software, by the investigator to find appropriate test stimuli. Appropriate stimuli involved a passage of play within the activity in which a player in possession of the ball was presented with more than one viable course of action.

Passes within these passages of play originated from, and were played to, different areas of the pitch. Passes were played by players in different positions i.e., defenders, midfielders and attackers, and differed in terms of type and distance. This ensured that the investigation was more representative of the game. Suitable passages of play were coded using Focus X2's bookmaking facility, with the possession of interest being time-stamped. Finalised video clip sequences of 20 seconds were exported as an AVI file for subsequent editing. Video editing was conducted using Windows Movie Maker.

Each finalised video clip was preceded by a 3 second countdown. Clips were not a standardised length. After a period of build up play, the clip froze when the player in possession of the ball approached the point of initiating an action. A freeze image of that frame remained on screen until an answer was provided. This is shown in Figure 6.1.

Figure 6.1 – Example of the final frame from the football task

Results were obtained by coding a digital video, including verbal responses, of the test protocol using a pre-defined category set in Focus X2. The category set was developed to code participants' responses and was pilot tested with expert coaches in each sport. This category set comprised a framework of topics which would be expected to be referred to by prospective participants. The category set contained a range of verbal measures reflecting a participant's explicit conceptual understanding of the game's strategic and tactical characteristics as well as the information they utilise in making their choices in decision making. The category set was refined following pilot testing. Each identified topic was included in the category set and was assigned a button. A total of 26 topics were identified. Buttons were also included in the category set to code the number of alternatives posited. The category set is shown in Appendix B.

The coding was conducted manually by the investigator. The software's bookmarking facility was used to timestamp each reference to the relevant topic in the verbal report framework. When events had been coded, Focus X2 created a database of events which was exported to Microsoft Excel where further analyses were conducted. Each individual participant's responses were proportioned by topic from the overall number of responses.

To facilitate subsequent statistical analysis, the individual topics were combined. The combinations of the original constituent topics were first categorised by the investigator. In football, these newly created categories were verified by one UEFA Pro Licence coach. In hockey, the categories were verified by a grade one hockey coach. Five overall categories were identified in each of the sports:

1. Motion

2. Space

3. Patterns

4. Pass

5. Future actions

Motion consisted of references to Movement, Tempo, Time on ball and See what happens. Space comprised references to Space, Marking, Pressure, Open, Congestion and Pressure. Patterns of players consisted of references to Shape, Position, Location, 2v1, In Behind, Offside and Other Side. Pass comprised references to Possession, Danger, Pass Difficulty, Posture, Negative, Looking, Positive and Open Up. Future Actions were statements which relate to anything that happens after the initial course of action; for example, a further pass played by the person who receives the ball.

Once completed, the data were exported to SPPS statistical software where subsequent analysis was performed. Stepwise discriminant function analyses were employed to determine which variables were most predictive of skill level and to determine how accurately the model predicted group membership. Group was the dependent variable and motion, space, patterns pass and future actions were predictor variables. This method was used by Ward and Williams (2003).

6.2.3 Procedure

The general investigation set-up was as outlined in Chapter 3, pages 50-51.

Participants viewed two practice clips followed by ten test clips. The clips were approximately 10-15 seconds in length. When the clip froze, participants were asked to place themselves in the position of the player who had the ball. Participants were asked to identify what course of action they would take in the situation. They were then asked to explain their choice and intimate what information they used to formulate their decisions. Participants were then asked to identify possible alternative courses of actions and describe their rationale for selecting these options. The investigator would continue to ask for alternative options until the participant stated that there were no more viable options.

6.3 Results

The following section outlines the results for investigations 3a) football and 3b) hockey. Results are shown for mean number of alternatives postulated. Results are also shown for the proportion of topics to which participants refer.

6.3.1 Investigation 3a

As noted in Table 6.1 More alternative actions were provided by the non-elite football players (mean = 3.26) in comparison with the elite football players (mean = 2.91). An independent t-test revealed the difference was statistically significant (t = 2.300, df = 38, p < 0.05). The effect size was d = 0.74.

Table 6.1 – Investigation 3a Results: Alternates

	Elite	**Non-Elite**	***p***
Number of Alternates	2.91 (0.46)	3.26 (0.49)	0.027

Table 6.2 illustrates the proportion of topics referred to by the elite and non-elite players in football. Future actions was the most referred to topic by the elite players (mean = 0.30). Non-elite players most often referred to Space (mean = 0.28).

Table 6.2 – Investigation 3a Results: Categories

	Elite	**Non-Elite**	***p***
Motion	0.20 (0.07)	0.26 (0.09)	0.03
Space	0.21 (0.09)	0.28 (0.07)	0.02
Patterns	0.15 (0.06)	0.11 (0.04)	0.04
Pass	0.14 (0.07)	0.17 (0.09)	0.15
Future Actions	0.30 (0.09)	0.18 (0.1)	0.01

A stepwise discriminant analysis was performed with level of play (elite vs non-elite) as the DV and proportion of references to each category as the IV. A total of 40 cases were analysed. Univariate ANOVAs revealed that the elite and non-elite group differed on four of the predictor variables: Space, Motions, Patterns and Future. The discriminate function calculated for group was significant and accounted for the total between group variability, $\chi 2 = 17.13$, *p<0.001*.Standardised canonical coefficients indicated that future actions was the greatest contributor (ß = 0.92). Patterns (ß = 0.67) was included in the second step. Overall, the discrminant function accurately predicted outcome for 75% of cases with accurate predictions being made for 70% success for the elite group and 80% for the non-elite.

6.3.2 Investigation 3b

As noted in table 6.3, more alternatives were offered by the Elite players (mean = 3.21) in comparison with the non-elite players (mean = 2.59). An independent t-test revealed the difference was statistically significant ($t = 4.830$, df = 28, $p = <0.01$. The effect size was $d = 1.74$.

Table 6.3 – Investigation 3b Results: Alternates

	Elite	**Non-Elite**	***p***
Number of Alternates	3.21 (0.32)	2.59 (0.39)	<0.01

Table 6.4 illustrates the proportion of topics referred to by the elite and non-elite players in hockey. Space was the most referred to topic by both the elite players (mean = 0.28) and the non-elite players (mean = 0.34).

Table 6.4 – Investigation 3b Results: Categories

	Elite	Non-Elite	*p*
Motion	0.15 (0.04)	0.12 (0.08)	0.14
Space	0.28 (0.08)	0.34 (0.14)	0.16
Patterns	0.14 (0.05)	0.05 (0.04)	<0.01
Pass	0.22 (0.07)	0.31 (0.11)	0.02
Future Actions	0.21 (0.07)	0.19 (0.09)	0.62

A stepwise discriminant analysis was performed with level of play as the DV and proportion of references to each category as the IV. A total of 30 cases were analysed. Univariate ANOVAs revealed that the elite and non-elite group differed on two of the predictor variables: Patterns and Pass. The discriminate function calculated for group was significant and accounted for the total between group variability, $\chi 2 = 24.891$, $p<0.001$.Standardised canonical coefficients indicate that Patterns was the greatest contributor (ß = 1.0). Motion (ß = 0.62) was included in the second step. Overall, the discriminant function accurately predicted outcome for 90% of cases with accurate predictions being made for 86.7% of the elite group and 93.3% for the non-elite group.

6.4 Discussion

The purpose of these investigations was to gain an insight into the organisation of the cognitive networks and the degree of conceptual understanding displayed by elite players in comparison with non-elite players. The task required participants to assume the role of a player in possession of the ball, select possible alternative courses of action in a football or hockey scenario, differentiate between these options and provide rationale for doing so. This study was designed to gain an overview of the topics covered by two differing levels of players when making a decision and to ascertain whether there were any differences in postulated rationale between the experts and non-experts. There appear to be expert – non-expert differences with regard to number of alternates proposed and the rationale underpinning these choices.

Fundamentally, the function of the alternatives task was to illustrate that there is more than one possible option in a situation. However, the results elicited are worthy of discussion. It was hypothesised that the elite players would provide more possible alternative courses of action. This result was observed in hockey but not so in the football task where non-elite players provided more alternatives.

The rationale for the hypothesis was that the wider knowledge base of the elite players would allow this group to perceive more options. However, it is possible that this enhanced knowledge base has had another effect in that it regulates the selection of alternates. Evidence of experts offering fewer alternatives in comparison with non-experts has been found in chess (Klein, Wolf, Militello & Zsambok, 1995) and tennis (McPherson & Kernodle, 2003). The results in football may point toward a knowledge driven filter system so that only viable options are presented. Options which are unviable are, therefore, not considered and not articulated. Non-experts may have selected options that the experts would not consider as they understand that they are not viable or advantageous.

Overall, the results found in relation to alternatives are inconclusive. However, the effectiveness of this approach was to illustrate the proposition of more than one alternative in each scenario. The follow-up questioning asking for reasoning and explanation was intended to ascertain what information was used and examine rationale in relation to these alternatives. To discuss further, the next section will discuss the results relating to references made to the categories.

As stated, the purpose of these investigations was to gain an insight into the organisation of the cognitive networks and the degree of conceptual understanding displayed by elite players in comparison with non-elite players. This was investigated by means of verbal report protocol in which participants provided rationale for the alternates they had offered. The rationale was coded in reference to the categories provided. Given the purpose of these investigations, the aim was not to determine if one category was more important than another *per se* but rather to ascertain how the categories were utilised by elite and non-elite players when providing rationale for alternates.

The distribution of mean references to the categories does suggest that the elite and non-elite players in each sport do refer to the same categories. This is evidenced in hockey, for example, where Space was the most often referred to topic by both elite and non-elite players. This would suggest that the Space category, with its constituent topics, is globally important in hockey. However, there does appear to be a difference in the relative importance of the categories.

In football, statistically significant differences between the elite and non-elite players were observed on four of the five predictor variables. These were Patterns and Future actions with elite players more often referring to these categories. Additionally, significant differences were observed for Space and Motion with non-elite players more often referring to these categories. No significant difference was observed for Pass. Of the five predictor variables, two were included in the discriminant analysis to predict group membership; Future Actions and Patterns.

In hockey, statistically significant differences between the elite and non-elite players were observed on two of the predictor variables. Patterns were more often referred to by elite players whereas Pass was more often referred to by non-elite players. No significant differences were observed for Future Actions, Motion or Space. Of the five predictor variables, two were included in the discriminant analysis to predict group membership; Patterns and Motion.

In both sports, Patterns was included in the discriminant analysis to predict group membership. The importance of patterns of play points toward a linkage to deeper, meaningful tactical principles which are applicable in both sports. The composition of the Patterns category was shape, position, location, 2v1, in behind, offside and other side. These concepts appear to be shared in football and hockey and this is not surprising given the structural similarities between the two sports which were outlined in Study 2. Referring to pattern recall and recognition literature, previous research in football and hockey has shown that expert players are more adept at identifying previously viewed game sequences. The theoretical explanation provided for the expert v non-expert differences is that the expert players initially draw relational information from the display such as overall team shape, position of other players and the location of the ball. These are then linked to the individual's internal knowledge such as the tactical and strategic importance of these relations (Dittrich, 1999). Non-experts on the other hand tend to focus on superficial, surface features of the display such as the condition of the pitch and the colour of the teams' strips. Although employing a different methodological approach, results in these investigations may suggest a similar phenomenon with experts being more attuned to the importance of these concepts.

In addition to the importance of Patterns in relation to higher-order tactical concepts, the results obtained in football can be further linked to underlying theoretical concepts. The apparent importance of future actions with the elite players, demonstrates a deeper conceptual understanding of the task and an appreciation of the relative consequences of an action. With regard to the non-elite players, results are suggestive of an over reliance on the superficial aspects of the display. This is evidenced with the significant differences in relation to space and motion.

The differences between the elite and non-elite players outlined above are significant from a theoretical stance. These findings are in line with previous research investigating expert - novice differences in complex problem solving where studies in a number of domains have found that experts, in comparison with non-experts, tend to work forward and rely less on superficial elements.

The stepwise discriminant analysis revealed that Future Actions was the greatest contributor for expert football players. The description of what will happen after initial action provides an indication of the appreciation of the relative consequences of the chosen action. These results indicate that the concept of working forward in football may manifest itself in a description of what may happen after the initial course of action has occurred.

A salient point here is that future actions are not available within the display *per se*; they are generated based on the internal representations of the participant. Research by McMorris & colleagues (McMorris, 1997; McMorris & Graydon, 1996) illustrated that decisions made which require cognitive restructuring skills, i.e., being able to imagine the display if people and objects move to different positions, are significantly poorer than those that require simply reacting to the present environment. In line with the theory and utilisation of E3 representations, this suggests reconciliation between the information in the environment and the individual’s knowledge.

There is further evidence of this reconciliation as future actions can be used to interpret the superficial aspects of the display. An elite player may, for example, refer to a player being marked. This does not necessarily mean that the rationale for a choice is impoverished as this initial statement may be augmented by detailing the relative consequences of a player being marked in relation to future actions. For example, if a participant identifies that a centre forward with his back to goal is being marked by the central defender, it may then be suggested that any ball played into the centre forward would most likely lead to a lay off pass back toward the path of an oncoming supporting midfield player.

The results in relation to the non-experts may suggest a difficulty moving beyond the superficial element of a player being marked. Therefore, as their knowledge is not akin that of an individual with E3 level representations, their explanation may remain as the player is being marked. Thus, there is little reconciliation between the display and internal representations in that an important cue has been identified but may not be accompanied by an explicit explanation linked to deeper theoretical principles as to the implications and the relative consequences.

