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COGNITION IN ORIENTEERING

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SUMMARY

Cognition in Orienteering.

Orienteering has received little research interest within psychology. Therefore, the objectives of this thesis were to identify constraints inherent in orienteering, and adaptations to constraints by experienced orienteers that were responsible for performance increases. Three studies were conducted to meet these objectives. In the first study, 17 elite orienteers were interviewed and a grounded theory of expert cognition in orienteering was developed. Managing attention to the map, environment, and travel, was identified as a fundamental constraint in orienteering. Results revealed adaptations by experts to this constraint, characterised by cognitive skills such as planning. The second study explored the relationship between orienteering experience and the allocation of attention to the map, environment, and travel. While orienteering, 20 more and 20 less experienced orienteers wore a video camera and verbalised what they were attending to (map, environment or travel) at any given time. Films were coded at each point in time in terms of what the participant was attending to and whether they were moving or stationary. Experienced orienteers were faster than less experienced orienteers, and better at attending to the map without stopping. Planning was one skill proposed to explain these differences. The final study investigated the use of two planning heuristics reported in the first study: attending to the start first and planning forward to the control, and attending to the control first and planning backwards to the start. Two process tracing methods were employed while 20 experts and 20 novices planned orienteering legs. Orienteers were also interviewed about heuristic use. Results indicated that experts attended to the control, and novices to the start, first when planning. There was some evidence that novices worked forwards, and experts worked backwards when planning. The results of the thesis have implications for expertise research, and skill acquisition within orienteering.

CHAPTER 1

GENERAL INTRODUCTION

Objectives of the Research Programme.

Sports that place both high physical and cognitive demands on the performer are intuitively attractive to sport psychology researchers. Orienteering is such a sport, as exemplified by the British Orienteering Federation (1999) promotional literature: Can you read a map while running over rough terrain as fast as you can, at the same time making route choice decisions and checking the landscape for features without getting lost or falling over? However, there is currently little or no empirical research into orienteering from a psychological perspective although, in common with other sports, there is a substantial amount of research into orienteering from a physiological perspective (e.g., Jensen, Johansen, & Karkkainen, 1999). Therefore, the first objective of the research programme was to explore the constraints of the task of orienteering from a psychological perspective, and the problems these constraints impose on the performer. An understanding of these constraints and problems might have implications for a general understanding of problem solving and navigation in real world tasks. The second objective of the research programme was to identify any adaptations by experienced orienteers to the constraints of the task that appear to reduce the problems imposed by these constraints, and, in turn, account for performance increases. An understanding of these adaptations might have implications for an understanding of skill acquisition within and beyond the sport of orienteering.

Introduction to the sport of orienteering.

Currently, orienteering is a sport with 1 million participants in 58 countries around the World (International Orienteering Federation, 2000) and is a recognised Olympic sport. In orienteering, winning is achieved by being the fastest individual to navigate through points, known as controls, in the environment. The order in which the controls are visited is specified but the route taken to each control is decided by the orienteer. Typically, each control is a coloured flag sized approximately 15 by 15 cm and is suspended from a cane driven into the ground. A manual or electronic punch is associated with each flag and must be used to register that the orienteer has visited the control. The distance from one control to the next is known as a leg. Typically, for an elite adult performer, an orienteering course comprises 20 to 25 legs over 10 to 15 kilometres.

Controls are symbolised by circles printed on a topographical map that is presented only seconds before the race begins and is used, with a compass, as a source of information during the race. Typically, orienteering maps range in scale from 1:5,000 to 1:15,000 and, like Ordnance Survey maps, contain the following information: cultural features, such as buildings and paths; natural features, such as boulders, cliffs and streams; and the shape of the land, expressed by contours lines that join points of equal height and are usually marked at five metre intervals.

However, there are various differences between an orienteering map and an Ordnance Survey map. First, an orienteering map contains extra information concerning ground level vegetation: different colours symbolise categories of vegetation from orange, denoting open land, to dark green, denoting impenetrable forest. These colours are often labelled as indicators of runnability , a term used to describe the influence of the vegetation in a given area on the speed of travel through that area. Second, skilled orienteering cartographers will emphasise, on the map, the shape or size of certain environmental features during the cartographic process to facilitate navigation in the actual environment (Hale, 1997; Peel Land Surveys, personal communication, August 22nd, 2000). For example, distinctive shapes that occur in the landscape may be symbolised by emphasising bends in contour lines, and, in areas that are rich in features, only specifically selected features may be included as symbols on the map, such as large boulders. Third, orienteering maps are aligned to magnetic north to facilitate the use of a compass. Finally, in addition to the control circle, orienteering maps are accompanied by a control description list that specifies the exact description of each control point, for example, control 12 is on cliff, south end . No other equipment that facilitates navigation is permitted. Orienteering events are typically held on forest, park, moor, or fell land.

Introduction to the review sections.

The following review sections begin with a review of the few scientific journal and book articles that are concerned with psychological investigations of orienteering. Subsequently, limitations of the current literature on orienteering are highlighted, and suggestions of how to overcome these limitations are proposed. This is then followed by a brief overview of other areas of research that might be related to any investigation of orienteering. First, there is a discussion of paradigmatic issues, and the adoption of the information processing conceptual framework during the thesis. Second, there is an overview of research on the origins of skill, and a discussion of the adoption of an adaptations approach to skill acquisition during the thesis. Third, an overview is provided of the findings of research into skill acquisition and expertise. Fourth, there is a description of each major theory of skill acquisition and expertise. Fifth, the current understanding of navigation and wayfinding is discussed. Finally, there is an overview of the current understanding of problem solving.

Review of psychological research into orienteering.

A search of the major research databases available via the Internet reveals that there exist only six studies within peer-reviewed academic journals and book chapters that are concerned specifically with psychological aspects of orienteering. The findings of these studies are reviewed here.

Gal-Or, Tenenbaum, and Shimrony (1986) conducted the earliest study involving orienteering. These authors explored the use of cognitive-behavioural strategies, competition-related thoughts, and level of state anxiety within three groups of orienteers who competed in World class competitions in 1983: a top class group, an intermediate group, and a group with unknown international qualifications . Questionnaires with Likert rating scales were completed at different times during competition. They found that, prior to competition, the top class group had higher expectations of success than the group with unknown international qualifications. The top class group also used more self-regulatory strategies (such as self-talk), perceived they possessed more control over fears, looked more for solutions to possible difficulties, and perceived themselves more as winners, than the other two groups. There were no significant differences in strategy use between groups during competition but the greatest ratings of strategy use in all groups pertained to the use of mental imagery and self-talk. Approximately 70% of competition-related thoughts were rated by the orienteers as allocated to present actions with approximately 10% allocated to the past and approximately 20% to the future. However, there were no significant differences between groups on this variable. Perceived state anxiety increased in all groups as competition neared and was highest one hour before competition. The top class group perceived lower levels of state anxiety than the other two groups in the final two stages leading up to competition (while changing and warming up).

Hancock and McNaughton (1986) followed this first attempt at understanding cognitive processes in orienteering by investigating the effects of fatigue on visual information processing in a sample of experienced orienteers. The authors used treadmill running protocols that caused the orienteers to run at an intensity level above that of their anaerobic threshold, while requiring them to undertake contrived tests of various components of visual information processing, such as map interpretation and focus of attention. Results revealed a significantly lower composite test score of visual information processing in the fatigue condition when compared to a control (rest) condition.

Seiler (1990) also investigated cognitive processes in orienteering. In contrast to the study by Gal-Or et al., Seiler s objective was to identify domain-specific decision-making strategies rather than performance strategies used generally in sports (cf., Thomas, Murphy, & Hardy, 1999). Seiler investigated decision strategies during route choice in orienteering using 44 elite and junior elite orienteers. Sections of an orienteering map were exposed to one group of the orienteers using a tachistoscope for 0.2 s and the orienteers were asked to plan routes. After each presentation, the orienteers verbally and graphically described the information they perceived to be important for route choice, without being able to refer back to the map. Another group of the orienteers was exposed to the same map sections and was asked to draw in their chosen route on the map. Both groups were then interviewed about route choice. Finally, all the orienteers ran the previously viewed course under competitive conditions and were subsequently required to draw their routes on the map and complete questionnaires concerning their decision-making strategies.

The results from both the laboratory tests were interpreted as suggesting that contour lines, open ground, and paths on the map provided the most important information for route choice. Some orienteers did not execute the route they had chosen in the laboratory when in the field. This result was interpreted as indicating that route choice decisions were influenced by more information than was available from the map. Data from the interviews and questionnaires were interpreted as suggesting that the orienteer reduces physical and/or technical expenses (p. 40) by using information such as paths when planning routes.

This is understandable given the effects of fatigue on visual information processing in orienteers found by Hancock and McNaughton (1986). Features such as paths are stated to provide a hand rail for orienteers to follow so that expenses are reduced. The questionnaire from the orienteer in the study who was fastest around the orienteering course was analysed separately in order to ascertain detailed information about a successful route choice. Based on these results, it was suggested that the avoidance of hindrances, such as obstacles in the terrain or dense forest, was a more important factor in route choice than maintaining a high running speed. Other factors included control difficulty , whether a control would be difficult to locate, and runnability , the effect of underfoot vegetation on running speed.

Omodei and McLennan (1994) attempted to improve on methods of understanding cognitive processes in orienteering by investigating the efficacy of using a head mounted video camera to promote the recall of performance-related information by orienteers after competition. Given that Seiler (1990) had suggested that decision-making in orienteering might be affected not only by map information but by environmental information, the use of equipment that might facilitate the investigation of cognitive processes in orienteering in a field setting might prove worthwhile. To this end, Omedei and McLennan (1994) hypothesised that performance recall would be enhanced by reviewing a video of performance before a post-performance interview (video recall condition) when compared to a standard post-performance interview (free recall condition). The data from the recall interview were analysed quantitatively by contrasting the quantity of information elicited in the free recall and video recall conditions: the latter condition elicited between two and four times the information of the former condition for each participant. The data were also analysed qualitatively. The results were interpreted as suggesting that the video recall condition facilitated the recall of more experiences, and experiences more directly related to orienteering errors, than did the free recall condition. Also, the video condition facilitated greater experiential recall and, in turn, greater awareness of distractions and errors.

Alongside the study by Seiler (1990), a study by Whitaker and Cuqlock-Knopp (1995) is one of the two reviewed here whose objective was the various constraints inherent in off-road navigation, and the adaptations of navigators to those constraints. Whitaker and Cuqlock-Knopp conducted interviews with a sample of 16 participants that comprised military scouts and civilian orienteers in an attempt to develop a model that specified the relevant information used in off-road navigation. Qualitative analysis of the interviews revealed that various visual cues were used to navigate. These were man-made, water and vegetation features, and terrain contours. Problem-solving strategies included prediction of the terrain, recovery (relocation of one s position after getting lost), catching features (using a specific feature to prevent the navigator from going too far in the terrain), and aiming off. Aiming off involved navigating to a location on a large, and hence obvious, linear feature that was near to the actual desired location. The linear feature could then be used as a hand rail to guide the navigator towards the desired location, and thus reduce the possibility for error. Seiler also reported the use of linear features in navigation and that their function was effectively that of a hand rail that reduced the demands of the task on the performer. Whitaker and Cuqlock-Knopp also identified navigational skills. These included choosing a route based on the amount of climb, distance, risk of exposure to enemy fire, and a general assessment of danger. Other navigational skills included location detection (a comparison of the terrain and the map), orientation, and the ability to follow a chosen route. Seiler had identified similar factors in route choice, such as avoiding dense forest. Whitaker and Cuqlock-Knopp stated that these three components (visual cues, strategies, and skills) constituted a general off-road navigation task.

Omodei, McLennan, and Whitford (1998) built on the earlier research by Omedei and McLennan (1994) by introducing a second replay stage to their video-based interview. The authors believed that after the initial stage of recall an evaluative stage would be beneficial to performance. This stage involved the coach and performer replaying the tape to identify particular mental processes underlying problematic aspects of competition performance (Omedei et al., 1998, p. 119). An intervention was conducted between seasons using the new two-stage procedure. Performance of junior national level orienteers improved significantly between competitive seasons and this difference was attributed to the intervention. The authors analysed the recall data from both stages of the interviews qualitatively and reported that the orienteers were often shocked to discover how often, and for how long, they stopped running to check the map, and how long they spent searching for controls. Other factors affecting performance included losing concentration and individual biases in route choice. The orienteers also became more accepting of criticism after recognising their errors, and coaches were able to alter training regimens and, specifically, design strategies to help performers maintain concentration. Omedei et al. (1998) proposed that the analysis of the interview data revealed that orienteering involves complex thought processes that are controlled, and hence can be verbalised, rather than automatic (cf. Schneider & Shiffrin, 1977).

Limitations of the psychological research into orienteering.

Although the previous research into orienteering has begun to establish an understanding of orienteering, there are a number of criticisms that might be made of this existing literature. First, a number of the previous research papers in this domain have not been concerned with psychological aspects of orienteering specifically; rather, orienteering has been used as a medium to test some more general psychological phenomenon or the studies have focused on issues peripheral to orienteering. This is reflected in the fact that the studies rarely cite one another. Examples of the lack of a specific focus on orienteering include the study by Gal-Or et al. (1986). These authors explored the use of cognitive-behavioural strategies in elite orienteers but it is clear from the objectives of the paper that the authors were concerned primarily with identifying the use of strategies by an elite athlete population, not by an orienteering population. This criticism might also be applied to the study by Hancock and McNaughton (1986). Furthermore, the studies by Omedei and McLennan (1994) and Omedei et al. (1998) were concerned with testing the efficacy of a new method of investigating decision making in orienteering, not with the cognitive processes involved in decision making in orienteering *per se*. The study by Whitaker and Cuqlock-Knopp (1995) identified various constraints of, and adaptations to, navigation in off-road environments but the implications of their results were limited because they used a sample comprised of orienteers and soldiers but did not specify either the proportions of the sample constituted by these populations or the performance standard of the orienteers. Only the study by Seiler (1990) was conducted with the specific objective of identifying cognitive processes in orienteering although the impact of this study was limited by poor translation from a foreign language. The authors of three of the studies (Gal-Or et al., 1986; Seiler, 1990; Whitaker & Cuqlock-Knopp, 1995) suggested possible adaptations that had implications for skill acquisition and thus pertained to the second objective of this thesis. However, all three studies used samples with unspecified demographics thus limiting generalisations, and each was limited in ways discussed elsewhere in this critique.

Second, many propositions concerning the constraints of orienteering were made prior to scientific investigation because they were considered self-evident. None of the studies focused on providing empirical evidence of the specific and detailed constraints of the task, and the problems these constraints impose on the performer, through an accepted, systematic, and rigorous system of scientific investigation. Third, the studies by Hancock and McNaughton (1986), Omedei and McLennan (1994), and Omedei et al. (1998) had small sample sizes (e.g., six participants) and hence possessed limited statistical power (see Cohen, 1988). Fourth, methodologies were often under-specified, and hence the validity of the methodologies was difficult to establish, making replication difficult. This was certainly evident in the study by Seiler (1990) and appears to be the product of poor translation from a foreign language and a substantial condensing of a number of separate methodologies into one short paper. The studies by Omedei and McLennan (1994), and Whitaker and Cuqlock-Knopp (1995) do not explain how the qualitative data were analysed or whether a consensus validation procedure was undertaken.

The limitations in previous research could be addressed by investigations that begin to provide empirical evidence of the task constraints inherent in orienteering, and the problems these constraints impose on the performer, in a detailed, systematic, and scientific manner. Furthermore, the limitations could also be addressed by identifying how skilled orienteers might have begun to adapt to these constraints. Currently, few studies attempt to address these issues, and those few that do possess some limitations, as previously discussed.

Paradigmatic issues.

The objective of this section is to discuss the conceptual framework that underpins this thesis and to briefly consider contemporary alternatives to this framework. This is because the adoption of a framework might influence the thinking of the researcher, the methodologies employed in the studies, the interpretation of the results by the researcher, and the theoretical and applied implications that result from the research programme.

An academic discipline is often dominated by one particular theoretical orientation, often referred to as a paradigm (Kuhn, 1977), at least for a certain period of time in the discipline s history before it is challenged. Before the current dominance of the cognitive paradigm, psychologists were disinclined to regard thought or mental processes as relevant in understanding human behaviour. This approach was known as the behaviourist paradigm. For the behaviourists, all aspects of behaviour were caused by, and hence could be explained by, the environment, with no recourse to any cognitive mediation between behaviour and environment. Interestingly, one of the earliest lines of research to challenge this paradigm was concerned with navigation. Tolman (1948) proposed that he could not explain his findings from research on navigation in rats without recourse to mental processes and structures. For example, he placed rats at the start of a maze and let them run free to locate a food store. The rats learned the location of this food store with increased experience of the maze. However, Tolman observed that rats were still able to find the food store despite changes in the stimuli, such as a rearrangement of the maze structure between the release point and the food store. He concluded that his findings were not consistent with a behaviourist paradigm in that the rats were not helplessly responding to a succession of external stimuli (p. 28, cited in Downs & Stea, 1973). Instead, he proposed that something like a field map of the environment gets established in the rat s brain (p. 31, cited in Downs & Stea, 1973). The recourse to mental representation and mental processes as mediators between environment and behaviour by Tolman and others presaged a major paradigmatic shift to what has now become known as cognitive psychology.

The rapid advances in technology that occurred during the middle of the twentieth century began to be used by psychologists as analogues of thinking. The origin of the term processing lies in communications (for examples, see Shannon & Weaver, 1949, or Broadbent, 1958) and, more recently, the powerful influence of the computer has resulted in cognitive psychology being characterised by strong computational metaphors. Influential works by Newell and Simon (1972), and Anderson (1982) are examples of explicit attempts to model thinking on computer processing and hence have been influential in research linked to artificial intelligence, in which attempts are made to program computers to think like humans.

These historical trends have culminated in a framework within cognitive psychology with which to study thinking in humans: the information processing approach. This approach is the current dominant paradigm in psychology. Most authors either implicitly or explicitly adopt this approach during studies of behaviour. The majority of researchers in areas that impinge on orienteering (skill acquisition, e.g., Anderson, 1982; expertise, e.g., Ericsson & Smith, 1991; navigation, e.g., Siegel & White, 1972; and problem solving, e.g., Newell & Simon, 1972) also adopt this approach. For these reasons, the information processing paradigm underpins the investigations conducted in this thesis.

The prominent features of this approach are as follows (for an overview see Eysenck, 1993). The approach uses a metaphor of the structure of, and the processes that occur within, a computer. Real world phenomena are represented in a symbolic form in the brain. These symbols, also known as mental representations, are affected by mental processes and can be transformed by these processes. The identification of both the processes and representations that determine behaviour is the goal of cognitive psychology. The processes themselves operate in a mostly serial fashion and hence are time consuming and, therefore, time is often used as a measure of processing. From the information processing approach, the brain is regarded as a limited-capacity processor of information. Information is processed within three stages from the onset of an environmental stimulus to a response from the human. The first stage is the stimulus identification stage in which an environmental stimulus must be detected and identified. The second stage is the response selection stage during which a response to the identified stimulus must be selected. The final stage is the response programming stage in which the selected response must be programmed in order to produce behaviour. Various cognitive systems and stores are utilised during these stages of information processing: principally, the attentive and perceptive systems, and short-term/working memory and long-term memory stores. Each of these has received empirical and theoretical attention: attention (e.g., Broadbent, 1958), perception (e.g., Marr, 1982), short-term or working memory (e.g., Baddeley, 1986), and long-term memory (e.g., Ericsson & Kintsch, 1995).

Despite the predominance of the information processing approach it is important to recognise that alternative frameworks might better explain the empirical findings of this thesis. Recent theorists have become dissatisfied with the computational metaphor fundamental to the information processing approach (e.g., McClelland, Rumelhart, & The PDP Research Group, 1986; Rumelhart, McClelland, & The PDP Research Group, 1986). For example, some theorists argue that the brain does not operate like a computer, and that processing can be better explained by using the brain itself as a metaphor (e.g., Betchell & Abrahamsen, 1991; McClelland et al., 1986; McLeod, Plunkett, & Rolls, 1998). This approach is known as connectionism. In connectionism, thinking is not conceived of as symbol (mental representation) manipulation. Furthermore, processing does not occur serially but in parallel, and is distributed about a network of nodes characteristic of the neural networks of the brain. Each node communicates information to the next on the basis of the sum of the information it has previously received from other nodes and the strength (weighting) of the connections between nodes. One set of nodes receives information from external stimuli (the environment) and another the output of the network (a response). Learning occurs as a consequence of the strengthening of the connections (weightings) between some nodes. The more a connection is strengthened, the greater the influence from one neuron to the next.

It has been proposed that the neural networks of the connectionist approach can account for some phenomena better than the information processing approach, because neural networks have the ability to processes information in parallel, and, therefore, rapidly. Examples of such phenomena include rapid behaviours, such as recognising faces, and thinking that requires an integration of information from different domains, such as during the solution of ill-defined problems (for an overview, see Moran, 1996).