Related to the above, the apparent importance of future actions may play a role in differentiating between options. If there is a situation where, in the first instance, two options present ostensibly the same benefits and are underpinned by the same, superficial-based rationale, the subsequent action will most likely be the determinant. For example, in a situation in which there are two players in space, it is not possible to differentiate between the merits of each if the rationale for both options is based on the same aspect. The difference might be that in one instance, the only benefit of passing to one player is that it retains possession. However, the other player in space may be able to further develop an attack by passing to a player in a position to have an attempt on goal.

Referring to future actions in these ways suggests that expert players have a deeper conceptual understanding of the task. They can interpret elements in the display and utilise this information to postulate effective strategies which best meet the demands that the particular situation presents. Then, based on a rationale of relative merits and consequences of the proposed action, differentiate between these possibilities and execute an optimal solution.

Given the relative importance of future actions in football, it is somewhat surprising that the same effect was not observed in hockey. One possible explanation relates to a potential methodological issue in that the footage within the hockey investigation was potentially too close to the players thus limiting the full picture in some of the clips. This means that, perhaps, the participants did not have as many opportunities for commenting on future actions.

Another possible explanation is that there are different requirements within each sport. Whilst there is replication in the football and hockey tasks with reference to Patterns, results would suggest that the topics deemed important for experts in each sport are relatively domain specific. This is evidenced by the inclusion of motion in hockey discriminant analysis but not in football. This would echo the findings of the second study and would be expected as the manifestation of RR itself appears to be domain specific. Therefore, the concept of future actions is not as important in hockey as it appears to be in football. However, the germane issue is there are skill-based differences evident in both sports which point toward utilisation of a different representational level when offering rationale for a choice of action.

The concept of selecting an appropriate action bears a similarity to formulating a situational probability, as discussed by Ward and Williams (2003). In this case, there is a hierarchy of events that are likely to happen with more likely events assigned a higher probability. Relating that concept to the current study, having demonstrated that there are alternative courses of action available in a situation, there has to be a decision making process so that, in the context of ACT, the most appropriate action is selected. There appears to be a difference in the rationale used by experts and non-experts in determining the option at the top of the hierarchy, i.e., the most effective option.

6.4.1 Summary

In sum, results from these investigations suggest that elite and non-elite players in both football and hockey are able to offer alternative courses of action. However, there appear to be domain-specific, elite v non-elite differences in the rationale underpinning these choices. Results suggest that elite players' rationale is based on more higher-order concepts such as tactical and strategic knowledge. Furthermore, there is evidence which suggests elite players in football have a greater appreciation of the relative consequences of these actions and utilise this in the decision making process.

Although this study involved verbalisation of a participant's thoughts, it did not derive a measure of explicitness *per se***.** Engaging the participant in a discussion obviates the opportunity to elicit a measure of "explicitness" as the probing encourages participants to offer more information than they may be able to articulate. The next study takes these observations into account.

Chapter 7: Study 4

7.1 Introduction

The concept of explicitness is worthy of further consideration; it is not a case of volume of information provided, but rather the pertinence of the information provided and the efficiency in which this is delivered (Thomson, Tolmie, Foot, Sarvary, Whelan & Morrison, 2005).

Related to the issue of pertinence in terms of explicitness, a further consequence of the RR process is that knowledge becomes more connected. Gobbo and Chi (1986) found that child experts in the field of palaeontology had more structured knowledge. This was evidenced by referring to connected concepts. There is observational evidence from the third study that experts' knowledge is more connected. When providing a description of future actions, there is a more detailed depiction of what will happen and connection of related concepts. As Study 3 was not designed to measure this, there is a need to examine this further.

Both of the above points, pertinence of articulated information and connected knowledge, can be related to RR and the progression along the representational continuum. Furthermore, it can also be cited with regard complex problem solving. In the introductory chapter, common features of expert knowledge were identified. Amongst these characteristics, it was posited that experts store their knowledge in large units that can be accessed rapidly and relate specific features of a problem to meaningful underlying concepts. This is in contrast to non-experts who store their knowledge as a fragmented set of individual pieces of information and focus on surface features of the problem (Muir, Beswick, & Williamson, 2013).

In attempting to gain an insight into the problem representations and conceptual framework of expert performers, it is necessary to design a task which requires conceptual understanding and can be related to meaningful underlying concepts (Abernethy, Thomas & Thomas, 1993; Auclair, 2007). An example of a task which requires conceptual understanding is the so-called sorting task whereby participants are required to categorise items such as, for example, food, (Ross & Murphy, 1999). In the sports domain, Allard and Starkes (1991) cite a study by Parker (1989) in which groups of ice hockey players, coaches and spectators were asked to sort pictures of game segments into conceptual categories. Examples of such categories would be in relation to player position, phases of play and microstates. The expert players and coaches utilised their domain-specific knowledge to interpret the contents of the photographs and sort them accordingly into more meaningful, conceptually underpinned categories. Non-experts on the other hand, sorted the pictures using only the superficial information present in the display such as the colour of the players' uniforms. Yarlas and Sloutsky (2000) investigated the problem representation of experts and novices when sorting mathematical equations. Results indicated that experts categorised the equations in terms of the deeper arithmetic principles.

Despite its positive results and insights into conceptual understanding, the sorting task does have limitations. Whilst it is possible to incorporate a verbal component into the task by asking participants to explain their categorisation, principally, the task does not require a verbal report measure and consequently, it is difficult to elicit a measure of explicitness. Secondly, this task is not entirely representative of the real world task as players are not required to sort pictures in football. Therefore, in order to investigate the hallmarks of expertise, it is important that the task in question adequately taxes the expert but does so in a realistic manner.

Given that football can be considered to be an example of a complex problem solving task, participants need to be presented with a complex problem. The current investigation incorporates a means of investigating this in football, namely tactics. A tactical scheme employed by a coach is dependent on a number of players performing specific jobs which contribute to the overall objective (Tenga, Holmebb, Ronglana & Bahra, 2010a). Despite these different roles and responsibilities, the players fulfil their respective duties in a collective fashion in order to facilitate a collective goal.

Consider the following example pertaining to defensive play which illustrates the connected nature of the game. The defending team (shown in blue) is playing a 4-4-2 formation and their philosophy is to apply pressure to the opposition's (red team) defenders when they have possession of the ball in their own defensive third.

Figure 7.1- example of a microstate within a football match

Figure 7.1 above shows that team red has possession of the ball, specifically their left full-back (shown with the circle). In this situation, the centre midfield player for team red has dropped off from the line of the rest of his midfield players so that he is in a position to receive the ball.

In terms of tactics and in order to combat the red team, team blue have implemented the following strategy:

- One of their two strikers is located so he can put pressure on the player who has possession of the ball
- The other striker has positioned himself on the centre back adjacent to the left full-back
- One of team blue's centre midfield players has gone to cover the centre midfield player who is looking to receive the ball.

The reasons for these actions are:

- The full back in possession of the ball is under pressure, which means he has to make a decision quickly
- The 2nd striker positioned beside the adjacent centre back means that the full back cannot pass to him
- Likewise, the proximity of team blue's centre midfield player to red's centre midfield player stops a pass being played to him

All of the above actions and coaching points are designed to force the full back to play a pass into the centre forward on the red team's right hand side of the pitch. Although not shown on the diagram, team blue's centre backs are primed for this event and have positioned themselves appropriately so that they can win or challenge for the header. At the same time, the centre midfield players of team blue have turned and retreated toward their centre backs in order to regain the ball from the opposition striker.

This example demonstrates that football at the highest level is both complex and highly structured. The actions undertaken by players are underpinned by a sound theoretical rationale and are carried out in attempt to achieve a goal; in this case, winning back possession of the ball. Furthermore, the preceding example illustrates the importance of relative consequences of actions. The individual events, such as closing down the full back and marking the centre back, are interdependent in achieving the goal.

Such instances in a game can be identified prior to the match and this information can impact on decision making. In the previous investigations, whilst the participants have linked the display to underlying concepts, solutions to the problems posed have been based on the information which been presented. A merited criticism, therefore, is a lack of context as decisions can be made based on *a priori* information and subsequent tactical deployment (Chamberlain & Coelho, 1993; McPherson 1993b) For example; Paull and Glencross (1997) showed that decision making was significantly improved in baseball when participants were provided with *a priori* contextual information.

To address this, another aspect of the elite game is a process undertaken called scouting, which provides this *a priori* information. Typically, a knowledgeable representative, a scout, from a club will attend matches involving forthcoming opponents in attempt to ascertain their tactics, formation, style of play, personnel, strengths and weaknesses. Following this observation, the scout will produce a written report. The findings will be utilised to formulate a game plan for when the team will play this particular opponent. In particular, a team’s strengths and weaknesses, both individually and collectively, are of crucial importance in formulating a game plan. High level coaches will identify situations within the game which have to be nullified or exploited depending on the opposing team’s attributes. In effect, coaches will provide solutions to complex problems within the game.

These examples of higher-order concepts provide a basis for an investigation. This football-based task provides a platform for participants to exhibit their explicit conceptual understanding and will elicit performance measures pertaining to explicitness and knowledge connection. Referring back to the overall hypothesis of IF…THEN…DO...BECAUSE, this investigation will provide a series of IF scenarios and participants will be required to generate appropriate solutions, accompanied by sound rationale, for the complex problems posed, i.e., a THEN…BECAUSE. It is hypothesised that elite players will provide more relevant information by identifying more of the relevant roles and responsibilities of the players involved in achieving the overall tactical objectives. Furthermore, based on their more connected knowledge, as a result of RR, experts will provide this pertinent information in a more efficient manner in comparison with non-experts.

7.2 Method

This investigation employed a verbal based protocol and related to a hypothetical match. Participants (as outlined in the 'Participants' section below) were provided with elements of a scouting report outlining the strengths and weaknesses of a forthcoming opponent and basic elements of a game plan. The findings of the match report and the game plan are shown in Appendix C. Participants were then presented with defensive and offensive situations which may arise in a game. Participants were required to generate appropriate solutions for game situations. Participants were asked to describe overall tactical deployment, the players involved and their roles & actions.

Several dependent variables were collected in the investigation. Five dependent variables were recorded in two conditions, attack and defense, using a repeated measures design: Yellow players, Red players, Score, Time and Explicit score. The measures pertaining to players comprised number of players within the respective teams to which participants refer. The score measure is derived from the actions, roles and topics to which the participants refer. Time was taken from the first to the last tagged event in each scenario. The explicit score was calculated by dividing the score measure by the time measure. The independent variables were level of play (elite and non-elite) and clip type (defensive v offensive).

Three additional dependent variables were measured across all 6 scenarios, exclusive of clip type: Yellow units, Red units and Match report. The term unit encompasses collections or groups of players, such the midfield or defence, to which the participants may refer. The dependent variable entitled match report relates to number of references to the contents of the match report.

7.2.1 Participants

Groups of elite football players (n=20), non-elite football players (n=20) participated in the study. The elite football group was recruited from the under 19 squads of two Scottish Premier League teams and were aged between 17 and 19 (M = 17.9). The non-elite participants were recruited from the University's amateur football team and were aged between 18 and 21 (M = 19.2).

7.2.2 Materials

The investigation content was based on a coach's assignment for the UEFA Pro Licence (Freitas, Dias & Fonseca, 2013). The assignment was to conduct an assessment of a game and the teams involved. The coach was then required to create a game plan that could be implemented if a team of his charges were to play against the winners of the game. The game plan consisted of defensive situations intended to counteract the opposition's strengths, and offensive situations designed to exploit their weaknesses. The investigation is based on the game plan and these various scenarios. Teams and players were made anonymous; the opposing team was termed Red Team F.C. and the participant's team was entitled Yellow United F.C. Players were referenced by their position and number.

The investigation was carried out using Microsoft PowerPoint presentation. Text based slides were created using PowerPoint's functionality. The game-based scenarios were created using Coach FX (Express Coaching, Scotland). Images from Coach FX were exported in JPEG format and presented in the PowerPoint presentation as static slides. The titles and arrows were added using PowerPoint's functionality and were included to identify the player in possession of the ball. An example is shown in Figure 7.2.

Figure 7.2 – An example of a defensive scenario presented in the investigation

Results were obtained by coding the digital video containing the participant's verbal responses in Focus X2 using a pre-designed category set. Every player in both teams was assigned a number relative to their position on the field. Within the category set, each player was assigned an individual button. Buttons were also assigned for team units; defence, midfield and attack. Elements from the coach's game plan were reframed and related to roles and responsibilities of players and each of these was assigned a button. Additionally, a number of buttons were included to code observations or explanations made in reference to the various scenarios. 62 topics were included. The category set is shown in Appendix D. The coding was conducted manually by the investigator. For each scenario, every reference to a player, unit or topic was coded so that it was time-stamped and logged. When events had been coded, Focus X2 created a database which was exported to Microsoft Excel for further analysis.

Verbal data were screened to control for repetition. Only one reference to the player was recorded for each of the clips. For example, if player number 7 for the yellow team was mentioned on three separate occasions, this was considered to be one reference to yellow player number 7 as opposed to three. This procedure was also used in relation to team units. Measures pertaining to score were also screened. In each scenario, if a participant referred to the same topic more than once, this was recorded as one reference. Participants were allocated a point for each item they mentioned. The measure of time was based on the point from the first coded event to the last remaining coded event in each scenario. The explicit score measure was derived by dividing the score measure by the time measure.

Data were exported to SPSS statistical software. A 2x2 mixed ANOVA was used to analyse the following dependent variables: mean number of yellow players, mean number of red players, mean score, mean time and explicit score. These variables were examined for both the offensive and defensive scenarios. For the 2x2 mixed ANOVA, the between participants factor was level of play (elite and non-elite) and the within participants factor was clip type (defensive and offensive). To control for the number of comparisons made, a Bonferroni correction procedure was applied for the ANOVAs conducted and the alpha level was set at $p<0.01$.

In addition, three independent t-tests were conducted for the three dependent variables measured across all six scenarios. These were number of yellow units, number of red units and number of references to the match report. The alpha level in this particular case was set at $p<0.05$.