Other theorists have proposed an ecological approach to human behaviour that almost constitutes a complete paradigm shift (e.g., Gibson, 1979; Kelso, 1995). These theorists have been concerned predominantly with visual perception and motor behaviour, and have argued that the information processing approach places too great an emphasis on the human and does not consider the human s inextricable relationship with the environment. The ecological approach is less concerned with higher order causal entities, that is, mental representations of movement such as motor programs (discussed later), and is more concerned with studying the organism-environment synergy rather than the organism per se (Beek & Meijer, 1988, p. 160). One of the biggest criticisms of the use of mental representations in the explanation of motor behaviour is concerned with the multiple degrees of freedom inherent in the human movement system. According to the information processing approach, a different motor program must account for each movement. However, this would result in an unfeasibly large burden on the human s limited processing resources. Consider how many variations exist in a golfer s drive. These might depend on factors such as wind direction, length of hole, the nature of the relief, the fatigue of the golfer, and so on. How could the brain store all the motor programs necessary to produce all the different variations of drive? From the ecological perspective, the visual perception of physical parameters in the environment directly tune the movement system without recourse to mental representations; slight changes in environmental constraints result in slight changes in the way the movement system is tuned. Consequently, the storage problem is not relevant (for overviews see Handford, Davids, Bennett, & Button, 1997; Moran, 1996).

An example of a physical parameter is the change in an individual s perception of the surface texture of an object as he or she moves towards it. Imagine running towards a brick wall. From a distance, the bricks seem relatively smooth. As you near the wall, the bricks are perceived as rougher in texture. As you move very close, what were minute cracks now look much bigger, and the detailed texture of the brick can be perceived. According to the ecological perspective, the change in this parameter, known as the texture gradient, is linked inextricably with action; in this situation the action would probably be to raise the arms and shut the eyes in order to prepare for an impact with the wall.

In conclusion, researchers continue to debate the relative merits of information processing, connectionist, and ecological approaches to human behaviour (e.g., Abernethy, Burgess-Limerick, & Parks, 1994). Each approach has its own advantages and disadvantages, and researchers are exploring ways to integrate different approaches for use in future research (Abernethy et al., 1994). To reiterate, although this thesis adopts an information processing approach to cognition, it is prudent to recognise that alternative paradigms might better explain some of the phenomena discussed in the following chapters.

Overview of research into the origins of skill.

This section comprises an overview of the current findings of research into the origins of skill. The second objective of this thesis is to identify any adaptations by experienced orienteers to the constraints of orienteering that appear to account for performance increases. The assumption underpinning this objective is that humans are able to adapt to the constraints of tasks in which they have previous experience. One obvious alternative explanation for observed performance differences between individuals at a given task is that they possess inherited natural talent; that is, their adaptations to the task are minimal. Clearly, efforts to establish performance-related adaptations to constraints in orienteering would be fruitless if evidence for adaptations in other domains had not been obtained. This issue warrants discussion here.

The origin of human attributes is one of the most fundamental topics in psychology and also one of the most contentious (Howe, Davidson, & Sloboda, 1998). Galton s (1869) early work on the origins of genius attributed skill largely to hereditary factors and proposed that practice was a necessary but not sufficient condition for the acquisition of a high level of skill. Since Galton s work, researchers have proposed theories about the origins of skill that might be considered to lie on a continuum running from a nativist position through to an environmentalist position. Nativist theorists (e.g., Galton, 1869) attribute skill primarily to hereditary or genetic factors, and talent, whilst environmentalist theorists (e.g., Ericsson, Krampe, & Tesch-Romer, 1993) attribute skill primarily to environmental factors such as learning and practice. Constructivist theorists (e.g., Ceci & Williams, 1999) lie between these two more extreme positions on the continuum by attributing skill to a combination of both native and environmental factors. It could be argued that Galton was a constructivist but he merely acknowledged, rather than enthused about, the role of practice in the acquisition of skill. He studied eminent people of his day and proposed that eminence was largely hereditary, using William James, the psychologist, and his brother Henry James, the author, as an example.

More recent theorists have adopted an environmentalist position (e.g., Sloboda, 1996) arguing that research has provided little evidence of talent. For example, laypersons often regard significant accomplishments in early childhood as evidence of talent but environmentalists argue that there is little evidence of accomplishments that could not be explained by factors other than innate talent, such as encouragement by significant others. Furthermore, the environmentalists also suggest that research reveals few differences in the speed of learning. Instead, skill is attributed to a high level of deliberate, structured practice and extensive experience (e.g., Chase & Simon, 1973a, 1973b; Ericsson et al., 1993). Many environmentalists still acknowledge the role of genetic factors (e.g., Howe et al., 1998) but maintain that these factors account for very little variance in the acquisition of skill. For example, Chase and Simon (1973b) proposed that practice is the major independent variable in the acquisition of skill (p. 279).

However, there remain fierce critics of this contemporary stance (Detterman, Gabriel, & Ruthsatz, 1998). These critics argue against what they consider as absurd environmentalism (Detterman et al., 1998, p. 411). Similarly, very few researchers within this area of psychology have taken a purely nativist position. Most agree that skill must be acquired to a certain extent. For example, Ceci and Williams (1999) argued that most researchers actually adopt a constructivist position:

> Nearly all responsible researchers agree that human traits are jointly determined by both nature and nurture, though they may disagree about the relative contributions of each. . . . The battle today seems more over the specific genetic and environmental mechanisms [that determine skill] than over whether genes or environments matter (pp. 7-8).

Ceci and Williams cite a classic study by Skodak and Skeels (1949) of intelligence quotient (IQ) to demonstrate that there is nothing inconsistent about saying that a trait is both highly changeable and highly heritable (p. 2). This study provided evidence that IQ could undergo large increases as a consequence of environmental factors. Mothers who offered their offspring for adoption were tested for their IQ. The offspring were later tested during adolescence and their IQ was found to be on average 21.5 points higher than their mothers, suggesting that changes in the environment between birth and adolescence, such as education, had caused an increase in the IQ of the offspring. However, while the means between pre- and post-test scores were significantly different, the pre-test scores were also significantly correlated with the post-test scores. Clearly, the offspring had experienced an increase in IQ as a consequence of environmental factors but this variable was still influenced by hereditary factors: those with a mother with an IQ at the lower end of the range of the group at pre-test would still possess an IQ at the lower end of the range at post-test, despite an average increase of 21.5 points.

If performance differences between individuals can be accounted for by environmental factors, at least in part, the next topic pertaining to this thesis is how environmental factors, such as practice, education, and experience, effect a change in skill. One popular account of how these factors affect skill is that humans learn to adapt to their environments (e.g., Ericsson et al., 1993; Sloboda, 1996; Salthouse, 1991). From this perspective, it might be argued that there is a functional equivalence between physiological and psychological adaptations to task constraints. For example, myopia (shortsightedness) in Western populations is thought to be an adaptation to the regularity with which these populations focus on nearby objects such as televisions, computer screens, and reading material (Wallman, 1994). Furthermore, there is evidence from physiology research of substantial and significant changes in the cardiovascular systems of previously sedentary individuals in response to prolonged aerobic training (Saltin, 1969), and in the muscles of previously sedentary individuals in response to prolonged resistance training (MacDougall, Ward, Sale, & Sutton, 1977). There are equivalent cognitive adaptations in response to training. Skilled typists have been shown to look further ahead in the text when typing than less skilled typists and hence have more time to prepare their finger actions for the typing of a given word (Genter, 1988). Chase and Ericsson (1982) presented evidence that individuals who had been trained extensively in memory tasks, and subsequently experienced large performance increases in these tasks, had adapted by using existing knowledge and associating it with the information to be memorised. In a review of the literature, Ericsson et al. (1993) proposed that there are few limits to skill acquisition given the evidence for adaptations that occur with deliberate practice and experience.

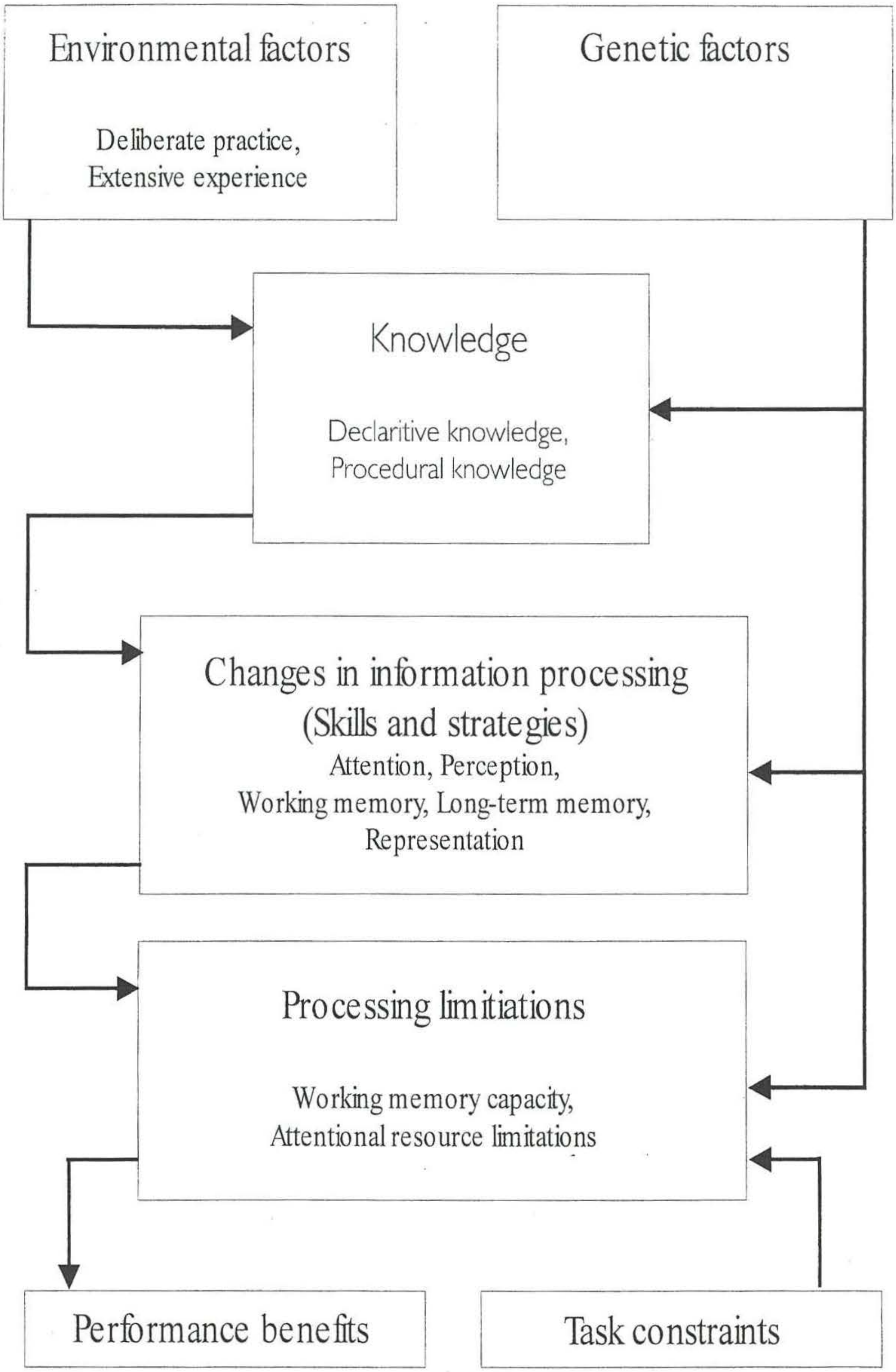
It should be noted that Ericsson et al. (1993) adopted a strong environmentalist position. However, regardless of the possible existence of hereditary factors, and, in turn, their possible contribution to variance in performance, Ericsson et al. provided strong evidence that a considerable proportion of performance variance can be accounted for by adaptations to practice and experience. Ericsson and his co-workers (e.g., Ericsson et al., 1993; Ericsson, 1996; Ericsson & Lehmann, 1996; Ericsson, 1998) adopted a limited-capacity model of the human brain consistent with the information processing approach. They proposed that practising a task allows the human to circumvent the proposed processing limitations of the brain through the acquisition of cognitive skills and strategies, that is, by adapting to the task. These adaptations are task specific such that practising a task causes adaptations specific to the constraints of that task. Consequently, these task specific adaptations rarely transfer to other tasks; individuals who are skilled at one task often behave like novices on a novel task (Voss, Green, Post, & Penner, 1983). Extensive periods of deliberate practice and experience are thought to ultimately cause maximal adaptation to the constraints of the task. Consequently, experts are individuals who have achieved the greatest adaptations to their task.

Researchers of expertise have often proposed that knowledge is the mediator between practice and the adaptations suggested to underpin expertise (e.g., Bedard & Chi, 1992). More specifically, practice and experience in a domain determine the amount of knowledge of that domain, and how well organised that knowledge is. In turn, knowledge causes changes in the way information from that domain is processed, and, subsequently, these changes cause the circumvention of processing limitations. This approach to expertise is encapsulated by Bedard and Chi (1992):

> In the past two decades, there has been a significant amount of research on the nature of expertise. . . . The studies have shown that a large, organized body of domain knowledge influences the perceptual processes and strategies of problem solving. . . . On the basis of their greater knowledge and better organization, experts perform better than novices in domain related tasks. (pp. 135-139)

This approach is adopted throughout this thesis and is illustrated in Figure 1. The pathways illustrated in the figure are explained here. Task constraints impose burdens on processing resources. However, environmental factors such as deliberate practice in, and extensive experience of, a domain cause an increase in domain-specific declarative and procedural knowledge (see Anderson, 1982, discussed below). This knowledge facilitates the adoption of domain-specific cognitive skills and strategies that cause changes in the way information is attended to, perceived, and stored in working and long-term memory (represented). These changes effect a circumvention of the limitations of processing resources by reducing the demands imposed by the constraints of the task on those resources. In turn, performance benefits are afforded. However, genetic factors are also acknowledged in this thesis. For example, they might affect how fast knowledge can be acquired and accessed, and how fast skills and strategies can be learned, and might also cause individual differences in processing limitations.

Figure 1: An adaptations approach to skill acquisition.



Researchers interested in the acceleration of skill acquisition have used this approach to direct their research in two ways. First, researchers have tried to identify the constraints of a task and how the human has learnt to adapt to that task. Attempts to meet these objectives have often taken the form of considering the knowledge required, and hence acquired, by experts compared to novices (e.g., Chi, Feltovich, & Glaser, 1981; McPherson, 1993) or considering how information is processed differently as a consequence of this knowledge by comparing experts with novices (e.g., Abernethy, 1990). Less commonly, these objectives are met by longitudinal training studies (e.g., Chase & Ericsson, 1981). The result of such research is the identification of the cognitive skills and strategies that account for higher levels of skill in a domain.

Second, researchers adopting the adaptations approach have used knowledge of adaptations by skilled individuals to a given task to structure training programmes, with the objective of accelerating skill acquisition in individuals less skilled in that task. For example, researchers interested in skill acquisition have proposed that anticipation of future events (e.g., Chiesi, Spilich, & Voss, 1979) and elaborate planning strategies (e.g., McPherson, 2000) are characteristics of expertise. Consequently, researchers have tried to integrate anticipation training (e.g., Singer, Cauraugh, Chen, Steinberg, Frehlich, & Wang, 1994) and planning strategies (Kirschenbaum, Owens, & O Connor, 1998) into training protocols, the results of which have typically been an acceleration in skill acquisition.

Overview of research into expertise and skill acquisition.

Most studies of expertise have adopted a cross-sectional expert/novice paradigm, comparing experts with novices to identify differences in their cognitive and motor behaviour. This is because expertise takes many years to acquire; consequently, training studies are often unfeasible. However, training studies do exist and the findings from such studies are used to inform this overview, but learning in these studies is often limited to simple, contrived, laboratory tasks (e.g., Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Experts posses specialised, elaborate, and embellished schemata that comprise large quantities of domain-specific declarative and procedural knowledge. Experts knowledge is also highly organised and integrated, and is easily accessible (e.g., Ericsson & Kintsch, 1995). Consequently, problems are represented in terms of abstract and underlying elements of the problem domain. In turn, experts can employ sophisticated domain-specific strategies and heuristics during problem solving (e.g., Allard, 1993). For example, experts are often observed to work forward from the information given in the problem to the goal by recognising a problem as a given category of problem, using their knowledge, and associating that with a given solution (e.g., Larkin, McDermott, Simon, & Simon, 1980). Novices knowledge is not only limited compared to experts but is poorly organised, less interrelated and slower to access. As a result, problems are inaccurately represented (e.g., Bedard & Chi, 1992), or are represented in terms of surface, superficial, and literal features of the problem (e.g., Chi, Glaser, & Rees, 1982). Consequently, novices must rely on domain-independent and intuitive problem-solving strategies (e.g., McPherson, 1993). For example, they are often observed to work backward from the goal or employ means-end analysis; this is an analysis of how to minimise the discrepancy between the givens and the goal (e.g., Larkin, McDermott, Simon, & Simon, 1980).

Experts are able to encode the necessary information from their domains rapidly by recognising, using their knowledge, meaningful configurations of domain-relevant information in the environment of the domain, and hence are able to simplify the problem space. Novices are slow to identify pertinent information and are often overwhelmed by the available information (e.g., Chase & Simon, 1973a).

Experts complete their tasks faster for a given level of accuracy but spend proportionately longer representing a current problem with their vast knowledge base before commencing the task. By contrast, novices proceed to commence with problem solving rapidly because they are less able to represent a problem accurately (which takes time) owing to their poor knowledge base. However, because novices cannot represent problems as well as experts, novices spend longer completing the task and are less accurate for a given solution time (e.g., Chi, Glaser, & Farr, 1988). Experts are highly efficient using fewer processing resources and less physical energy to complete a task for a given time and level of accuracy. Consequently, spare cognitive resources can be reallocated to other components of the task and physical resources are conserved. Novices are less efficient using more resources and energy for a given level of performance than experts (e.g., Schneider & Shiffrin, 1977). During performance, experts appear to know when and where to allocate processing resources, and are better able to divide their attention, so as to achieve the greatest performance benefits. Novices do not posses knowledge of when and where to allocate processing resources, and frequently experience processing overloads (e.g., Moray, 1984).

Experts are proactive: experts in dynamic domains anticipate changes in the status of their task based on environmental cues that are recognised from prior knowledge and are apparent before those changes occur. Thus, experts are able to prepare responses to changes before they occur and in turn circumvent limitations in reaction time. Novices are reactive: they are less able to anticipate changes in the status of their task and are forced to respond quickly to those changes as they occur. They have no knowledge allowing recognition of cues in the environment and thus are relatively passive recipients of information in contrast to experts who are active samplers of it (e.g., Abernethy, 1990). Experts engage in more planning and generate more expectations prior to performance. Consequently, they are able to detect the probabilities of the occurrence of future events that may take place during performance. In turn, they are better able to prepare responses to these events. Novices rarely plan and when they do they exhibit less advanced planning strategies. Consequently, they are not able to prepare their actions and are forced to react to events (e.g., McPherson, 2000).

Experts can better predict the difficulty of a particular problem and can structure future behaviour accordingly. For example, they can decide where and when to allocate effort and resources. Novices are less able to predict the difficulty of a given problem and are often overwhelmed by the task requirements and the available information (e.g., Chi, 1978). Experts use more metacognitive strategies. They are better able to monitor and evaluate their cognition and performance, and hence are more sensitive to errors in cognition. Novices use fewer metacognitive strategies. They rarely monitor their progress and do not have sufficient knowledge to detect errors in solution pathways (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989).

Expertise is domain-specific. For example, evidence from tests such as basic (domain-independent) reaction time show that expert athletes do not generally posses superior sensory or neural systems. Novices are often shown to be equivalent to experts on these tests (e.g., Starkes & Deakin, 1984). In addition, when problems are atypical, or not from within the expert s domain, expert problem solvers behave more like novices during the solution process, in terms of most of the characteristics outlined above (e.g., Voss et al., 1983).

Experts have undertaken at least 10 years and/or 10,000 hours of quality, structured, and deliberate practice, and have gained extensive experience in their domain. They have had the best instruction from educators who have previously been experts in the domain and, frequently, they have begun early in childhood. Novices may have never had the opportunity to gain experience in or practice at a given task (e.g., Simon & Chase, 1972).

Overview of theories of expertise and skill acquisition.

Each of the following theories of learning, skill acquisition, and expertise could contribute towards an understanding of the processes underlying adaptations by humans to task constraints and, hence, account for the behavioural and cognitive differences between experts and novices discussed in the last section. It is also worth noting that these theories need not be regarded as mutually exclusive; many of these theories possess commonalties with the other theories in this overview.

Fitts (1964), and Fitts and Posner (1967), proposed an early theory of motor learning that could potentially be generalised to cognitive tasks. Fitts and Posner (1967) described three stages of learning: the early or cognitive stage, the intermediate or associative stage, and the final or autonomous stage. During the first stage the learner attempts to understand the task demands. This is often accompanied by instruction from a teacher. The teacher may demonstrate what information (or cues) should be attended to in the environment, and what movements are required at each step, in order to successfully complete the overall task. These cues and movements are explicitly taught and practised, and can be easily verbalised by the learner. Typically, the performer is not aware of these cues or movements later in learning because they become more automated. Fitts and Posner (1967) explained that early learning experiences are the first stage in the development of an executive motor program for the task being learned. A motor program is a type of schema. Schemata are higher-order mental representations of knowledge that can be used to control lower-order systems that, in turn, produce overt behaviour. Motor programs and schemata are discussed in more detail later in this section.