7.2.3 Procedure

The general investigation set-up was as outlined in Chapter 3, pages 50-51.

Participants were provided with a slide outlining the background of the investigation. Participants were then presented with a total of 6 scenarios, 3 offensive and 3 defensive, which may occur within the match. Viewing of these clips was split into two sections; defensive sequences were presented first, followed by the offensive sequences. Prior to viewing the first slide in each section, participants were shown a guide slide which outlined their task. Participants were required to provide as much information as they could in relation to:

- What Yellow United are trying to do and why
- What might happen as a result of doing that
- The roles of the players involved

Participants were then presented with the first scenario and provided their answers. The next scenario was not shown until the participants had intimated they had completed their answer. The three scenarios were administered in a continuous fashion. Once the first section of defensive scenarios had been completed, the guide slide was shown again before presenting the three, offensive scenarios. During the protocol, the investigator did not engage in any other dialogue with the exception of possible repetition of the prompt or to answer to a specific query.

7.3 Results

The following section details the results obtained in the investigation. The first part shows the results of the 2x2 mixed ANOVA. The second part shows the results of the independent t-tests for references to red and yellow team units and the match report.

As noted in Table 7.1, more yellow players were referred to in the attacking clips. There was a statistically significant effect for clip $F(1,38) = 22.79$, $p<0.001$, $\eta^2 = 0.38$. As noted in Table 7.2, there was no statistically significant effect for group in relation to yellow players $F(1,38) = 5.812$, $p = 0.021$, $\eta^2 = 0.133$. There was no significant interaction effect.

As noted in Table 7.1, more red players were referred to in the defensive clips. There was a statistically significant effect for clip $F(1,38) = 88.18$, $p<0.001$, $\eta^2 = 0.70$. Non-elite players more often referred to red players than elite players (Table 7.2). There was a statistically significant effect for group $F(1,38) = 9.745$, $p<0.01$, $\eta^2 = 0.20$. There was no significant interaction effect.

As noted in Table 7.1, there was no statistically significant effect for score in relation to clip type $F(1,38) = 5.53$, $p = 0.024$, $\eta^2 = 0.1$. A shown in Table 7.2, there was no statistically significant effect for group in relation to score $F(1,38) = 2.37$, $p > 0.1$, $\eta^2 = 0.06$. No significant interaction effect was observed.

There was no statistically significant effect for time in relation to clip type $F(1,38) = 0.70$, $p > 0.40$, $\eta^2 = 0.018$. As noted in Table 7.2, elite players were quicker than the elite players in providing information. There was a statistically significant effect for group $F(1,38) = 17.02$, $p<0.001$, $\eta^2 = 0.31$. No significant interaction was observed.

There was no statistically significant effect for explicit score in relation to clip type $F(1,38) = 0.95$, $p > 0.30$, $\eta^2 = 0.02$. Elite players had a greater explicit score than the non-elite players (Table 7.2). There was a statistically significant effect for group $F(1,38) = 27.27$, $p<0.001$, $\eta^2 = 0.42$. No significant interaction effect was observed.

Table 7.1 – Results for Offensive and Defensive scenarios

	Defence		**Attack**		***p***
	Elite	**Non-Elite**	**Elite**	**Non-Elite**	
Number of yellow	4.05 (1.16)	2.97 (1.33)	4.83 (1.10)	4.50 (1.22)	<0.01
Number of red	2.10 (1.00)	3.05 (1.64)	0.33 (0.45)	1.15 (0.91)	<0.01
Score	8.07 (2.69)	8.72 (3.19)	6.69 (2.28)	8.38 (2.45)	0.024
Mean time (seconds)	24.2 (9.04)	39.31 (18.84)	21.78 (7.79)	38.79 (15.29)	0.409
Explicit score	0.37 (0.08)	0.25 (0.08)	0.33 (0.12)	0.25 (0.08)	0.335

Table 7.2 – Results for Level of Play

	Elite	**Non-elite**	***p***
Number of yellow	4.44 (0.67)	3.73 (0.91)	0.021
Number of red	1.22 (0.99)	2.10 (1.13)	0.003
Score	7.38 (1.06)	8.55 (0.71)	0.132
Mean time (seconds)	23.00 (4.25)	39.06 (4.02)	<0.01
Explicit score	0.34 (0.10)	0.23 (0.07)	<0.01

In reference to the Yellow team units, as noted in Table 7.3, an independent t-test revealed no significant difference between the non-elite players (M = 1.35, SD = 0.94) and the elite players (M = 1.10, SD = 0.95). $t(38) = 0.035$, $p>0.20$, $d= 0.27$.

A noted in Table 7.3, non-elite players more often referred to red team units than did elite players (M = 0.53, SD = 0.55 and M = 0.22, SD = 0.36 respectively). An independent t-test showed the difference between the groups was significant $t\ (33.1) = 2.164$, $p<0.05$, $d= 0.68$.

A noted in Table 7.3, non-elite players more often referred to the match report than did elite-players (M = 2.35, SD = 1.87 and M = 0.95, SD = 1.05 respectively). An independent t-test revealed the difference between the groups was significant $t\ (29.9) = 2.92$, $p< 0.01$, $d = 0.97$.

Table 7.3 – Results for Team Units and Match Report

	Elite	**Non-elite**	***p***
Yellow units	1.10 (0.95)	1.35 (0.94)	0.409
Red Units	0.22 (0.36)	0.53 (0.55)	0.037
Match report	0.95 (1.05)	2.35 (1.87)	0.006

7.4 Discussion

This study was an attempt to further investigate the overall hypothesis; expert propositions are organised as IF…THEN…DO...BECAUSE statements. The investigation consisted of participants providing solutions to six game situations i.e., IF scenarios. The aim of the investigation was not to assess the merits of the solutions posed, but rather examine the wider issue of explicitness, the manner in which information is conveyed and its implications on the RR model.

It was hypothesised that the expert players would provide more relevant information and would do so in a more efficient manner. In discussing this further, the logical starting point is the concept of explicitness and the importance of pertinence of information as opposed to volume. Participants were asked to provide as much information as possible pertaining to the yellow players. This provision was implemented for two reasons; to eliminate prompting from the investigator and to provide a guide for the participants as to what information to convey. Thus, it was explicitly stated prior to the first scenario in each of the two conditions that the yellow team was the main focus.

Results indicate that participants significantly more often referred to yellow players in the attacking scenarios.With regard to group, although a significant difference was not observed at the adjusted alpha level of $p<0.01$, a difference between the groups was discovered at the 0.05 level. This information is relevant as the task is concerned with the actions of the players within the yellow team. This finding suggests that experts provide more pertinent information and it is suggested that the enhanced conceptual understanding is responsible.

A recurrent theme throughout in relation to the ACT-RR model has been an increased understanding of the relative consequences of action. Results in this study are suggestive of this. For example, in the defensive scenario in which the red team's left winger has possession of the ball, the coach's solution to this problem was to create a 2v1 situation in favour of the yellow team with the yellow team's right back engaging the red winger and being supported by the yellow team's wide right midfield player. Even if implemented successfully, there will be consequences of this tactic. One possible outcome of the 2v1 against the wide left player is that he will pass the ball back to the left full back. Based on this, players in the Yellow team have new responsibilities, such the wide right player having to break from the 2v1 situation to close down the full back and the yellow team centre forward having to position himself beside the Red Team's centre half in order to try and prevent a switch of play. In terms of the investigation, if the participants had an appreciation of the relative consequences, they would, therefore, identify and refer to more yellow players and their subsequent game actions and this appears to have been the case.

Another possible reason why more yellow players have been mentioned relates to offering of alternatives. Before discussing this further, a methodological point to be made is that this exemplifies the merits of not basing measures on a definitive answer. It may be that alternates are offered as the participants are unsure of the opposition's intentions and are attempting to cover all eventualities. An example of this occurs in the attacking scenario beginning with the Yellow team's goal kick. The solution postulated by the coach was to exploit a perceived aerial weakness with the Red team's right back. The game plan was for the goalkeeper to play the ball high and long for the Yellow wide left player to beat the right back in the air and develop the player from the initial header. A number of the participants did identify this course of action but often did so after suggesting an alternative; playing the ball short to the Yellow team's centre backs if they split. This can be viewed as a safer option as it is more likely that the ball will be retained whereas playing the ball long has a lower percentage chance of being retained. However, if participants can recall the findings of the match report, and provided it is executed well, the long option is advantageous as it exploits a weakness in a more advanced area of the field which may create a goal scoring opportunity. The overall implication with regard to a score for yellow players is that the Yellow centre backs will be referred to as part of the alternative solution whereas they would not have been mentioned had only one solution been proposed. Thus, the postulation of alternative courses of actions will enhance the yellow player score and, furthermore, this is more likely to occur in attacking clips as there are more options and this is evidenced by the statistically significant difference.

In addition to the difference observed with the yellow team, results indicate that there were statistically significant differences between the elite and non-elite groups relating to references to the players of the red team. This was evidenced with both individual players and team unit measures with, in both cases, the non-elite participants more often citing these players. The task fundamentally concerns the Yellow team but it is not surprising, however, that the red players have been referred to; their actions and abilities are the basis of the match report and dictate the tactical deployment of the yellow team. For example, the Red team right back is likely to be referred to in the defensive scenario in which he has possession of the ball. However, the non-elite players have referred to them significantly more than the elite players and this is worthy of consideration.

It was reported that there was a significant effect for clip with regard to yellow players with more references in the attacking scenarios. Although no significant interaction effect was observed for group and clip type, there does appear to be an effect associated with the non-elite group. In scenarios in which the yellow team is defending, the non-elite group's player score is essentially the same for each of the teams; three Yellow and three Red players. In comparison, in instances when the Yellow team are attacking, the elite players, on average, refer to 4.5 Yellow players and 1.15 Red players.

The results also show a significant effect for clip in relation to the Red team with players from this team being more often cited in the Yellow defensive scenarios. As suggested, reference to red players is by no means unexpected and an example has been provided as to how this may manifest itself in the Yellow defensive scenarios. Thus, this may account for the high number of references to the red players. That being the case, the same would be expected in the Yellow offensive clips with regard to, for example, the Red right back being negligent defensively or the centre back not blocking shots. However, this does not appear to have been as frequent with a mean of 1.15 Red players observed in Yellow attacking scenarios.

It would appear that the non-elite players offer more information on the yellow team in the attacking condition, thus suggesting a possible difficulty in articulating information in the defensive sense. It may be that the lack of higher-order conceptual understanding in non-elite players results in possession of a naïve theory of defending which is simplistic and merely based on stopping the opposition. The elite players have an appreciation that it is possible to dictate to opposition teams through defensive tactics (Tucker, Mellalieu, James & Taylor, 2005). As was outlined in the introductory section, a sophisticated tactical set-up can force the opposition to surrender possession through co-ordinated action. In relation to the implications on the red team players, the guide slide outlined that participants were required to provide as much information as possible and it is plausible that this deficiency in understanding, is offset in the defensive scenarios by referring to the attacking play of the Red team (Ge & Land, 2004), thus inflating the Red player score.

No statistically significant difference was observed and this is somewhat contradictory to the hypothesis as it would have been expected that elite players would have exhibited a superior score. The larger number of red players referred to by the non-elite players may have influenced the score measure as many of the actions and observations may have been provided in relation to the red team's players. Whilst this is a potential weakness with the methodology employed, in a theoretical sense this observation is linked to the postulation that non-elite players have provided somewhat superfluous information in the Yellow team defensive scenarios by providing descriptions of the Red team's attacks.

Results indicate that the elite players articulated information more quickly in comparison with non-elite participants. The main value of this measure relates to its role in calculating explicit score which was calculated by dividing the score by time. This resultant measure was intended to provide an indication of volume of information articulated within the period of time and provide a further insight into explicitness. Based on this measure, results demonstrate a statistically significant difference in favour of the elite players. Given that there is a non-significant difference between the groups pertaining to score, but a significant difference between the groups with regard to time in favour of the elite group, this finding is not surprising (Chi, 2006a). It does suggest, however, that the elite players are more efficient and economical in articulating information. Furthermore, it is plausible to suggest that the experts can offer information more readily and can do so in a more connected fashion. This would be in line with the characteristics displayed in complex problem solving in other domains which suggests that the experts store knowledge in large units that can be accessed rapidly. Furthermore, evidence from medical reasoning studies has found that the superiority of experts emerges, as shown by references to higher-order concepts, when time is constrained (Norman, Eva, Brooks & Hamstra, 2006).

A further point to be made relates to the statistically significant difference in relation to references to the match report. The contents of the match report are central to the investigation as it provides an initial overview of the strengths and weaknesses of the opposition. Just as was done by the coach, these findings should have been used by the participants to formulate a game plan to nullify threats posed or exploit opportunities presented. It is likely, therefore, that the match report was utilised by the participants in some form or another. Thus, the issue with the measure is not that participants are using the findings of the match report *per se*, but rather the need to verbalise that they are using it. In this case, the non-players referred significantly more to the report.

There are two main points emanating from this finding. First of all, in relation to an observation made with the Red players, references to the match report may be indicative of compensating for lack of domain specific knowledge. Thus, in order to conform to the task of providing as much information as possible, non-elite players are referring more often to the findings of the match report. In a closely related point, this is in keeping with findings derived from other complex problem solving tasks; non-experts tend to focus on superficial elements (Rabinowitz & Hogan, 2008), which in this case, can be construed as the information contained with the report.

Drawing all of these observations together, results in this study tend to suggest that the elite players are more adept in providing pertinent and connected information in a more efficient and parsimonious manner in comparison with the non-elite players. This is evidenced by the differences observed in relation to the yellow players and the time and subsequent explicit score measures. Evidence suggests that the non-experts refer more to superfluous and erroneous information as illustrated by results relating to the red players and the match report.