Fitts and Posner (1967) also proposed that a variety of subroutines, and subroutine sequences, are tried in an attempt to successfully execute the new task. Subroutines are sequences of behaviour that are short and inflexible, and are component parts of many previously learned activities. Successful movements are selected to form a repertoire for the activity. The sequence of subroutines, and their execution time, are controlled by the executive program and are affected by the task demands. As a new skill is learned, a new sequence and timing of the subroutines will be established as part of the program. During the intermediate stage of learning the subroutines that were selected in the first stage continue to be tried and tested. Grossly inappropriate subroutines, wrong sequences of acts, and responses to the wrong cues (Fitts & Posner, 1967, p. 12) are attenuated so that new and more appropriate sequences of subroutines emerge. The length of this stage is proportional to the complexity of the task. In the final stage of learning, the task becomes more automatic, more resistant to interference, and skills demand less processing. Consequently, the individual becomes more efficient. Where overt verbalisation of each component of the task would aid performance during the first stage of learning, such verbalisation now disrupts performance. Responses will continue to become more rapid with continued practice.

Chase and Simon (1973a, 1973b) proposed a pattern-recognition theory to account for chess expertise. This theory departed from the work of Fitts and Posner (1967) in two ways. First, Fitts and Posner were primarily interested in motor skill acquisition and approached skill acquisition from a motor control and learning perspective. Chase and Simon were more concerned with cognitive tasks and approached skill acquisition from a cognitive perspective. However, Chase and Simon proposed that their theory could account for expertise at a more general level, that is, in both cognitive and motor tasks. Second, Chase and Simon s theory provided an explanation of the mechanisms underlying skill acquisition whereas Fitts and Posner (1967) provided a comparatively descriptive account of skill acquisition.

Early researchers of chess (e.g., de Groot, 1946/1965) had discovered that the chess masters memory for briefly presented chess pieces on a board was far in excess of the limits of short-term memory. However, this effect only held for real game positions but not for random positions. Less expert players did not posses this superiority regardless of the arrangement of the pieces. The number of pieces recalled by less expert players was consistent with the capacity of short-term memory. Chase and Simon (1973a, 1973b) suggested that the masters memory superiority in chess could be accounted for by their ability to recognise, from long-term memory, configurations or patterns of pieces based on meaningful relationships at various levels of abstraction. Tests for the existence of these patterns in the masters were undertaken, and the number of patterns detected in short-term memory was consistent with the limits of short-term memory. It was proposed that the ability to recognise patterns was based on the masters knowledge of thousands of patterns that had been acquired through years of experience.

Chase and Simon (1973a, 1973b) proposed that recognised patterns were associated with appropriate responses stored in long-term memory and explained this recognition-association relationship with reference to productions. Productions comprise a condition and action relationship using IF-THEN connections. From a production-system perspective, long-term memory contains many such relationships. IF a specific condition is detected in working memory THEN an action is triggered in long-term memory. Once an action is triggered a new state is created. IF a condition in the new state is present THEN a new action is triggered. This excerpt from Chase and Simon (1973b) introduces the fundamental concepts of their theory:

> Why, as has been often observed, does the Master so frequently hit upon good moves before he has even analyzed the consequences of various alternatives? Because, we conjecture, when he stares at the chess board, the familiar perceptual structures that are evoked from long-term memory by the patterns on the board act as move generators. . . . It is the organization of stored information that permits the Master to come up with good moves almost instantaneously, seemingly by instinct and intuition.
>
> We can conceive this part of long-term memory to be organized as a production system. . . . Each familiar pattern serves as the *condition* part of a production. When this condition is satisfied by recognition of the pattern, the resulting *action* is to evoke a move associated with this pattern and to bring the move into short-term memory for consideration. (pp. 268-269)

Chase and Simon (1973a, 1973b) proposed that experts in other domains would recognise patterns in the environments of their domains from long-term memory. In turn, these patterns would be associated with responses learned through experience. The expert footballer might recognise patterns of player positions, such as a weakness in defence, and the associated response would be an attempted strike at goal. Similarly, the expert snooker player might recognise a pattern of balls associated with a safety opportunity.

Unlike Chase and Simon (1973a; 1973b), Shiffrin and Schneider (1977; see also Schneider & Shiffrin, 1977) proposed a theory that was not concerned with accounting for expertise or skill acquisition specifically, but with the shift from controlled to automatic processing that accompanies skill acquisition. Fitts and Posner (1967) had described a similar phenomenon: the first stage of learning was known as the cognitive stage because movements in this stage required explicit thought and planning; the final stage was called the autonomous stage because movements were more automatic, and, hence, required fewer processing resources. Like the theory proposed by Fitts and Posner (1967), Shiffrin and Schneider s (1977) theory was descriptive rather than explanatory. The theory proposed that early in practice processing is slow, serial in nature, flexible, resource consuming, consciously controlled, and voluntary. However, later in practice processing of task-specific information becomes rapid, automatic, inflexible, parallel in nature, involuntary, places no demands on processing resources, and the learning that has occurred is difficult to unlearn. Furthermore, because responses to task specific stimuli become automatic and involuntary, performance on a novel task involving similar stimuli is inferior to novice performance at the same task.

The shift from controlled to automatic processing occurs when a given stimulus is consistently mapped with a given response over extensive periods of practice (around 2500 trials of a memory search task in Schneider & Shiffrin s experiments). When automaticity is obtained, rapid processing times occur regardless of the size of the processing load. However, when unreliable (varied) mapping occurs, automaticity is not acquired, and the processing time increases proportionate with processing load.

Anderson (1982) proposed a cognitive architecture that could account for the acquisition of cognitive skill called the Adaptive Control of Thought (ACT). Anderson built on the work of Fitts (1964), and Fitts and Posner (1967). One criticism of this earlier work was that it described the processes of learning but did not explain how learning occurred. This criticism has also been levelled at the work of Shiffrin and Schneider (1977), and Schneider and Shiffrin (1977); the shift from controlled to automatic processing was described but not adequately explained. Anderson proposed that ACT could explain learning, and automaticity, with reference to the stages proposed by Fitts and Posner (1967).

ACT relies on production systems comprising productions (discussed earlier). One component of ACT, called declarative memory, contains no productions, but contains a simple propositional network of knowledge about the skill domain (see McNamara, 1994, for a discussion of propositional representations). Anderson (1982) proposed that learners in the first stage of learning (proposed by Fitts and Posner, 1967) acquire declarative knowledge about their novel task.

A second component of ACT was called procedural memory, a long-term store of productions. Anderson (1982) proposed that learners in the second and third stages of learning (proposed by Fitts & Posner, 1967) acquired productions pertaining to their novel task. The aggregate of these productions Anderson (1982) called procedural knowledge. The final component in ACT was called working memory. Encoding was the process by which information from the senses was delivered to working memory.

Early in learning, the performer only has access to discrete declarative knowledge structures that must be explicitly interpreted. For example, when an individual attempts a tennis serve for the first time they must access several discrete knowledge structures that comprise this difficult movement such as ball and racquet pressed together with hands , straight arms , arms pointing down , bend knees when you reach the lowest point of the bend, part ball and racquet , and so on. Each declarative knowledge structure in the movement sequence must be individually interpreted. The interpretation of each discrete knowledge structure places a large burden on working memory. Working memory is limited in capacity (see Miller, 1956) and cannot contain all the stages required to execute a given task in a declarative form. Consequently, learners in the first stage of learning exhibit jerky and poor performances as they grapple with each discrete component of the movement sequence. In addition, learners in this stage can verbalise their declarative knowledge.

Anderson (1982) proposed that during the second and third stages of learning each discrete declarative knowledge structure associated with each component of a task becomes composed into a single production. Slowly, with continued practice, a complex task requires fewer and fewer productions. Furthermore, as practice continues, versions of these productions are produced that do not require access to declarative knowledge. This process is called proceduralisation. Providing that the encoding processes deliver conditions with an action pairing in procedural memory, working memory need only be burdened by the outputs of a production and not the declarative knowledge structures of the production sequences themselves. The productions are executed automatically through the triggering mechanism: IF information that is delivered to working memory constitutes a condition THEN a production is triggered, resulting in overt behaviour. Owing to the new processes underlying this behaviour, performance becomes more efficient, automatic, and smooth, but is difficult to verbalise.

Some theorists have proposed that knowledge is represented in a relatively generic way, can be applied to any given situation, and that its application is shaped by the nature of its acquisition. These theorists have commonly labelled the structure responsible for the organisation and representation of knowledge in this way as a schema (e.g., Bartlett, 1932; Schmidt, 1975; Schank & Albenson, 1977). Fitts and Posner (1967) suggested that movement might be controlled by a kind of schema known as a motor program. Schmidt (1975) used the same notion to propose that a general motor program controlled movement. This theory was considerably better specified than Fitts and Posner s (1967) early contribution and provided a solution to two major problems facing theorists of skill representation. First, there are an infinite number of scenarios and problems where the human must apply knowledge. How do humans apply knowledge gained in previous scenarios to a novel scenario, specific to time and in nature? Any novel scenario is likely to differ from previous scenarios in various ways. Second, how do humans store knowledge specific to each previously learned movement without a severe burden on storage and processing (discussed earlier)?

Schmidt (1988) drew an analogy with a computer program so as to explain how the generalised motor program operates, and how adopting the concept of this representation solves the problems of novelty and storage:

> Many different packages of statistical programs do common statistical procedures. Consider a program that calculates means and standard deviations. Such a program is generalized so that it can produce output for various numbers of subjects and for various numbers of scores per subject. . . . How does this program solve our storage and novelty problems? First, the storage problem is reduced because, for this class of computing problem, there is the need for only one program to be stored in the system; and this one program can accommodate a wide variety of different combinations of number of subjects and number of scores. . . . With respect to the novelty problem, notice that the program for means and standard deviations can produce results for combinations of subjects and scores it has never been asked to produce previously. . . . In this sense, the generalized motor program provides one kind of solution to our novelty problem. (p. 240)

Schmidt (1975) also theorised on how a motor program for a movement is created, and thus how learning occurs. When an individual tries to achieve a desired movement, four sources of information are stored. The first source stored is that of the initial conditions of the motor response. This information consists of all sensory information about the body and the environment that the individual is in, that is, all proprioceptive, extroceptive, and extropropriceptive information about the preresponsive state (Schmidt, 1975, p. 235). Second, the response specifications are stored. The individual stores all specifications of the movement response such as force, direction, speed, and timing. This serves as a record of the specifications of the movement produced (p. 235). Third, the sensory consequences of the movement produced are stored. This information is a copy of all afferent information produced during movement. Finally, outcome information is stored. This consists of the knowledge of the resulting outcome and may contain reinforcement from other sources of feedback. The quality of this final source of information is dependent on the quality and amount of feedback the individual can obtain.

With practice, and quality response-outcome information, individuals begin to abstract information about the relationship among these four sources of information. This abstraction constitutes a schema. When a novel scenario is encountered for which a schema exists, novel response specifications must be created. This process is informed by the relationship between the past response specifications and past actual outcomes. This relationship is termed the recall schema.

During the creation of novel response specifications, the relationship between past actual outcomes and past sensory consequences, or the recognition schema as this relationship is known, allows a set of expected sensory consequences to be created. The expected sensory consequences and the actual sensory consequences are compared upon movement completion, and any mismatch constitutes feedback to the schema. With an increased number of trials, the mismatch is reduced and the specifications of the schema are embellished.

Finally, Ericsson and Kintsch (1995) built on earlier work by Chase and Simon (1973a) (discussed above), and Chase and Ericsson (1981) by proposing a theory of expertise accounted for by long-term working memory (LTWM). As Chase and Simon (1973a) discovered, in order to cope with the cognitive demands imposed on working memory by the complex game of chess, the expert player effectively extends the limits of working memory by chunking information together. However, Ericsson and Kintsch (1995) proposed that working memory could not account for the quantity of information processed during the performance of tasks, such as chess, at an expert level. Instead, expert individuals were suggested to be able to access long-term memory (LTM) during these tasks in order to extend working memory effectively.

In LTWM theory, access to LTWM is via a set of retrieval structures. Retrieval structures are a set of retrieval cues that link simple nodes in working memory to chunks of information in LTWM. Through this mechanism, working memory is not burdened with a large quantity of information. One retrieval structure node in working memory could give access to many retrieval cues, each of which could be associated with information encoded in LTWM. In turn, information may be interrelated with other information in a complex manner in LTWM and this other information can be easily accessed using retrieval cues. It is proposed that LTWM only develops as a product of extensive experience in a specific task:

To meet the particular demands for working memory in a given skilled activity, subjects . . . acquire encoding methods and retrieval structures that allow efficient storage and retrieval from LTM (Ericsson & Kintsch, 1995, p. 239).

Overview of research into wayfinding and navigation.

Coincidentally, Tolman (1948) was not only influential in the beginning of cognitive psychology but also in the beginning of an understanding of how humans come to know and understand the space and environment in which they operate. Tolman (1948) used the term cognitive map to explain the ability of rats to navigate in mazes during his experiments. The cognitive map was a mental representation of a particular environment built up through experience of that environment. Moore and Golledge (1976) described the creation of a cognitive map, in information processing terms, as the process of encoding, storing, and recalling environmental information. Evans (1980) reviewed empirical evidence in this area and expressed the view that the cognitive map was an analogical representation (see McNamara, 1994, for a discussion of the debate over analogical and propositional representations): the representation, although not strictly cartographic, contains some maplike properties (Evans, 1980, p. 259). Some researchers argue that cognitive maps may be propositional in nature and hence spatial knowledge may not be stored as an image-like representation but as a more abstract language-like representation (e.g., Hirtle &

Heidorn, 1993). More commonly, theorists have suggested that such knowledge can be represented both analogically and propositionally (e.g., Cohen, 1996). Recent research has indicated that the nature of the representation changes with development: evidence has suggested that younger children rely on analogical representations but are not able to create, and thus utilise, propositional representations. However, older children are able to use both types of representation (Fenner, Heathcote, & Jerrams-Smith, 2000).

Tolman (1948) proposed that humans could use cognitive maps to facilitate decisions about movement in the environment. Later, Kaplan (1973) proposed that the cognitive map was necessary for survival, providing humans with a mechanism that facilitated rapid access to relevant environmental knowledge in a world where danger must be avoided and food located. Furthermore, Kaplan (1973) proposed that man must be born with a tremendous propensity to make and extend [cognitive] maps (p. 77) because they are a fundamental tool in location and orientation and, hence, in survival.

Researchers interested in how cognitive maps are developed have proposed that young children begin to manufacture representations of the environment based on information obtained through an egocentric frame of reference; that is, the child views objects in relation to themselves (e.g., in front of or behind me, and to the left or right of me). As children get older these representations gradually become based on information pertaining to nearby landmarks. With further development, the representations become based on information pertaining to the individual s position in space from a more abstract perspective, independent of the child s own viewpoint (e.g., Hart & Moore, 1973; Piaget & Inhelder, 1967).

Siegel and White (1975) proposed a similar hierarchy to account for how children learn and represent knowledge about the environments they experience. Basic knowledge is established early in learning and comprises the bottom of the hierarchy, and more complex knowledge is established later and comprises the top of the hierarchy. First, the child notices and represents landmarks that occur along a route or in a setting. This representation is built upon during actual movement through, and hence experience in, the environment. Second, the child begins to integrate this knowledge into a route-map . The representation begins to take a sequential form such as one-landmark-comes-before-the-another-which-comes-before-the-next . Third, with more experience the child begins to represent clusters of landmarks that possess good internal organisation in terms of the how landmarks are spatially related to each other. However, at this stage of learning the external organisation of the clusters is poor in terms of how the clusters are spatially related to each other. Finally, as experience increases, the external organisation of the clusters increases and the representation becomes a complete map of the landmarks. This is a survey-type representation integrating all routes and settings. Thus, the child s development of their representation of space progresses from being simple, egocentric, and route-based to being abstract, non-egocentric, and survey-based. Golledge (1987) proposed that theoretically and empirically there appears support for the notion that knowledge progresses from landmarks to specific path knowledge to an integrated frame of reference system for structuring spatial information (p. 142; see also Hart & Moore, 1973).

Similarly, adults also show a shift from route to survey knowledge with an increase in experience of a novel environment (e.g., Lawton, 1994; O Keefe & Nadell, 1978). Seigel and White (1975) proposed that survey-based representations of environmental knowledge are the most advanced an individual can possess. Route-based representations are less flexible during wayfinding owing to the simple, sequential way in which landmarks are represented. Wayfinding has been defined as the ability to navigate successfully through an environment from a given position to a given goal and thus is spatial problem solving in essence (Arthur & Passini, 1992; Passini, 1984). Adults who possess only route-based representations have been observed to get lost more easily during wayfinding (e.g., Lawton, 1994). This is because route-based representations are useful only while on the route. In contrast, survey-based representations are global representations of the environment and are not linked to any particular route, or orientation of an individual. Individuals who have acquired survey-based representations are able to use cardinal directions and find short cuts between points in the environment (O Keefe & Nadell, 1978). This latter phenomenon was among those that lead Tolman (1948) to conclude that rats must develop a cognitive map.

As noted, the development of survey-based representations seems to occur with increased experience of a terrain. Golledge (1987) proposed that a person s knowledge of an environment is at least partially influenced by his or her interactions with it and the extent, organization, and efficiency of those interactions (p. 144). The relationship between experience and knowledge (represented as a cognitive map) means that distortions in cognitive maps occur as a consequence of the way the environment is experienced. The fundamental elements of a given cognitive map tend to be representative of areas of the environment where behaviour most frequently occurs, and are often incomplete (Passini, 1984). Blades and Spencer (1987) proposed that the experience that influences the nature of the cognitive map is often functionally related: Cognitive maps do not necessarily correspond to a cartographic map of the same area. Rather, people will remember and emphasize those aspects of an area . . . which are particularly useful for wayfinding (p. 71). The relationship is not only bottom-up but also top-down : behaviours within a given environment are affected by the cognitive map representing that area (Golledge, Smith, Pellegrino, Doherty, & Marshall, 1985), and hence are affected by distortions in that representation. For example, McNamara, Ratcliffe and McKoon (1984) provided evidence that individuals are quicker to name cities that are connected directly by a road but are a considerable Euclidian distance apart, than those that are nearer in Euclidian distance but are connected by a longer circuitous road. The cognitive maps of these individuals were clearly distorted as a consequence of experience pertaining to function, that is, the distance one has to travel by road to get to a particular city.

A number of other factors affect wayfinding performance. First, in man-made environments that are unfamiliar to the individual, wayfinding performance seems to depend on layout legibility (Lynch, 1960; Appleyard, 1970). The layout of an environment is said to be legible if it possesses good form (a term originating in Gestalt psychology; see Kohler, 1940), that is, can be recognised as a coherent pattern. An example of good form is a city layout possessing parallel streets and perpendicular intersections. Second, Garling, B k, and Lindberg (1986) proposed that wayfinding performance depends on three other environmental factors: degree of differentiation, degree of visual access, and complexity of spatial layout. Degree of differentiation refers to the extent to which parts of an environment can be differentiated from other parts, such as a church in the centre of a row of terraced houses. Degree of visual access refers to the extent to which the environment can be seen. For example, narrow and twisting streets would clearly restrict visual access to the surrounding environment. The complexity of spatial layout refers to the ease with which travel plans can be executed. This variable is similar to the concept of layout legibility discussed above. Garling et al. (1986) proposed an additive model based on these three variables, and that wayfinding in a novel environment could be predicted from this model. Third, gender has been suggested to affect wayfinding performance (McGee, 1979; Devlin & Berstein, 1995), albeit controversially, with males frequently showing superiority. Research evidence suggests that adolescent and adult males employ strategies that are consistent with the development of survey-based representations whereas adolescent and adult females employ strategies consistent with the development of route-based representations (Lawton, 1994, 1996). Fourth, research has suggested that handedness may affect wayfinding (Devlin & Bernstein, 1997). The right hemisphere dominance of left-handed individuals has been suggested to affect creativity, and hence mental rotation and visualisation, skills proposed as useful in navigation requiring maps.

Overview of research into problem solving.

Behaviourists conducted early research into problem solving and believed this phenomenon (and every other phenomenon) could be explained by a series of responses to stimuli, learned by reward (for an overview see Anderson, 1985). Most of their evidence was provided by classic experiments on animals, such as those conducted by Thorndyke (1911) in which cats learned how to escape from cages to find food. However, Gestalt psychologists believed that problem solving could not be explained simply by learned responses. Furthermore, Gestalt psychologists suggested that past experience could actually hinder problem solving because individuals can become entrenched within the use of a particular solution strategy that has been used successfully in the past but is useless in the novel problem (for an overview see Anderson, 1985).

Another phenomenon that Gestalt psychologists used to critique the notion that previous knowledge would always aid problem solving was functional fixedness . Dunker (1926, 1945) provided a famous example of functional fixedness. Participants were given a number of items including a candle and tacks, and were asked to mount the candle on a wall so as to avoid dripping wax onto the floor when the candle was lit. Typically, participants tried to melt the candle onto the wall or tack it on but none thought to tack the casing from the box of tacks onto the wall and stand the candle in it. Dunker argued that the cause of this phenomenon was that past experience of the role of tacks (in mounting objects directly) fixated the participants and thus quashed creativity and insight, that is, prevented them from thinking about using the casing.