In line with the theory, a feature of RR which can be applied in terms of complex problem solving is that the process of redescription into more explicit forms facilitates the linkage and organisation of previously context-specific, implicitly grasped, responses into a more explicit explanatory framework. This process results in a deeper conceptual understanding of the task and appreciation of the relevance of information. The task in this study is complex in nature or, perhaps more accurately, it can be made complex by the individual if it is related to meaningful underlying concepts. At the recreational level, it is unlikely that such sophisticated tactics are incorporated into matches and only at the elite level would such high level tactics such be evident (Tenga, Holmebb, Ronglana & Bahra, 2010b). Results in this study are suggestive of this with non-elite players exhibiting an inferior level tactical awareness which manifested itself through the proposition of weak strategies for the given situation accompanied by rationale devoid of the key football principles in favour of superficial features.

It was suggested in the overall rationale section that non-expert rationale could be considered as impoverished should it contained predominantly superficial aspects and be based on naïve theory. Given that the concept of IF…THEN…DO...BECAUSE is the manifestation of the reconciliation between the external environment and the internal knowledge structures, a feature of an individual further along the RR continuum, it was suggested that rationale provided by experts should contain more salient theoretical information based on deeper principles of the game and understanding of relative consequences and this appears to be the case.

7.4.1 Summary

In summary, in line with previous research examining complex problem solving, results in this study suggest that elite football players are more adept in conveying pertinent, conceptually underpinned information in an efficient manner with this information being more connected. In contrast, their non-elite counterparts provide information in a less proficient manner which is largely comprised of superficial elements and naïve theory.

Chapter 8: General Discussion

8.1 Summary of Results

This thesis aimed to enhance understanding of the nature of knowledge bases possessed by elite sports performers which underpin perceptual-cognitive and decision making skills. The literature review focused on the practice history of development pathways of elite sport performers. Complex problem solving literature in a number of domains was examined where common features of expert knowledge were identified and contrasted with novice populations. Literature on perceptual-cognitive skill in sport was reviewed and differences between elite and non-elite sport performers were highlighted. An overview was provided of two main theories, ACT and Representational Redescription. Based on the review, a number of unresolved issues were presented.

The expertise approach was cited as an appropriate methodological framework for studying sporting expertise. In line with the theory, methodologies employed were response time paradigms (Studies 1 & 2) and verbal report protocols (Studies 3 & 4). All studies utilised sport-based test stimuli presented on a large screen display. Each investigation involved a comparison of elite and non-elite players. The sports involved in the studies were football and hockey.

Study 1 comprised two separate investigations; a football-based and hockey-based protocol. ACT theory suggests that, as a result of practice, individuals solve problems with increased speed and accuracy. The results indicated that elite players in both sports were quicker and more accurate in their expectation of pass destination when the individual components of speed and accuracy were considered concurrently. This was evidenced by significant differences between elite and non-elite players in the combination measure. Furthermore, it was shown that elite players in both sports were better able to alter their initial expectation should the play evolve in another way. This was evidenced by significant differences between elite and non-elite players in total response accuracy measure. The main finding was that elite players in both sports employ a continual-type processing strategy which allows for the postulation of an early and accurate expectation which can be altered if required. In relation to RR, this is indicative of enhanced conceptual understanding.

Study 2 aimed to understand the extent to which knowledge is domain-specific. The results elicited were inconclusive. Contrary to the RR model, the results indicated that the elite player's knowledge is relatively domain specific. However, subsequent examination of the results did suggest that elements of underlying task strategy may generalise from one sport to another. Findings in this study suggested that while task-specific, higher-order concepts may be explicit in one activity, they do not transfer directly to another. It is suggested that the implications of this study relate to expertise development with an assertion that domain general elements may generalise.

Study 3 consisted of two investigations; a football-based and hockey-based protocol. Significant differences were observed in both investigations in relation to proposed number of alternative courses of action available to a player in possession of the ball. Non-elite football players offered more alternatives than elite players. In hockey, elite players offered more alternatives than non-elite players. Results revealed differences in the way elite players differentiate between alternatives. Results in football showed significant differences between elite and non-elite players in references to topics. Elite players more often referred to Patterns and Future Actions. Non-elite players more often referred to Motion and Space. Further analysis found Future Actions to be the greatest contributor to prediction of group membership. Patterns were also found to contribute to prediction of group membership. Results in hockey showed significant differences between elite and non-elite players in references to topics. Elite players more often referred to Patterns. Non-elite players more often referred to Motion. Further analysis found Patterns to be the greatest contributor to prediction of group membership. Motion was also found to contribute to prediction of group membership. Overall, findings illustrate that elite players differentiate between possible courses of action based on higher-order concepts. Non-elite players differentiate on the basis of superficial elements of the display. These findings are in keeping with the RR model and suggest that decision making in elite and non-elite players is underpinned by different representations.

Study 4 focussed on problem representations of elite and non-elite football players. Results suggested that elite players' problem representations were more pertinent. This was evidenced by the elite players more often referring to the Yellow Team's players which was the main focus of the investigation. Non-elite players more often referred to the Red Team's players. Furthermore, elite players articulated this information in a more efficient manner as shown by the significant difference in the explicit score measure. In line with the RR model, the elite-player problem representations were found to be more sophisticated, relevant, connected and explicit. This indicates that elite players are further along the RR continuum and have a greater conceptual understanding of the task.

8.2 Theoretical Considerations

This thesis focuses on the nature of the knowledge bases possessed by elite footballers which are believed to underpin perceptual-cognitive skill. Of particular relevance was the relationship between implicit procedural and explicit declarative knowledge. The overall theoretical basis for the current work was that there was a co-ordination of two theories, Anderson's ACT theory and Karmiloff-Smith's Representational Redescription (RR) model. The integration provided a framework to account for the both the implicit procedurilisation of skill and the explicitation of declarative knowledge. A potential model of this framework depicting the integration of ACT and RR, the transition from implicit information to explicit knowledge and the characteristics of the representations, is shown in Figure 8.1. The figure shows the continuum from implicit information to explicit information. Rather than a dichotomy, it is suggested that there are levels of explicitness underpinned by different representations and processes. It is suggested that ACT is responsible for the characteristics evidenced at the implicit. This information is then made gradually more explicit through the process of representational redescritpion (RR).

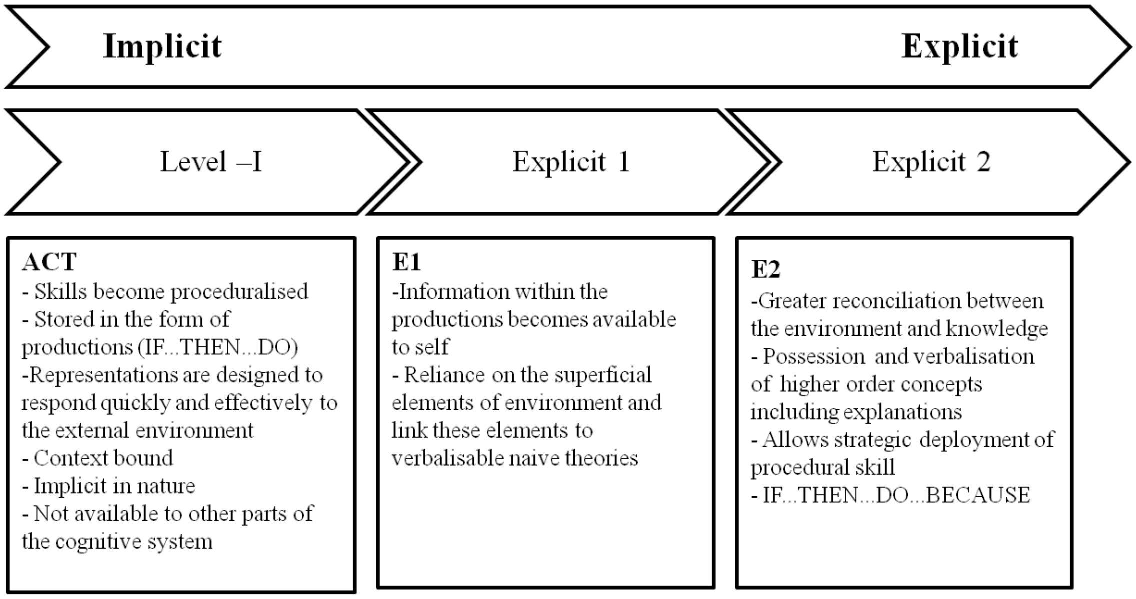


Figure 8.1 – Diagram of a potential model of the proposed ACT-RR framework.

Sport related literature had inferred that there is a relationship between procedural and declarative knowledge (Starkes & Deakin, 1984; Williams & Davids, 1995; Chauvel, Maquestiaux, Ruthruff, Didierjean, Hartley, 2013). Williams and Davids (1995) suggested that the experience of playing and therefore gaining procedural knowledge, facilitated the acquisition of domain specific declarative knowledge. In the unresolved issues section, it was suggested that rather than facilitating the retention of declarative knowledge, this high level conceptual understanding was directly derived from procedural knowledge. The integration between ACT and RR was cited to account for this so that information contained with implicit productions was progressively redescribed into explicit knowledge. This has broader theoretical implications in terms of the effectiveness of an ACT-RR based approach.

Developmental theory suggests that learning proceeds from the specific to general and from action to representation (Thomson, Tolmie, Foot & McLaren, 1996). The benefit of the declarative knowledge being generated in the way the theory suggests is that it is derived from the procedural knowledge already possessed and there is a progression from action to representation through a sequential process. The participants in these studies differed on their skill level (elite v non-elite). As such, the elite players possess a greater level of technical competence. Therefore, elite players have a wider procedural knowledge base on which to build a more extensive explicit network of conceptual understanding. Findings from these investigations suggest that players of differing skill levels are able to verbalise knowledge, however, there are empirical differences in the content and utilisation of this knowledge. Whilst the non-elite players' explicit knowledge is based on naïve theory, akin to earlier stages of the RR continuum, the explicit knowledge of the elite players consists of higher-order concepts which are directly derived from and tied to their procedural knowledge.

The link between the two is important from both a theoretical and practical perspective. For example, as Stratton, Reilly, Williams and Richardson (2004) point out, there is little value in perceiving a 40 yard diagonal pass in football if the player in question does not have the requisite procedural knowledge to successfully execute the skill. Given the skill level of the elite player, it is likely that they will be able to execute the skill. However, a more salient point emanating from the findings is that the elite player will also derive explicit knowledge which guides strategic deployment of that skill. That is, there is a conceptual understanding of when and why that particular skill should be executed in a given instance. For the elite players, this appears to be based on an appreciation of the relative consequences of that action and linkage to the underlying tactical concepts.

The key point is that explicit knowledge which guides strategic deployment of the procedural skill is derived from the implicit procedural knowledge structures. Related to this point, the theoretical integration of ACT and RR was posited as a framework for skilled decision making. One of the main strengths of the ACT model in relation to decision making was that the concept of productions initiated appropriate responses under specific conditions. These productions were also termed IF…THEN...DO statements. However, as has been evidenced, microstates present within a football match may present more than one possible response. Furthermore, whilst the game is comprised of regularly recurring events, the exact conditions within these events are variable. Both of these observations suggest the original framework ACT model is not a suitable framework for decision making skill.

However, findings in this research programme, point toward application of the theory in another way. Investigations undertaken were in contrast to some previous decision making tests which derived a measure of ability based on number of correct decisions made. In doing so, decisions not deemed to be correct are thus classified as wrong. In actuality, decisions made are not an arbitrary right or wrong. Even if the so-called correct decision is not selected in a situation, providing that possession of the ball is retained, it will lead to a new set of circumstances and the passage of play will evolve in a different way. Therefore, the decision cannot be considered to be wrong.

It is more accurate to say that one decision is optimal and others are less optimal. As a result, decisions between possible courses of action can be seen as a hierarchy from optimal to least optimal and not a dichotomous right or wrong. Previous research by McMorris (1986) suggested that decisions in football were made on the basis of a hierarchy. It was postulated that when a player has the ball, the first option they will consider is to attempt to score. If this option is viable, they will deliberate over which technique to use. If there is no opportunity to score, the player will consider other options in a hierarchical fashion such as passing to a player in a goal scoring position and so on. This concept was then refuted by, amongst others, the original author (McMorris, 2004).

The original McMorris (1986) hierarchy is founded on the optimal solution to the overall problem which is to score goals. In this regard, the model proposed has logic but the generic approach proposed does not accurately reflect the demands of the game. Similarly, based on ACT theory, it is not feasible to have a pre-defined, specific response, i.e., an IF…THEN…DO, for every microstate in a football match. There is a more applicable framework based on the findings of this research programme. Football can be viewed as a series of problems to be solved. Thus, before the overall problem can be solved, there are a number of interrelated sub-problems with differing demands which must be negotiated. To solve these problems, it is hypothesised there will be a unique hierarchy for each situation with a number alternatives available ranging from optimal to least optimal.

The use of ACT - RR in this context relates to the concept of IF…THEN…DO…BECAUSE. This approach is not advocating specific condition-action links but is supporting the notion of appropriate responses under specific conditions. There is a distinction based on the way in which the chosen course of action is decided upon. As opposed to a pre-described response for each and every situation, this framework is proposing flexibility whereby only applicable responses are considered with the eventual choice being based on effective rationale. This rationale is considered to be the "BECAUSE" element. There appears to be a difference in the rationale used by experts and non-experts in determining the option at the top of the hierarchy. In terms of RR, there is a progression along a continuum of explicitness with the quality of the explanation being of critical importance. As the RR continuum progresses, the explanations offered shift from physical features to more theoretical based concepts accompanied by an appreciation of the relative consequences. Evidence from Study 3 suggests that the expert rationale for a course of action is based on these latter principles, such as team shape and relative consequences, with non-experts relying on superficial information and naïve theory.

There are further theoretical implications with regard to the development of elite players**.** If, as is the case with the results in these studies, conceptual understanding is an important component of elite performance, then the methods by which this is enhanced are of critical importance. In the RR section, reference was made to studies investigating the effects of tuition on the RR process and progression along the continuum. The nature of intervention was deemed important from a theoretical standpoint, as initially, the process of RR was deemed to be endogenous. Evidence from a number of studies, however, suggested that there is also an exogenous component which facilitated the progression from implicit information to explicit knowledge.

In a theoretical sense, the findings from the current studies show that the elite players have a more explicit conceptual knowledge base. In addition to the wider implicit base hypothesised earlier, a further possible mechanism for this finding is that the development pathway of an elite player will have involved significant input from a high level coach. Exposure to this coaching setting will have enhanced the elite player's implicit procedural knowledge base but, furthermore, it will likely have facilitated a more expedient progression along the RR continuum.

Interventions aimed at training perceptual cognitive skill in sport have focused on enhancing the underlying knowledge structures responsible for these skills. Aside from the methods employed, the more salient element is the instruction method. For example, Smeeton, Williams, Hodges, and Ward (2005) showed that guided discovery techniques were the most effective in improving anticipation in tennis. In RR based interventions studies, findings suggest that adult guidance and peer interaction are amongst the most effective mediums for facilitating the generation of explicit, conceptual knowledge in children's road safety (Tolmie et al., 2005). This is in keeping with findings in sport presented above. Additionally, in a football related study, Grehaigne et al., (2001) suggest a three-pronged approach to developing decision making and tactical skill in football involving action settings, observation settings, and debate-of-idea settings. Interestingly, these suggested settings are comparable with the RR underpinned progression with action, internal thought construction through observation and explicitation of knowledge through language.

It has been suggested by Tolmie et al., (2005) that interventions which focus solely on behaviour and do not incorporate the conceptual component will not have as large a degree of success. Whilst the expert players will have benefited from exposure to a high-level coaching environment, there appear to be specific methods which are more applicable in accelerating this progression from implicit information to explicit knowledge and the resultant creation of higher-order conceptual understanding which drives behaviour.

Whilst the section above has discussed elite and non-elite differences in relation to perceptual-cognitive skills and their underlying knowledge bases, it is important to acknowledge the role of other factors which contribute to these differences in skill classification. Such factors include motivation (Fletcher and Sarkar, 2012), personality (Woodman, Zourbanos, Hardy, Beattie & McQuillan, 2010), confidence (Hays, Thomas, Maynard & Bawden, 2009) and the influence of the coach (Arthur, Hardy & Woodman, 2012). Future researchers could take these factors into account by, for example, administering an accompanying questionnaire to ask participants to rate their level of confidence and motivation in relation to the tasks. Furthermore, the role of the coach could be considered by interviewing participants regarding their perceptions of the coaching environment and its influence on their development.

8.3 Methodological Considerations

This section will outline some specific methodological considerations for each of the four studies. Furthermore, some general methodological considerations will be discussed.

In coding the participants' responses in Study 1, it was apparent that the non-players were less accurate in their initial prediction of pass destination. Non-elite players often selected an option which could be construed as less likely to occur, whereas experts appeared to choose an option which, although incorrect, was more probable. In a pattern recall experiment, Ward and Williams (2003) employed a radial error method for measuring errors. Errors in recalling player positions were calculated using distance between actual position and that provided by the participant. Whilst it is an applicable approach in such matter-of-fact based experiments, conceptualising a measure in the type of protocol employed in Studies 1 and 2 is challenging. The issue is that the location of the player may not be the overriding factor in determining inaccuracy. The player who is adjacent to the player who receives the ball, may not necessarily be a viable option as, for example, they may be heavily marked. The potential resolution is to create a probable hierarchy to the viable options and assign a probability, or likelihood, of this player being the recipient in the situation. This information could then be used to derive a measure of error.

A specific consideration with Study 2 relates to the participants and the incorporation of other tasks. There is a need to empirically verify the nature of transfer of skill between sports (Abernethy, Farrow, Gorman & Mann, 2012). In order to do so, it would be appropriate to have a range of tasks, incorporating a number of different sports, with participants being recruited from these differing activities. It would be appropriate to include sports which do share a degree of similarity but have differing conceptual underpinnings. Examples of such sports would be team-based sports such as football, rugby and basketball. However, this represents a difficult undertaking due to the inherent problems in recruiting high-level sports performers. If it was possible to undertake such a project, it would be useful to collect additional data on the individuals' participation profile during their development. By investigating this issue across sports, a clearer picture may emerge as to whether early specialisation or diversification is advantageous in developing sporting expertise.

Although not measured as part of the investigations in Study 3, there was an observable difference between the quality and level of detail provided by the expert players in comparison with the non-elite players. This was particularly evident in relation to the description of future actions in football. A fruitful avenue to explore would be to implement a grading system to score the answers provided. This would retain fidelity with regard to quantifying verbal utterances but would further elicit elite v non-elite differences as the content of the explanations could be analysed using a qualitative methodology.

Relating to the proposition of a hierarchy for microstates within the game in the theoretical considerations section, it would be appropriate to investigate this directly. This could be achieved using the test materials employed in this investigation. However, as a result of utilising a semi-structured approach in this study, a more rigid framework would need to be implemented. An enhanced method would be to ask participants to firstly rank the options available in each of the scenarios. Once completed, the participants would then be asked to provide reasons for the choices they had identified previously. This approach would allow the verbal references to topics to be directly linked to the alternates proposed and would provide a further degree of context in which the topics were discussed.

The fundamental methodological consideration with Studies 3 and 4 relates to the verbal protocols employed. Some specific methodological considerations from Study 3 were addressed in Study 4. The main issue related to prompting participants to provide more information than they may have been able to readily verbalise. The premise of this approach was to eliminate the issue of prompting and its effects on explicitness. To control for this in Study 4, a guidance slide was shown prior to the first scenario in the offensive and defensive sections of the protocol. The purpose of the slide was to outline the task and identify the information the participants were required to provide. No other guidance or dialogue was provided by the investigator. The ability to further interrogate participants would have been useful in some circumstances in order to elicit reasoning, explanation and conceptual understanding but, in doing so, the initial concern in relation to prompting is once again applicable. A possible solution is to employ a training procedure prior to the protocol which focuses on generic elements on providing verbal reports as opposed to specific examples which may bias resultant data (Eccles, 2012).

One of the main aspects considered when conceptualising Study 4 was that of connected knowledge. Whilst it was shown through other measures, a suggested improvement would be to implement a protocol which measures this directly. A potential approach would be to examine information per proposition, i.e., a statement or series of statements relating to a specific element, as opposed to overall per trial. This would require strict criteria as to what constitutes a proposition and clear understanding of when one proposition ends and new one begins. However, this may offer a fruitful avenue to explore. Likewise, it would be useful to include a means of measuring associations between statements within the proposition such as the order in which the players were referenced. For example, are players mentioned in a logical order with strikers followed by the various midfielders or are players cited in a haphazard, incoherent fashion such as the right back, followed by the striker and then a central defender and midfield player.

In summary of the verbal report protocols in Studies 3 and 4, there appear to be general considerations. Firstly, there is a need to incorporate a qualitative methodology so that the constituent parts of the verbal responses can be examined to further elicit more subtle elite v non-elite differences. Secondly, there appears to be a need to strike a balance between providing prior guidance whilst not prejudicing the subsequent content and explicitness of the participants' responses. Additionally, there is a need to ensure a more structured verbal framework approach so that participants provide the relevant information in relation to the investigation's aims.

In terms of general methodological issues, the participants in this research programme were differentiated on the basis of their current playing status. However, the wider issue of what constitutes an expert is something which has to be considered. Chi (2006b) suggested a proficiency scale which has attempted to define participants as naïve, initiate, apprentice, journeyman, expert and master. A limitation of this approach is that it does not specify number of hours required to obtain each status. However, it is not merely accumulation of practice hours which is the determinant in attaining a certain status, but rather the adaptations which arise from these practice hours (Williams & Ericsson, 2007). Furthermore, there may be variability of ability between the individuals in a category. As such, another potential approach may be to use a generic template, such as the proficiency scale, and then administer a further categorisation procedure based on a within-task criterion. This approach was used by Roca, Williams and Ford (2012). To reiterate a point made in the general methods chapter, a cautionary note would be that regardless of the categorisation and definitions, there is an inherent difficulty in accessing elite performers which must be considered in any methodology.

A further general point relates to the technology employed. Although the protocols employed tasks representative of the real-world activities, lack of access to sophisticated equipment was a limiting factor in the investigation designs. In Studies 1 and 2, a limitation was a lack of sophisticated video editing software. When creating the experimental clips, the software used was Windows Movie Maker. This is a basic editing tool which has a number of limitations (Robin & McNeil, 2013). This software lacks flexibility and sophistication in relation to the addition of titles, specifically their placement. This, therefore, dictated that the "red hash" would appear in a relatively fixed location. Had a more powerful tool been available, it would have been advantageous to place the red hash, or another suitable stimulus, in the vicinity of the player who would play the final pass. This procedure was employed by Roca et al., (2011) who presented a red dot beside the player in possession of the ball. This can be incorporated with an appropriate editing software package. Furthermore, technological advancements allow video sequences to be presented on a life-size screen and this approach is widely utilised (Roca, Ford, McRobert & Williams, 2013).

8.4 Practical Implications

The research undertaken has a number of practical implications. Firstly, one of the core elements of any sport is talent identification and player recruitment. Williams and Reilly (2000) suggested that game intelligence skills are more likely to differentiate between elite and sub-elite athletes than physiological and anthropometric measures. Given their relative importance in identifying talented players, it is surprising that game intelligence factors are often overlooked (Abbott & Collins, 2004) in favour of physiological assessment. A possible reason is that physiological assessment protocols are more readily available and physical characteristics are easier to measure. However, protocols such as those used in this research programme could be utilised to provide a measure of a player's perceptual-cognitive abilities and could enhance any potential talent identification test battery. In a more real-world context, it is important that talent identification personnel are more attuned to game intelligence characteristics when out in the field scouting potential players (Vaeyens, Coelho e Silva, Visscher, Philippaerts & Williams, 2013).

Secondly, a critical component of high level sport is performance analysis. Through this process, a myriad of physical, technical and tactical data on team and individual performance is generated following each match. This is a manual process whereby a skilled individual will code a player's actions and generate data on specific key performance indicators (KPI's). A possible practical application from the studies undertaken would be to supplement the existing performance analysis data with a decision making analysis. At a rudimentary level, this could encompass a simple grading system where players are awarded a score based on decisions made. At the higher levels of the game, this approach could be implemented in a more sophisticated manner. As an example, a widely cited KPI in football is percentage of successful passes. Following a similar premise and incorporating elements of the proposed situational hierarchy, it may be possible to generate a measure of percentage of optimal decisions.

Thirdly, although there are examples of interventions aimed at enhancing facets of perceptual-cognitive skill in sport (Abernethy, Schorer, Jackson, & Hagemann, 2012), there is a wider issue of creating appropriate coaching environments to facilitate the development of elite performers. The issue of instructional method has been raised in relation to RR and perceptual training interventions. Of note, it is suggested that discovery learning models are the most effective means of engendering representational change and facilitating enhanced conceptual understanding. Furthermore, there has to be consideration to the initial stage of the ACT-RR process and the importance of action; specifically the accumulation of procedural knowledge. Ford, Ward, Hodges and Williams (2009) discovered that elite football players who eventually go on to attain professional status engaged in more non-coach led football-specific play such as small-sided games. This trend has also been found in elite Brazilian players (Ford et al., 2012). It has been shown that players who have engaged in more of this type of activity during childhood, possess superior anticipation and decision making skills (Roca, Williams, & Ford, 2012; Williams, Bell-Walker, Ward, & Ford, 2011). It is suggested that this type of activity is more conducive to the development of perceptual cognitive skill as this environment facilitates guided discovery learning (Williams & Hodges, 2005). Furthermore, if explicit high-level conceptual understanding is derived from implicit procedural knowledge as advocated by RR, it is advantageous for the procedural knowledge to be accumulated in an environment which mimics the real-world activity such as football-specific play. In order to facilitate the development of perceptual-cognitive skill in line with the ACT-RR model, coaches should seek to create practice environments which mimic the game itself and facilitate the progression from action to representation through discovery learning.

8.5 Future Research

The work undertaken in this thesis was the first application of the RR model in sport. Furthermore, there was the novel integration of the ACT and RR theories to create the IF...THEN...DO...BECAUSE framework. Given the positive results elicited, these theories and framework can be used as a basis for future investigations. Whilst some potentially fruitful avenues have been discussed in practical and theoretical considerations sections, the following will outline further possible future research directions.

Fundamentally, the RR model is based on the principle of developmental progression. As such, one course of future research is to conduct a quasi-longitudinal project involving elite and non-elite players at different ages. Football is an effective vehicle for investigation of this type as the academy structure affords an opportunity to test players of differing skill levels from age 12 right through to adulthood. This approach would allow the researcher to examine aspects of the RR model in football at various ages. This would lead to the creation of a profile of the behavioural and conceptual characteristics associated with the levels in RR and the developmental phases. Such research could extend the work of Pine and Messer (2003) cited in the RR section.

Linked to the above, the issue of training interventions was raised in the theoretical considerations section. The creation of a representational profile would be integral to the success of any intervention. If the premise of an intervention is to facilitate the development of explicit conceptual knowledge, akin to E3 or E4 representations, then a clear understanding of what constitutes these representations has to be empirically verified. Moreover, for any intervention to be successful, it would be important for the training be to be position specific. Therefore, any future research should seek to create a representational profile for each position which accounts for the varying perceptual-cognitive demands (Williams, Ward, Smeeton & Ward, 2008).