Gestalts psychologists proposed that problem solving was concerned with insight, a concept that departed significantly from the behaviourist paradigm but was consistent with other Gestalt work on form in visual perception (e.g., Kohler, 1940). Gestalt psychologists believed that one of the biggest problems for the behaviourist approach was the phenomenon of a-ha , the moment when one is suddenly able to see a problem differently. This they called restructuring . Studies of apes trying to reach food beyond their reach (Kohler, 1927) and humans trying to grasp two strings beyond their arm span (Maier, 1931) are classic examples of problem restructuring. In these experiments, the animal or human suddenly seemed to comprehend a successful method of completing a problem. The Gestalts provided valid criticisms of the behaviourists account of problem solving. However, their own account is criticised for a lack of specification and explanatory power. They described the phenomena of entrenchment , fixating and restructuring but did not specify or explain them (Eysenck & Keyne, 2000).

More recently, Newell and Simon (1972) proposed a problem solving theory called the Problem Space Theory. This theory remains highly influential in modern problem-solving research. Newell and Simon were cognitive psychologists using a computational metaphor. Furthermore, their theory was designed to be used as computer software in an attempt to model human behaviour. Problem space theory views the problem as a space in which all the possible solution paths, successful or unsuccessful, are contained. The state at the onset of the problem is known as the initial problem state, and the final, desired state as the goal state. Each possible solution path contains subgoals. Thus, the solution path comprises steps; the result of each step is the achievement of a subgoal. The steps between subgoals are achieved through the use of operators that are actions that allow progress to the next subgoal. Each operation is controlled by productions that were described above during the discussion of Fitts and Posner s (1967) account of skill acquisition. Productions are often organised into routines, that, in their totality, comprise a problem-solving program. Also, routines are often algorithms: sequences of productions that iterate until a desired state is reached, for example, the attainment of a subgoal.

Most problems are characterised by possessing an enormous search space. For example, there are probably a huge number of possible route options for travelling from your home to your place of work. Imagine you decide to explore them all. The first step of your travelling to work problem might be to leave your driveway. After achieving this there might be two path options: turn left to a cross roads or turn right to a roundabout. If you turn left to the crossroads there might be three other path options at that crossroads: the three other roads that meet to comprise the crossroads. However, if you turn right to the roundabout there may be three other path options: the roundabout exits. Some of these path options might lead to other turnings, and some might be dead ends where the only response is to turn around. You are still only yards from your house. Very rapidly there is an apparent combinatorial explosion (Holyoak, 1995, p. 271) of possible pathways to search through to locate the most accurate and efficient solution pathway. Imagine there are an average of three turnings at each junction and you explore no further than five junctions deep . You might be five minutes drive from your house and yet you have another 238 possible pathways to explore ($3^5 = 243$; 243 — the 5 roads you ve already driven down = 238). Modern computers have the processing capacity and speed to search many possible solution paths in the problem space. For example, Eysenck and Keyne (2000) reported that Deep Blue, the computer that beat the World Chess Champion Kasparov in 1997, searched 9 billion chess moves every second and 90 billion moves every turn.

However, many theorists regard the human brain as a limited capacity processor (e.g., Newell & Simon). Consequently, the brain is not able to search nearly as efficiently as computers like Deep Blue. Instead, humans make use of heuristics. These are mental short cuts or rules-of-thumb that are efficient but do not always guarantee successful performance, that is, humans trade off accuracy for speed. Unskilled problem solvers are suggested to universally employ heuristics that are based on intuition during problem solving. Three frequently used heuristics are means-end analyses, generate-and-test, and backward working. Means-end analysis attempts to minimise the distance between the initial state and the goal state by identifying differences between these states. Once a difference has been detected, an operator (an action) is applied in an attempt to eliminate that difference. If an operator cannot be applied, a new subgoal is created that involves reaching a position where an operator can be applied. Differences are minimised gradually through this process until the goal is reached (for an overview see Holyoak, 1995).

The generate-and-test heuristic is used as an attempt to solve the problem by testing different hypotheses. If a hypothesis does not prove successful it is eliminated and another hypothesis is generated by altering an element of the previously eliminated hypothesis. The working backward heuristic is used as an attempt to solve the problem by logically working backwards from the goal state of the problem to the initial problem state. For example, if one wished to make a paper aeroplane in a certain way but did not possess the necessary knowledge, they might picture the aeroplane and ascertain what the last folds in the paper were before the aeroplane was complete (the goal state). Once they had established this they might work out the folds that were made second to last, and then third to last, and so on, until there remained a flat piece of paper (the initial problem state).

As problem-solving knowledge increases within a domain the problem solver can recognise and represent problems more easily using this knowledge, and associate appropriate responses to these problems to solve the problem. Consequently, expert problem solvers tend to work forward from the initial problem state to the goal state (Chi et al., 1983). Put simply, the novice must search for a solution path but the expert has the knowledge of which solution path to use (Greeno & Simon, 1988). Egan and Greeno (1974) showed that problem solvers learn to fragment a given type of problem into simpler sub-problems as they receive more practice at that type of problem. Anzai and Simon (1979) showed that novices begin by using general, domain-independent problem-solving strategies and learn to adopt domain-specific strategies later in learning. Also, they do not plan the problem solving steps as much as later in learning. Novices also use other strategies during learning such as a loop-avoidance strategy whereby they avoid moving back a step towards the initial problem state. As novices learn, they use a shorter sequence of steps to reach a given goal.

Problem space theory has dominated problem-solving research since its conception. However, one criticism of problem space theory is that it is difficult to apply to problems that are not well defined (Holyoak, 1995). There is a well defined initial state, repertoire of operators, and goal state, when repainting the front of your house but not, it might be speculated, when aspiring to be a creative and innovative career as a painter of modern art. The domain of art is associated with such phenomena as creativity, insight, and innovation. These phenomena are accounted for better by the Gestalt psychologists approach to problem solving than by Newell and Simon s approach (Holyoak, 1995), albeit at a descriptive rather than explanatory level.

Summary of the objectives and overview of the thesis.

The first objective of the present research programme was to begin to identify the constraints of the task of orienteering from a psychological perspective, and the problems these constraints impose on the performer. The second objective of the research programme was to begin to identify any adaptations by experienced orienteers to the constraints of the task that appear to account for performance increases. Previous studies have attempted to address these objectives, and have begun to establish an understanding of orienteering, but have also been limited in various ways. These limitations included assuming constraints as self evident, not specifying sample sizes or sample demographics, and utilising methodologies that were not fully specified.

This thesis comprises three studies undertaken in an attempt to begin to address these objectives. Each study has been submitted as a paper for publication in an academic journal. The studies follow a logical sequence. In the first study (Chapter 2), attempts are made to identify the task constraints of orienteering, the problems these constraints impose on the performer, and adaptations of expert orienteers to those constraints. This is done by creating a theory of cognition in orienteering through the use of interviews with elite orienteers, and subsequent inductive qualitative analyses. In the second study (Chapter 3), differences between less and more experienced orienteers are explored at a behavioural level in a field setting. This study was conducted in response to a constraint identified as central to the theory proposed in the Chapter 2. In the third study (Chapter 4), two hypotheses are tested at a behavioural level in a laboratory setting. These are derived from the theory proposed in the first study, and the findings of the second study. In Chapter 5, the findings from all three studies are integrated and, subsequently, their theoretical and applied implications are discussed.

CHAPTER 2

A GROUNDED THEORY OF EXPERT COGNITION IN ORIENTEERING[1]

[1] An abridged version of this chapter has been submitted for publication in the Journal of Sport and Exercise Psychology.

Abstract

The objective of this study was to gain an understanding of expert cognition in orienteering. The British elite orienteering squad were interviewed (n = 17) and grounded theory (Glaser & Strauss, 1967) was used to develop a theory of expert cognition in orienteering. A task constraint identified as central to orienteering is the requirement to manage attention to three sources of information: the map, the environment, and travel. Optimal management is constrained by limited processing resources. However, consistent with research literature (e.g., Ericsson & Lehmann, 1996), the results reveal considerable adaptations by experts to task constraints, characterised primarily by various cognitive skills including anticipation and simplification. By anticipating the environment from the map, and by simplifying the information required to navigate, expert orienteers circumvent processing limitations. Implications of this theory for other domains involving navigation, and for the coaching process within the sport, are discussed.

Introduction.

The objective of this study was to gain an understanding of expert cognition in orienteering because such an understanding might have implications for an understanding of expertise, problem solving and navigation, and for the acceleration of skill acquisition within the sport.

Orienteering has received little research interest within sport psychology although it is distinctive in terms of possessing both highly cognitive and physical components. Winning is achieved by being the fastest to navigate through points, known as controls, in the environment. The distance from one control to the next is known as a leg. An orienteering course typically comprises 25 legs over 10 miles. Controls are symbolised by circles printed on a map, which is presented only seconds before the race begins and is carried with a compass during the race.

Whilst other perspectives exist (e.g., connectionism and self-organisation), investigations into expertise have typically adopted an information processing conceptual framework and employed an expert/novice paradigm, comparing individuals from across the continuum of skill, with the objective of isolating cognitive attributes responsible for skill differences (e.g., Chase & Simon, 1973a, 1973b).

It has been proposed that the possession of skill in humans is attributable principally to innate aptitudes (e.g., Galton, 1869) but while this issue is still contended (e.g., Howe et al., 1998), a more contemporary understanding is that expertise is attained through extensive experience (Simon & Chase, 1973) and deliberate practice (Ericsson et al., 1993).

The variable that is often proposed as the mediator in the relationship between experience and practice, and skill, is knowledge (e.g., Gilhooly, 1990). Domain-specific knowledge acquired through experience and practice is said to result in domain-specific adaptations in information processing. These adaptations are suggested to reduce processing demands on less adaptable, limited-capacity, basic visual and neural systems (Charness, 1988). Ericsson et al. (1993) suggested that an individual could overcome limits on speed and processing capacity by acquiring new cognitive skills that circumvent these limits by qualitatively different processes (p. 400) with deliberate practice. Furthermore, Ericsson and Lehmann (1996) stated that experts demonstrate evidence of maximal adaptation to task constraints (p. 273).

For example, early investigations of skill in sport (de Groot, 1946/1965) showed that expert chess players could encode game information rapidly, and in excess of the proposed capacity of short-term memory (e.g., Miller, 1956). In contrast, novices did not demonstrate this ability (Lemmens & Jongman, 1964, cited in Jongman, 1968). Closer investigations of this phenomenon provided evidence that experts recognised patterns of chess pieces on the board from long-term memory, and that pattern recognition enabled rapid encoding through the chunking together of pieces (Chase & Simon, 1973a, 1973b). The number of chunks encoded by experts was consistent with the proposed capacity of short-term memory, thus experts and novices did not differ in this capacity. The long-term storage of these patterns was suggested to reflect knowledge compiled through experience and practice. Interestingly, the concept of pattern recognition was proposed to account for expertise at a more general level, and still receives considerable research attention (e.g., Gobet, 1998; Gobet & Simon, 1998).