Although the sports involved in this research project were football and hockey, the concepts can be applied in a variety of sports and are not necessarily restricted to team-based sports; the ACT-RR framework and the IF...THEN...DO...BECAUSE concepts can be applied in any sports which involve strategic decision making such as cricket, golf and racquet sports. An integrative example of a research project using this model in tennis would be to ascertain a hierarchy of possible returns to an action within the game, such as cross-court return of serve, and examine postulated responses and accompanying rationale in groups of tennis players of varying ages and abilities.

Furthermore, the general principles of the ACT-RR co-ordination, such as the progression to an explicit knowledge, can be applied within in any sport requiring conceptual understanding. Conducting future research in a variety of sports using this framework will elicit findings on the domain-specific manifestations of the theory as well as more general evidence relating to expert performance. Whilst references to sport thus far have focussed on athlete decision making, a natural extension of this work would be to investigate decision making within match official populations (Weston & Helsen, 2013; Weston, Castagna, Impellizzeri, Bizzini, Williams & Gregson, 2012).

Outwith sport, the RR model was originally conceptualised in developmental psychology with research undertaken with child populations in, for example, language (Critten, Pine & Steffler, 2007) and road safety (Tolmie et al., 1995). The current applications in adult populations represent a new area for future research. In the literature review chapter, findings on adult expertise were cited from a number of domains including physics, mathematics and chess. Given the characteristics of experts evidenced in these studies, it may be possible to consider the ACT-RR model more generally as a theory of expertise in the aforementioned domains and in other areas such as the emergency services (Klein, Calderwood, & Clinton-Cirocco, 2010), medicine (Calder, Forster, Stiell, Carr, Brehaut, Perry, Vaillancourt & Croskerry, 2012) and the military (Ward, Farrow, Harris, Williams, Eccles, & Ericsson, 2008). Drawing on work of Raab and Johnson (2007), an example in a military setting would be to investigate the representations underpinning the first choice options generated by varying ranks of officers within command and control settings.

8.6 General Conclusions

The area of perceptual-cognitive expertise in sport continues to become more prevalent in both an academic and applied sense. Empirical research to date has demonstrated the skills elite athletes possess. It is believed that these skills are attributable to enhanced, task-specific knowledge bases. However, there is a dearth of research examining the underlying mechanisms through which these knowledge bases develop. The current research examined the nature of the knowledge bases in football and hockey through the integration of two theories; ACT and RR. This was the first application of the theory in sport, and the research found that elite players are quicker and more accurate in anticipating pass destination, have a deeper conceptual understanding of the task and use this to guide decision making, provide more pertinent information based on theoretical principles. Finally they appear to have relatively domain specific knowledge. The results overall suggest that there is merit in such an approach in researching the underlying mechanisms of perceptual-cognitive expertise in sport in future research. Furthermore, the principles of the approach have applied connotations which may have a tangible effect on sporting performance.

References

Abernethy, B. (1987). Anticipation in sport: A review. *Physical Education Review,* 10, 5-16.

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., Côté, J. & Baker, J. (2002). Expert decision-making in team sports. *Research Report to the Australian Sports Commission.* Canberra, Australia: Australian Sports Commission.

Abernethy, B., Farrow, D., & Berry, J. (2003). Constraints and issues in the development of a general theory. In J.L. Starkes and K.A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 349-370). Champaign, IL: Human Kinetics.

Abernethy, B., Thomas, K.T. & Thomas, J.T. (1993). Strategies for improving understanding of motor expertise (or mistakes we have made and things we have learned!). In J.L. Starkes and F. Allard (Eds.), *Cognitive Issues in Motor Expertise,*(pp 317-356). Amsterdam: Elsevier Science.

Abernethy, B., Zawi, K., & Jackson, R. C. (2008). Expertise and attunement to kinematic constraints. *Perception*, *37*(6), 931-948.

Abernethy, B., Farrow, D., Gorman, A.D., & Mann, D.L. (2012). Anticipatory behaviour and expert performance. In. N.J. Hodges and A.M. Williams (Eds.), *Skill Acquisition in Sport: Research, Theory and Practice* (2nd ed., pp. 287-305). London: Routledge.

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*(2), 143.

Abbott, A., & Collins, D. (2004). Eliminating the dichotomy between theory and practice in talent identification and development: Considering the role of psychology. *Journal of Sports Sciences, 22*, 395-408.

Alain, C., & Proteau, L. (1980). Decision making in sport. In C.H. Nadeau, W.R. Halliwell, K.M. Newell and G.C. Robers (Eds.), *Psychology of Motor Behavior and Sport* (pp. 465-477). Champaign, IL: Human Kinetics.

Alain, C., & Sarrazin, C. (1990). Study of decision-making in squash competition: a computer simulation approach. *Canadian Journal of Sport Science, 15*(3), 193-200.

Alain, C., Sarrazin, C., & Lacombe, D. (1986). The use of subjective expected values in decision making in sport. In D.M. Landers (Ed.), *Sport and Elite Performers* (pp. 1-6). Champaign, IL: Human Kinetics.

Allard, F., & Burnett, N. (1985). Skill in sport. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *39*(2), 294-312.

Allard, F., & Starkes, J. L. (1991). Motor-skill experts in sports, dance, and other domains. In K.A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp.126-152). New York: Cambridge University Press.

Allard, F., Graham, S. & Paarsalu, M.E. (1980). Perception in sport: Basketball. *Journal of Sport Psychology, 2*, 14-21.

Anderson, J.R. (1983). *The architecture of cognition*. Cambridge, MA. Harvard University Press.

Anderson, J.R. (1993). *The rules of the mind.* Hillsdale, NJ: Erlbaum.

Anderson, J. J. R., & Lebiere, C. J. (Eds.). (1998). *The atomic components of thought*. Psychology Press.

Anolli, L., Antonietti, A., Crisafulli, L., & Cantoia, M. (2001). Accessing source information in analogical problem-solving. *The Quarterly Journal of Experimental Psychology: Section A, 54*(1), 237-261.

Arthur, C. A., Hardy, L., & Woodman, T. (2012). Realising the Olympic dream: Vision, support and challenge. *Reflective Practice*, *13*(3), 399-406.

Auclair, F. (2007). Problem formulation by medical students: An observation study. *BMC Medical Education, 7*, 16-21.

Bar-Eli, M., Plessner, H., & Raab, M. (2011). *Judgment, decision-making and success in sport*. Chichester: Wiley-Blackwell.

Barlow, C.M., Jolley, R.P., White, D.G. & Galbraith, D. (2003). Rigidity in children's drawing and its relation to representational change. *Journal of Experimental Child Psychology*, *86*, 124-152.

Baker, J., & Young, B.W. (in press). 20 years later: Deliberate practice and the development of expertise in sport. *International Review of Sport & Exercise Psychology,7.*

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

Calder, L. A., Forster, A. J., Stiell, I. G., Carr, L. K., Brehaut, J. C., Perry, J. J. & Croskerry, P. (2012). Experiential and rational decision making: a survey to determine how emergency physicians make clinical decisions. *Emergency Medicine Journal*, *29*(10), 811-816.

Carraher, T. N., Carraher, D. W., & Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology*, *3*(1), 21-29.

Chamberlain, C.J. & Coelho, A.J. (1993). The perceptual side of action: Decision-making in sport. In J.L. Starkes an F. Allard (Eds), *Cognitive issues in motor expertise* (pp. 135-157). Amsterdam: Elsevier Science.

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

Chase, W.G., & Simon, H.A. (1973). The mind's eye in chess. In W.G. Chase (Ed.), *Visual information processing* (pp. 215-281). New York: Academic Press.

Chauvel, G., Maquestiaux, F., Ruthruff, E., Didierjean, A., & Hartley, A. A. (2013). Novice motor performance: Better not to verbalize. *Psychonomic Bulletin & Review*, *20*(1), 177-183.

Chi, M.T.H. (2006a). Laboratory methods for assessing experts and novices knowledge. In K.A. Ericsson, N. Charness, P.J. Feltovich, & R.R. Hoffman (Eds.*)*. *The Cambridge Handbook of Expertise and Expert Performance* (pp. 167-184). New York: NY: Cambridge University Press.

Chi, M.T.H. (2006b). Two approaches to the study of experts' characteristics. In K.A. Ericsson, N. Charness, P.J. Feltovich, & R.R. Hoffman (Eds.). *The Cambridge Handbook of Expertise and Expert Performance* (pp. 21-30). New York: NY: Cambridge University Press.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics by experts and novices. *Cognitive Science, 5*, 121-152.

Chi, M.T.H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R.J. Sternberg (Ed.) *Advances in the psychology of human intelligence*. (pp. 7-75). Hillsdale, NJ: Erlbaum.

Coles, M.G.H., Gratton, G., Bashore, T.R., Eriksen, C.W., & Donchin, E. (1985). A psychophysiological investigation of the continuous flow scheme of human information processing. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 529-553.

Côté, J. (1999). The influence of family in the development of talent in sports. *The Sport Psychologist, 13,* 395-417.Côté, J. & Hay, J. (2002). Children's involvement in sport: A developmental perspective. In J.M. Silva & D. Stevens (Eds.*), Psychological foundations of sport* (2nd ed., pp. 484-502). Boston: Merrill.

Côté, J., Baker, J., & Abernethy, B. (2001). Stages of sport participation of expert decision makers in team ball sports. In A. Papaioannou, M. Goudas and Y. Theodakris (Eds.), *In the dawn of the New Millenium: Proceedings of International Society of Sport Psychology* (vol.3, pp.150-152). Thessaloniki, Greece: Christodoulidis Publications.

Côté, J., Baker, J., & Abernethy, B (2007). Practice and play in the development of sport expertise. In R. Eklund & G. Tenenbaum (Eds), *Handbook of Sport Psychology*, (pp. 184-202; 3rd edition). Hoboken, NJ: Wiley.

Coyle, D. (2009). *The talent code*: *Greatness isn't born, it's made.* New York: Bantam Dell.

Critten, S., Pine, K. J., & Messer, D. J. (2012). Revealing children's implicit spelling representations. *British Journal of Developmental Psychology, 31* (2), 198-211.

Critten, S., Pine, K.J., & Steffler, D. (2007). Spelling development in young children: A case of representational redescription? *Journal of Educational Psychology, 99*(1), 207-220.

Davids, K. (2000). Skill acquisition and the theory of deliberate practice: It ain't what you do it's the way that you do it! *International Journal of Sport Psychology, 31*, 461-466.

de Grot, A.D. (1965). Perception and memory versus thought. In B. Kleinmuntz (Ed.), *Problem Solving Research, Methods, and Theory* (pp. 19-50). New York: Wiley.

Del Villar, F.; Iglesias, D.; Moreno, M. P.; Fuentes, J. P., & Cervelló, E. M. (2004). An investigation into procedural knowledge and decision-making: Spanish experienced inexperienced basketball players differences. *Journal of Human Movements Studies*, *46*, 407-420.

Dittrich, W.H. (1999). Seeing biological motion: is there a role for cognitive strategies? In A. Braffort, R. Gherbi, S. Giblet, J. Richardson & D. Teil (Eds), *Gesture-based Communication in Human-Computer Interaction* (pp. 3-22). Berlin, Germany: Springer-Verlag.

Ericsson, K. A. (2006). Protocol analysis and expert thought: Concurrent verbalizations of thinking during experts' performance on representative tasks. In K.A. Ericsson, N. Charness, P.J. Feltovich, & R.R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 223-241). New York: NY: Cambridge University Press.

Ericsson, K.A. & Simon, H.A. (1993). *Protocol analysis: Verbal reports as data.* Cambridge, MA. MIT Press.

Ericsson, K. A., & Smith, J. (1991). Prospects and limits of the empirical study of expertise: An introduction. In K.A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp.1-38). New York: Cambridge University Press.

Ericsson, K. A., & Williams, A. M. (2007). Capturing naturally occurring superior performance in the laboratory: translational research on expert performance. *Journal of Experimental Psychology: Applied*, *13*(3), 115.

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

Eriksen, C.W., Coles, M.G.H., Morris, L.R. & O'Hara, W.P. (1985). An electromyographic examination of response competition. *Bulletin of Psychonomic Society, 23*, 165-168.

Farrow, D. & Raab, M. (2008). Recipe to become an expert in decision making. In D. Farrow, J. Baker and C. MacMahon (Eds.), *Developing elite sports performers: Lessons from theory and practice* (pp. 137-154). New York, NY: Routledge.

Farrow, D., Baker, J. & MacMahon, C. (Eds.) (2013). *Developing elite sports performers: Lessons from theory and practice.* (2nd ed). New York, NY: Routledge.

Fitts, P.M. & Posner, M.I. (1967). *Human performance*. Belmont, CA: Brook/Cole.

Fletcher, D., & Sarkar, M (2012). A grounded theory of psychological resilience in Olympic champions. *Psychology of Sport and Exercise 13*, 669-678.

Ford, P. R., & Williams, A. M. (2012). The developmental activities engaged in by elite youth soccer players who progressed to professional status compared to those who did not. *Psychology of Sport and Exercise*, *13*(3), 349-352.

Ford, P. R., Yates, I., & Williams, A. M. (2010). An analysis of practice activities and instructional behaviours used by youth soccer coaches during practice: Exploring the link between science and application. *Journal of Sports Sciences*, *28*(5), 483-495.

Ford, P.R., Le Gall, F., Carling, C., & Williams, A.M. (2008). A cross-cultural comparison of the participation histories of English and French elite youth soccer players. In T. Reilly, F. Korkusuz, & E. Ergen (Eds.), *Science and Football VI* (pp. 113-117). London: Taylor & Francis.

Ford, P. R., Ward, P., Hodges, N. J., & Williams, A. M. (2009). The role of deliberate practice and play in career progression in sport: the early engagement hypothesis. *High Ability Studies*, *20*(1), 65-75.

Ford, P. R., Carling, C., Garces, M., Marques, M., Miguel, C., Farrant, A., & Williams, A. M. (2012). The developmental activities of elite soccer players aged under-16 years from Brazil, England, France, Ghana, Mexico, Portugal and Sweden. *Journal of Sports Sciences*, *30*(15), 1653-1663.

Franks, I. M., & Miller, G. (1991). Training coaches to observe and remember. *Journal of Sports Sciences*, *9*(3), 285-297.

French, K.E., & McPherson, S.L. (1999). Adaptations in response selection processes used during sport competition with increasing age and expertise. *International Journal of Sport Psychology, 30*, 173-193.

French, K.E., Nevett, M.E., Spurgeon, J.H., Graham, K.C., Rink, J.E., & McPherson, S.L. (1996). Knowledge representation and problem solution in expert and novice youth baseball performance. *Research Quarterly for Exercise and Sport, 66*, 194-201.

Freitas, S., Dias, C., & Fonseca, A. (2013). Elite soccer coaches use of psychological techniques. *International Journal of Psychological Studies*, *5*(3).

Ge, X., & Land, S.M. (2004). A conceptual framework for scaffolding ill-structured problem-solving processes using question prompts and peer interactions. *Educational Technology Research and Development, 52*(2), 5-22.

Gick, M.L. & Holyoak, K.J. (1980). Analogical problem solving. *Cognitive Psychology*, *12* (3), 306-355.

Gil, A., Moreno, M. P., Garcia-Gonzalez, L., Moreno, A., & Del Villar, F. (2012). Analysis of declarative and procedural knowledge in volleyball according to the level of practice and players' age. *Perceptual and Motor Skills*, *115*(2), 632-644.

Gobbo, C., & Chi, M. (1986). How knowledge is structured and used by expert and novice children. *Cognitive development*, *1*(3), 221-237.

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

Gregson, W., Drust, B., Atkinson, G., & Di Salvo, V. (2010). Match-to-match variability of high-speed activities in premier league soccer. *International Journal of Sports Medicine*, *31*(4), 237-42.

Grehaigne, J. F, Godbout, P., & Bouthier, D. (2001). The teaching and learning of decision making in team sports. *Quest 53* (1), 59-76.

Haugaasen, M., & Jordet, G. (2012). Developing football expertise: a football-specific research review. *International Review of Sport & Exercise Psychology, 5, 177-201.*

Hays, K., Thomas, O., Maynard, I., &Bawden, M. (2009). The role of confidence in world-class sport performance. *Journal of Sport Sciences 27* (11) 1185-1199.

Helsen, W. & Pauwels, J.M. (1993). The relationship between expertise and visual information processing in sport. In J. Starkesnand F. Allard (Eds.), *Cognitive issues in motor expertise* (pp. 109-134). Amsterdam: North-Holland.

Helsen, W.F., Starkes, J.L., & Hodges, N.J. (1998). Team sports and the theory of deliberate practice. *Journal of Sport & Exercise Psychology, 20*, 12-34.

Hodges, N.J. & Starkes, J.L. (1996). Wrestling with the nature of expertise: A sport specific test of Ericsson, Krampe and Tesch-Römer's (1993) theory of deliberate practice. *International Journal of Sport Psychology*, *27*, 400-424.

Holyoak, K. J. (1991). Symbolic connectionism: Toward third-generation theories of expertise. *Toward a general theory of expertise: Prospects and limits*, 301.

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory & Cognition*, *15*(4), 332-340.

Howe, C., Tolmie, A., Anderson, A., & Mackenzie, M. (1992). Conceptual knowledge in physics: The role of group interaction in computer-supported teaching. *Learning and Instruction*, *2*(3), 161-183.

Huber, J. (1997). Differences in problem representation and procedural knowledge between elite and nonelite springboard divers. *The Sport Psychologist*, *11*(2): 142-159.

Hughes, M. and Franks, I. (2007). *The essentials of performance analysis: An introduction*. London: Routledge.

Johnson, J. G., & Raab, M. (2003). Take the first: Option-generation and resulting choices. *Organizational Behavior and Human Decision Processes*, *91*(2), 215-229.

Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.

Karmiloff-Smith, A., & Inhelder, B. (1974). If you want to get ahead, get a theory. *Cognition, 3*(3), 195-212.

Keane, M. (1989). Modelling problem solving in Gestalt 'insight'problems. *The Irish Journal of Psychology*, *10*(2), 201-215.

Kioumourtzoglou, E., Michalopoulou, M., Kourtessis, G. T., & Kourtessis, T. (1998). Cognitive abilities supporting expertise in team sports. *Coaching and Sport Science Journal*, *3*, 30-36.

Klein, G., Calderwood, R., & Clinton-Cirocco, A. (2010). Rapid decision making on the fire ground: The original study plus a postscript. *Journal of Cognitive Engineering and Decision Making*, *4*(3), 186-209.

Klein, G., Wolf, S., Militello, L., & Zsambok, C. (1995). Characteristics of skilled option generation in chess. *Organizational Behavior and Human Decision Processes*, *62*(1), 63-69.

Knapp, B. (1963). *Skill in sport: The attainment of proficiency*. London: Routledge.

Larkin, J.H. (1979). Information processing models and science instruction. In J. Lochhead & J. Clement (Eds.). *Cognitive process instruction* (pp. 109-119). Philadelphia: Franklin Institute Press.

Larkin, J.H. (1983). The role of problem representation in physics. In D. Genter & A.L. Stevens (eds.). *Mental models* (pp. 75-98) Hillsdale, N.J: Erlbaum.

Larkin, J.H., McDermott, J., Simon, D.P., & Simon, H.A. (1980). Expert and novice performance in solving physics problems. *Science, 208,* 1335-1342.

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

McMorris, T. (1986). An investigation into the relationship between cognitive style and decision making in soccer. Unpublished Master's thesis, University of New Brunswick, Canada. Cited by McMorris, T. (2004). *Acquisition and performance of sports skills.* Chichester: John Wiley and Sons.

McMorris, T. (1997). Performance of soccer players on tests of field dependence/ independence and soccer-specific decision-making tests. *Perceptual and Motor Skills 85*, 467–476.

McMorris, T. (2004). *Acquisition and performance of sports skills.* Chichester: John Wiley & Sons.

McMorris, T., & Graydon, J. (1996). The effect of exercise on the decision-making performance of experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport, 67*(1), 109-114.

McPherson, S.L. (1993a). Knowledge representation and decision-making in sport. In J.L. Starkes and F. Allard (Eds), *Cognitive Issues in Motor Expertise* (pp.159-188). Amsterdam: Elsevier Science.

McPherson, S. L. (1993b). The influence of player experience on problem-solving during batting preparation in baseball. *Journal of Sport & Exercise Psychology 15*(3), 304-325.

McPherson, S. L. (1999). Expert-novice differences in performance skills and problem representations of youth and adults during tennis competition. *Research Quarterly For Exercise and Sport 70* (3), 233-251.

McPherson, S. L., & Thomas, J. R. (1989). Relation of knowledge and performance in boys' tennis: Age and expertise. *Journal of Experimental Child Psychology*, *48*(2), 190-211.

McPherson, S. L., & Kernodle, M. W. (2003). Tactics, the neglected attribute of expertise: Problem representations and performance skills in tennis. In J.L. Starkes and K.A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 137-167).Champaign, IL: Human Kinetics.

McPherson, S. L., & Kernodle, M. (2007). Mapping two new points on the tennis expertise continuum: Tactical skills of adult advanced beginners and entry-level professionals during competition. *Journal of Sports Sciences*, *25*(8), 945-959.

McPherson, S. L., & MacMahon, C. (2008). How baseball players prepare to bat: Tactical knowledge as a mediator of expert performance in baseball. *Journal of Sport and Exercise Psychology, 30,* 755-778.

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.

Messer, D.J., Pine, K.J., & Butler, C. (2008). Children’s behavior and cognitions across different balance tasks. *Learning and Instruction, 18,* 42-53.

Mori, S., Ohtani, Y., & Imanaka, K. (2002). Reaction times and anticipatory skills of karate athletes. *Human Movement Science*, *21*(2), 213-230.

Muir, T. A., Beswick, K., & Williamson, J. C. (2013). Approaches to problem solving: Developing an understanding of naïve, routine and sophisticated problem solving behaviours. In S.Helie (Ed.), *The Psychology of Problem Solving: An Interdisciplinary Approach*. (pp. 85-100). New York, Nova Science.

Müller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *The Quarterly Journal of Experimental Psychology*, *59*(12), 2162-2186.

Norman, G., Eva, K., Brooks, L., & Hamstra, S. (2006). Expertise in medicine and surgery. In K.A. Ericsson, N. Charness, P.J. Feltovich, & R.R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp.339-353). New York: NY: Cambridge University Press.

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.

Parker, S.G. (1989). Organisation of knowledge in ice hockey experts. Unpublished master's thesis, University of New Brunswick (cited in Allard and Starkes, 1991).

Patel, V. L., & Arocha, J. F. (2001). The nature of constraints on collaborative decision making in health care settings. In E. Salas & G.A., Klein (Eds.), *Linking Expertise and Naturalistic Decision Making.* New Jersey, Lawrence Erlbaum Associates, 383-405.

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

Pine, K.J., & Messer, D.J. (1998). Group collaboration effects on the explicitness of children's knowledge. *Cognitive Development*, *13* (1), 109-126.

Pine, K.J., & Messer, D.J. (1999). What children do and what children know: looking beyond success using Karmiloff–Smith's RR framework. *New Ideas in Psychology*, *17*(1), 17-30.

Pine, K.J., & Messer, D.J. (2000). The effect of explaining another's actions on children's implicit theories of balance. *Cognition and Instruction, 18*(1), 37-54.

Pine, K.J. & Messer, D.J. (2003). The development of representations as children learn about balancing. *British Journal of Developmental Psychology, 21*, 285-301.

Pine, K. J., Lufkin, N., & Messer, D.J. (2004). More gestures than answers: children learning about balance. *Developmental Psychology*, *40*(6), 1059.

Pine, K.J., Messer, D.J., & Godfrey, K. (1999). The teachability of children with naïve theories: An exploration of the effects of two teaching methods. *British Journal of Educational Psychology, 69*, 201-211.

Raab, M. (2002). T-ECHO: Model of decision making to explain behaviour in experiments and simulations under time pressure. *Psychology of Sport and Exercise*, *3*(2), 151-171.

Raab, M., & Johnson, J. G. (2007). Expertise-based differences in search and option-generation strategies. *Journal of Experimental Psychology: Applied*, *13*(3), 158.

Rabinowitz, M., & Goldberg, N. (1995). Evaluating the structure-process hypothesis. In: F. Weinert, & W.Schneider, *Memory performance and competencies: Issues in growth and development* (pp. 225-242). Hillsdale, NJ: Lawrence Erlbaum

Rabinowitz, M., & Hogan, T.M. (2008). Experience and problem representation in statistics. *American Journal of Psychology, 121*(5), 395-407.

Stratton, G., Reilly, T., Richardson, D., Stratton, G., & Williams, A. M. (2004). *Youth soccer: From science to performance*. London: Routledge.

Robin, B., & McNeil, S. (2013, March). The Evolution of Digital Storytelling Technologies: From PCs to iPads and e-Books. In *Society for Information Technology & Teacher Education International Conference* (Vol. 2013, No. 1, pp. 1712-1720).

Roca, A., Williams, A. M., & Ford, P. R. (2012). Developmental activities and the acquisition of superior anticipation and decision making in soccer players. *Journal of Sports Sciences*, *30*(15), 1643-1652.

Roca, A., Ford, P.R., McRobert, A.P., & Williams, A.M. (2011). Identifying the processes underpinning anticipation and decision-making in a dynamic time-constrained task. *Cognitive Processing*, *12* (3), 301-310.

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

Ross, B.H., & Murphy, G.L. (1999). Food for thought; cross classification and category organisation in a complex real-world domain. *Cognitive Psychology*, *38*, 495-553.

Savelsbergh, G.J.P., Williams, A.M., Van der Kamp, J. & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sport Sciences*, *20*, 279-287.

Savelsbergh, G.J.P., Williams, A.M., Van der Kamp, J. & Ward, P. (2005). Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics*, *48*, 11-14, 15, 1686-1697.

Schack, T., & Mechsner, F. (2006). Representation of motor skills in human longterm memory. *Neuroscience Letters*, 391, 77-81.

Schoenfeld, A.H., & Herrmann, D.J. (1982). Problem perception and knowledge structure in expert and novice mathematical problem solvers. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *8*(5), 484-494.

Schraagen, J.M. (1993). How experts solve a novel problem in experimental design. *Cognitive Science*, *17*(2), 285-309.

Shafto, P., & Coley, J. D. (2003). Development of categorization and reasoning in the natural world: Novices to experts, naïve similarity to ecological knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(4), 641.

Simon, H.A, & Chase, W.G. (1973). Skill in chess. *American Scientist, 61*, 394-403.

Simon, D.P. & Simon, H.A. (1978). Individual differences in solving physics problems. In R.S. Siegler (Ed.), *Children's Thinking: what develops?* (pp. 325-48). Hillsdale, NJ: Lawrence Erlbaum.

Smeeton, N., Ward, P. & Williams, A.M. (2004). Transfer of perceptual skill in sport. *Journal of Sports Science*, *19*, 3-9.

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.

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

Starkes, J.L. & Ericsson, K.A. (Eds.) (2003). *Expert performance in sports: Advances in research on sport expertise.* Champaign, IL: Human Kinetics.

Starkes, J.L., Deakin, J.M., Allard, F., Hodges, N.J., & Hayes, A. (1996). Deliberate practice in sports: What is it anyway? In K.A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts, sciences, sports and games*, (pp.81-106). Mahwah, NJ: Erlbaum.

Sternberg, R. J. (1995). Expertise in complex problem solving: A comparison of alternative conceptions. *Complex problem solving: The European perspective*, 295-321.

Swann, C., Moran, A., & Piggot, D. (under review). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport & Exercise*.

Syed, M. (2010). *Bounce: The myth of talent and the power of practice.* London: Fourth Estate.

Tenenbaum, G. (Ed.). (1999). The development of expertise in sport: Nature and nurture [Special Issue]. *International Journal of Sport Psychology, 2*.

Tenenbaum, G. (2003). Expert athletes: An integrated approach to decision making. In J.L. Starkes and K.A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 191-218). Champaign, IL: Human Kinetics.

Tenenbaum, G., Sar-El, T., & Bar-Eli, M. (2000). Anticipation of ball location in low and high-skill performers: a developmental perspective. *Psychology of Sport and Exercise*, *1*(2), 117-128.

Tenga, A., Holme, I., Ronglan, L. T., & Bahr, R. (2010a). Effect of playing tactics on goal scoring in Norwegian professional soccer. *Journal of Sports Sciences*, *28*(3), 237-244.

Tenga, A., Holme, I., Ronglan, L. T., & Bahr, R. (2010b). Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. *Journal of Sports Sciences*, *28*(3), 245-255.

Thomson, J., Tolmie, A., Foot, H. C., & McLaren, B. (1996). *Child Development and the aims of road safety education*. Report, Department of Transport.

Thomson, J.A., Tolmie, A.K., Foot, H.C., Sarvary, P.A., Whelan, K.M., & Morrison,S. (2005). Influence of virtual reality training on the roadside crossing judgements of child pedestrians. *Journal of Experimental Psychology: Applied, 11* (3), 175-186.

Tolmie, A., Thomson, J. A., Foot, H. C., Whelan, K., Morrison, S., & McLaren, B. (2005). The effects of adult guidance and peer discussion on the development of children's representations: Evidence from the training of pedestrian skills. *British Journal of Psychology*, *96*(2), 181-204.

Tucker, W., Mellalieu, S. D., James, N., & Taylor, J. B. (2005). Game location effects in professional soccer: A case study. *International Journal of Performance Analysis in Sport, 5*(2), 23-35.

Vaeyens,R., Coelho e Silva,M., Visscher, C., Philippaerts, R.M., & Williams, A.M. (2013). Identifying young players. In A.M. Williams (Ed.), *Science and soccer: Developing elite performers* (pp.289-306). London: Routledge.

Vaeyens, R., Lenoir, M., Williams, A.M., Mazyn, L. and Phillippaerts, R.M. (2007). The effects of task constraints on visual search behaviour and decision-making skill in youth soccer players. *Journal of Sport & Exercise Psychology, 29*, 147-169.

Voutsina, C. (2012). A micro-developmental approach to studying young children's problem solving behavior in addition. *The Journal of Mathematical Behavior*, *31*(3), 366-381.

Voustina, C. & Jones, K. (2000). Changes in young children's strategies when solving addition tasks. Proceedings of the British Society for Research into Learning Mathematics 20, 3, 97-102.

Wadden, K. P., Borich, M. R., & Boyd, L. A. (2012). Motor skill learning and its neurophysiology. In. N.J. Hodges and A.M. Williams (Eds)., *Skill Acquisition in Sport: Research, Theory and Practice* (2^{nd} ed., pp 247-266). London: Routledge.

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

Ward, P., Hodges, N.J., Williams, A.M. and Starkes, J.L. (2004). Deliberate practice and expert performance: defining the path to excellence. In A.M. Williams & N.J.

Hodges (Eds), *Skill acquisition in sport: research theory and practice* (pp.231-258). London: Routledge.

Ward, P., Hodges, N.J., Starkes, J.L. & Williams, A.M. (2007). The road to excellence: deliberate practice and the development of expertise. *High Ability Studies, 18* (2) 119-153.

Ward, P., Farrow, D., Harris, K. R., Williams, A. M., Eccles, D. W., & Ericsson, K. A. (2008). Training perceptual-cognitive skills: Can sport psychology research inform military decision training? *Military Psychology*, *20*(S1), S71.

Weston, M., & Helsen, W. (2013). Match Officials. In A.M. Williams (Ed.), *Science and soccer: Developing elite performers* (pp.271-286). London: Routledge.

Weston, M., Castagna, C., Impellizzeri, F. M., Bizzini, M., Williams, A. M., & Gregson, W. (2012). Science and medicine applied to soccer refereeing. *Sports Medicine*, *42*(7), 615-631.

Williams, A.M. & Davids, K. (1995). Declarative knowledge in sport: A by-product of experience or a characteristic of expertise? *Journal of Sport & Exercise Psychology*, 17, 259-275.

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

Williams, A.M. & Ericsson, K.A. (2005). Some considerations when applying the expert performance approach in sport. *Human Movement Science, 24*, 283-307.

Williams, A. M., & Ericsson, K. A. (2008). From the guest editors: How do experts learn? *Journal of Sport & Exercise Psychology, 30*, 653-662.

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. & Ford, P.R. (2013). ‘Game intelligence’: anticipation and decision making. In A.M. Williams (Ed.), *Science and soccer: Developing elite performers* (pp. 105-121). London: Routledge.

Williams, A.M., & Grant, A. (1999). Training perceptual skill in sport. *International Journal of Sport Psychology, 30*, 194-220.

Williams, A. M., & Hodges, N. J. (2005). Practice, instruction and skill acquisition in soccer: Challenging tradition. *Journal of Sports Sciences*, *23*(6), 637-650.

Williams, A.M., & North, J.S. (2009). Identifying the minimal essential information underlying pattern recognition. In D. Arajuho, H. Ripoll, & M. Raab (Eds), *Perspectives in cognition and action* (pp. 220-249). Champaign, IL: Human Kinetics.

Williams, A.M. & Reilly, T. (2000). Talent identification and development in soccer. Journal of Sports Sciences, 18 (9), 657-667.

Williams, A. M., Bell-Walker, J., Ward, P., & Ford, P. R. (2012). Perceptual-cognitive expertise, practice history profiles and recall performance in soccer. *British Journal of Psychology*, *103*(3), 393-411.

Williams, A.M., Davids, K., Burwitz, L., & Williams, J.G. (1993). Cognitive knowledge and soccer performance. *Perceptual and Motor Skills, 76,* 579-593.

Williams, A. M., Hodges, N. J., North, J. S., & Barton, G. (2006). Perceiving patterns of play in dynamic sport tasks: Investigating the essential information underlying skilled performance. *Perception*, *35*(3), 317.

Williams, A. M., Ward, P., Smeeton, N. J., & Ward, J. (2008). Task-specificity, role, and anticipation skill in soccer. *Research Quarterly for Exercise and Sport*, *79*(3), 428-433.

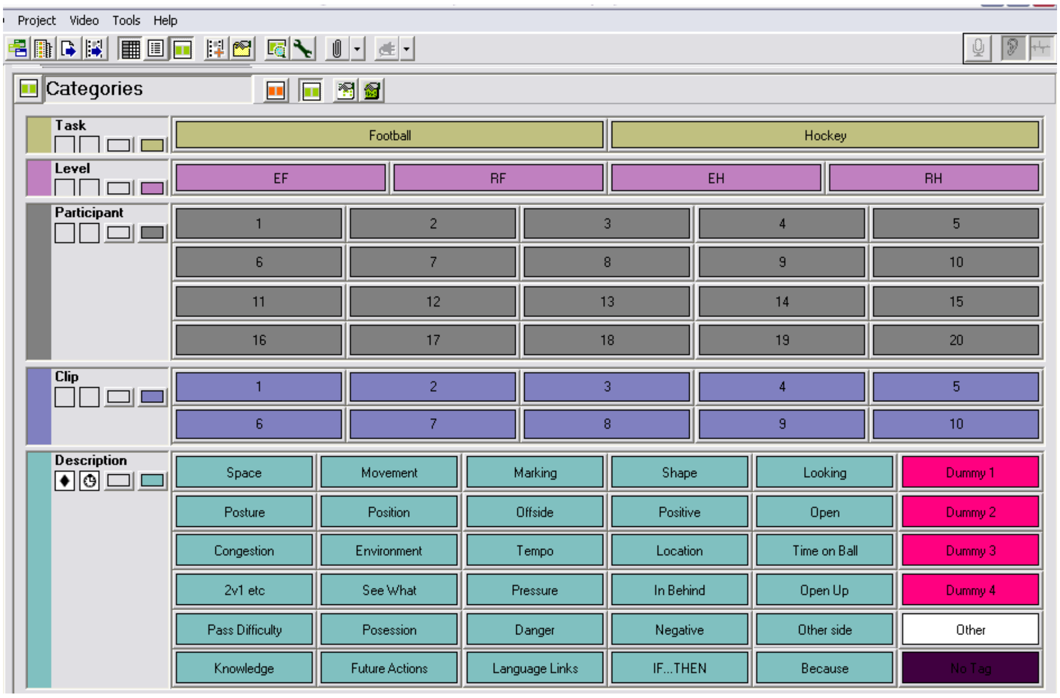
Woodman, T., Zourbanos, N., Hardy, L., Beattie, S., & McQuillan, A. (2010). Do performance strategies moderate the relationship between personality and training behaviours? An exploratory study. *Journal of Applied Sport Psychology*, *22*, 183-197.

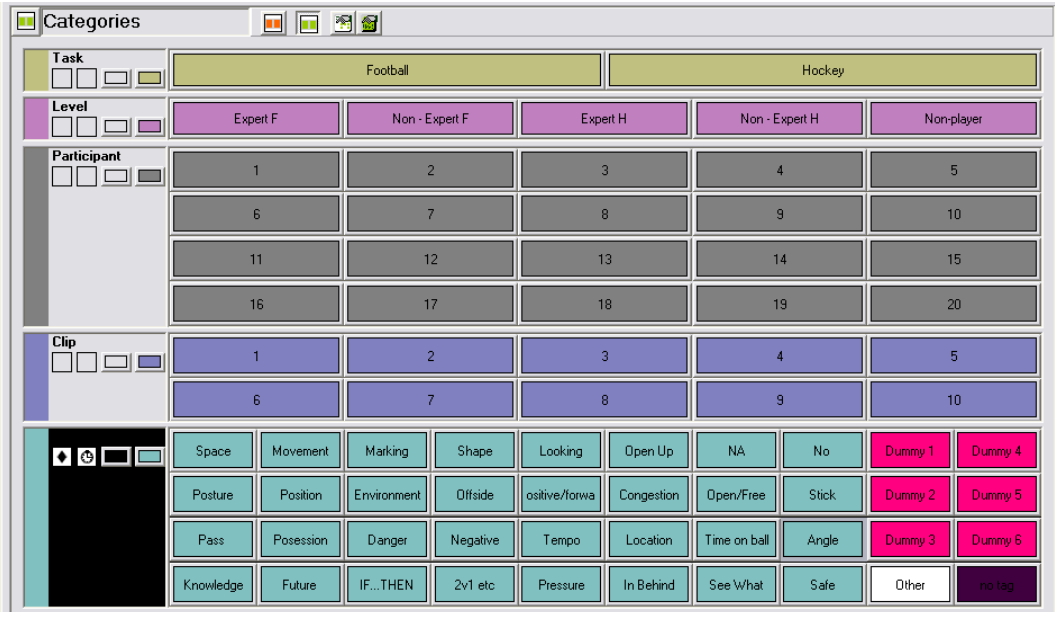
Yarlas, A.S., & Sloutsky, V.M. (2000). Problem representation in experts and novices: Part 1. Differences in the content of representation. In L.R.Gleitman & A.K. Joshi (Eds.), *Proceedings of the 22nd Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Erlbaum.

Appendices

Appendix A- Focus X2 Category Set used in Studies 1 and 2

Appendix B – Focus X2 Category Sets used in Study 3





Appendix C – Match Report and Game Plan from Study 4

Red Team Strengths

- Goalkeeper was a strength as he made some great saves, his distribution of the ball was excellent, setting up the 1st goal
- The pace of the wide players was a strength of the Red team, Left Midfield player and both the Right Back and Right Midfield Player
- Centre Forward was a threat both in the air and on the ground
- Had an advantage at set pieces due to being a big team

Red Team Weaknesses

- The space down their right side in the first half was a weakness, Right Back was exposed due to lack of cover and also due to him pushing forward so much
- They lost 2 goals with shots from outside the box, the Central Defenders did not come out to block the shots

Following on from the match report, participants were given the basic elements of the game plan pertaining to formation. The information provided is as follows:

- The Red Team will play a 4-4-2 formation
- Yellow United will play 4-3-3 when they have the ball
- Yellow United will play 4-5-1 when they do not have the ball

The following information, detailing the strategies to be employed, was included in the original game plan, but was not given to the participants:

- To stop the threat of the pace that Red Team have in the wide areas
- To stop crosses going into our box
- To double up in wide areas with our wide men working back to help our Full Backs
- When the Red Team Central Defenders have the ball, we shape up so they play straight passes through the centre of pitch
- To use our extra man in the centre of midfield to pass the ball through the Red Team
- Our Goalkeeper kicks the ball onto our wide left player who will beat the Right Backs in the air and will start an attack on the Red Team goal
- To shoot from long range as the Central Defenders of Red Team F.C. did not come out to block shots
- Due to the Red Team Right Back going forward so much we would want to use the space in the right back area.
- To create 1v1 situations against Red Team right back as he was not the best defender

Appendix D – Category Set used in Study 4