Another example of experts adaptations to task constraints is provided by research into fast-ball sports. Although expert athletes exhibit far greater anticipation than novices in these sports, athletes simple reaction times are equivalent to that of the general population (e.g., McLeod, 1987). Abernethy (1990) provided evidence that expert athletes possess a greater ability to recognise redundancy in the visual environment when compared to novices, and, therefore, are able to attenuate information that is to be processed to only the most pertinent cues. Experts also attend to cues occurring earlier in invariant movement sequences, such as an opponent s stroke in squash, when compared to novices. Consequently, experts can anticipate better than novices despite the groups equivalence in basic reaction times.

Again, this ability is attributed to knowledge acquired through experience and practice (Abernethy, 1990). This position is encapsulated by Annett and Kay (1956): In an invariant sequence of events the skilled man views all his information at its beginning; the unskilled is waiting to receive what is, if he did but know it, redundant information (pp. 114-115).

In summary, chess demands that board information be processed rapidly. Experts adapt by chunking together chess pieces, which results in the rapid encoding of information. This ability is afforded by knowledge acquired through experience and practice. Furthermore, fast-ball sports demand a rapid response time. Experts adapt by selecting only the most pertinent information from early in opponents movement. Again, this ability is afforded by knowledge acquired through experience and practice. In both domains the cognitive skills employed by the expert circumvent processing limitations to afford performance benefits, providing evidence of experts maximal adaptation to task constraints.

It might be argued that chess is a highly cognitive sport that requires little or no motor skill. In contrast, fast-ball sports are highly physical and require substantial motor skill, but posses a smaller cognitive component than chess. However, as suggested above, orienteering is a distinctive sport in that it possesses both highly cognitive and physical components. Any adaptations to the sport of orienteering by skilled performers may be of interest to sport psychologists because they may contain elements of adaptations to both predominantly cognitive sports, like chess, and predominantly physical and motor skill sports, like fast-ball sports. Therefore, the objective of this study was to gain an understanding of expert cognition in orienteering through the detailed identification of the constraints that exist in the sport of orienteering and of the possible adaptations of the expert orienteer to those constraints. Ericsson et al. (1993) proposed that further research into the characteristics of expert performance would provide a much deeper understanding of the possible adaptations and methods for circumventing processing limits so as to achieve performance benefits.

Traditional methods of investigating expert cognition have analysed expert behaviour through laboratory-based experiments using contrived tasks (e.g., de Groot, 1946/1965) or through the observation of experts in the performance of a familiar task (e.g., Gilhooly et al., 1997). Both approaches have also been accompanied by verbal protocol analysis (Ericsson & Simon, 1980), whereby individuals are required to introspect and verbalise their thoughts concurrent with the task. The protocol produced is recorded for analysis. Examples of the use of verbal protocol analysis in contrived and familiar tasks include the studies by de Groot (1946/1965) and Gilhooly et al. (1997) respectively.

Traditional methods of investigation are problematic in orienteering. There are few opportunities to observe orienteers performing their familiar task; typically, orienteering takes place in forest. For example, these problems result in reliance by coaches on recall by the athletes for performance-related information. The authors of the present study have attempted to obtain verbal protocols during orienteering but this method is limited by intense respiration and motivational self-talk. Contrived tasks, e.g., in chess studies (e.g., de Groot, 1946/1965), have typically taken place in, and have been suited to, static laboratory conditions. However, laboratory-based studies of orienteering would be of low ecological validity. Starkes and Deakin (1984) remarked that the size of the discrepancy between any contrived task and the real-world task is inversely proportional to the probability of discovering expert/novice differences. Consequently, a contrived task might not reveal the marks of mastership (de Groot & Gobet, 1996, p. 2) that de Groot (1946/1965) found so elusive, even when his domain of investigation was chess.

With regard to the problems of traditional methods of investigation in this domain, this study employed what is, essentially, the coaches method of investigation, that of interviewing, with the goal of creating a theory of expert cognition in orienteering. Whilst the use of introspection not concurrent with task performance is controversial (Ericsson & Simon, 1980; see also Nisbett & Wilson, 1977), Ericsson (1996) has argued that expert behaviour involves cognitive mediation that can be verbalised.

This study used grounded theory to analyse interview data (Glaser & Strauss, 1967). The strengths of this approach are two-fold: first, interviews yield much rich, diverse and detailed information, which is appropriate for a domain that is under-researched and, hence, not currently understood. Second, grounded theory allows the elicited information to be analysed inductively: in contrast to traditional hypothetico-deductive research approaches, the investigation of cognition in orienteering need not be constrained by prior theory; rather, theory can be generated from, but remain grounded in, the actual information elicited from the orienteer.

Furthermore, in contrast to alternative methods of analysing qualitative data, e.g., verbal protocol (Ericsson & Simon, 1980) and content analysis (Weber, 1985), grounded theory is not quantitative, and is not constrained by an imperative to operate in a reductionalist manner. For example, it does not involve counting the number of units of data categorised under any given concept, to discover the frequency, and, hence, the importance of that particular concept. In contrast, the frequency-equals-importance assumption is abandoned in favour of an approach where the goal is to elicit richness and diversity, collecting a set of different data units that point to the multiple and qualitative facets of a potentially significant concept (Pidgeon & Henwood, 1997, p. 261).

Despite claims that grounded theory is inductive, it is important to consider the role of the researcher in the research process. Glaser and Strauss (1967) acknowledged that no researcher enters the research process with a tabula rasa. This acknowledgment dictates logically that the researcher will affect the research process to a greater or lesser extent, i.e., grounded theory research cannot be conducted entirely inductively. As Pidgeon and Henwood (1997) suggest, the research process within the grounded theory approach is flip-flop (p. 255) in nature: the elicitation of theory is a combination of both the raw data, and the ideas and understanding of the researcher. This constitutes a constructionist revision of grounded theory at an epistemological level (Charmaz, 1995; Pidgeon & Henwood, 1997).

Given this revision, we believe it important to declare our research activities prior to this study as these might have influenced our constructions of the data. Before data collection we had limited knowledge of how the orienteer executed the task of orienteering. We believed that we were unlikely to prejudge the results of this research in terms of any specific theory of how orienteers executed their task. At the same time, as researchers we work predominantly within the popular and dominant information processing conceptual framework. We briefly explored the literature on expert adaptations prior to this study since this underpinned our objective to isolate cognitive attributes responsible for skill differences. However, Charmaz (1995) recommends delaying literature reviews until after data collection to avoid the influence of previous research on the analysis of the data. Therefore, the researcher responsible primarily for data collection and analysis did not explore the literature on navigation until after the analysis was complete.

A pre-defined data collection procedure is inappropriate in grounded theory; interviews comprise open-ended questions, use elaboration probes, and expand to pursue all new lines of investigation. Following collection, data are stored and coded. Coding involves generating categories that represent the concept underlying a unit of data. In the early stages of analysis, this occurs at a low conceptual level. As more data are analysed, concepts are built upon, modified, and possibly merged with, or split into two or more concepts. Data units may contain more than one concept and, hence, may be coded more than once.

Two methods, constant comparison and theoretical sampling, are used during coding. Constantly comparing new with established units within concept categories shapes the modification of concepts and pursues issues concerning the full range of types or continua of the category, its dimensions, the conditions under which it is pronounced or minimized, its major consequences, its relation to other categories, and its other properties (Glaser & Strauss, 1967, p. 106). Using this method, theoretical properties of a concept are embellished. There is also an active search for negative cases that contradict the emerging concept. Theoretical sampling involves sampling theories emerging from data with new sources of data that may, in turn, modify that theory. The uniqueness of grounded theory lies in this iterative process, whereby constantly moving between data collection, storage, and analysis facilitates an understanding of emerging concepts.

Eventually, coded concepts emerge into a language that represents the entire data set. This language of codes may be refined further through repeated theoretical sampling. Memos are written to document the ideas of the researcher regarding the research process and development of concept categories, and are updated cumulatively; at any stage in the research earlier thoughts can be revisited. Concept categories should eventually become saturated, in that there appears to be no further contribution from the data to the understanding of any given concept. A definition of each concept, informed by prior memo writing, is then created.

Definitions facilitate the final integration of concepts into higher order theory. Integration involves studying relationships between concepts whereby a structure of the interrelations of concepts is allowed to be created. This process is often aided by diagrammatic representations of how concepts are interrelated.

To summarise, the objective of this study was to gain an understanding of expert cognition in orienteering through the detailed identification of the constraints that exist in the sport of orienteering and of the possible adaptations of the expert orienteer to those constraints. Such an understanding might have implications for an understanding of expertise, problem solving and navigation, and for the acceleration of skill acquisition within the sport. In an attempt to meet this objective, an analysis of interview data using grounded theory was employed to create a detailed theory of expert cognition in orienteering.

Method.

Participants.

The whole of the British elite orienteering squad (nine men and eight women; mean age 30.1 years) were recruited. Participants possessed the two characteristics of expertise commonly reported by the research literature: each deliberately practiced orienteering (Ericsson et al., 1993), and had done so for at least 10 years (mean = 16.9 years) (Simon & Chase, 1973). Also, participants regularly competed at international level, and many were ranked among the top 20 performers in the world, with a small number achieving medals at world standard competitions in recent years. One is currently world champion. Whilst orienteering is officially an amateur sport, many participants receive funding in order to work part-time and train, for the remainder of their time, for orienteering competitions.

Interview guide.

An interview guide (Patton, 1990) was used and open-ended questions were employed to minimize the imposition of predetermined responses (Patton, 1990, p. 295). Questions were succeeded by elaboration probes (Patton, 1990); a sample is shown below.

So how would that work then?

Is that always the case?

I m not sure I understand that, could you explain that again?

Ten original interview guide issues were developed after piloting the study with one recreational orienteer. Issues were informed by the objectives of identifying the task constraints that exist in orienteering and the possible adaptations of the expert orienteer to those constraints. For example, one issue concerned the map: how does the map help you? A sample of typical questions asked, in order to better understand this issue, is shown below.

Please describe to me how you decide what information to use from the map in any given leg?

What do you first look for on the map when faced with a leg?

How is the map of use during navigation?

The number of issues was allowed to grow across interviews to cover new issues pertinent to the investigation. Questions became more specific as theoretical developments were made.

Procedures.

Each participant was contacted by mail, and subsequently by telephone, in order to request and arrange an interview, and was informed of their anonymity in the research and that all data would be treated confidentially. All participants agreed to an interview, which took place either in their home (n = 11), at their workplace (n = 3), in a restaurant (n = 1), in travel accommodation (n = 1), or at Lilleshall National Sports Centre, Staffordshire, England (n = 1).

Interviews lasted between 37 and 105 minutes (mean = 68 minutes), and were tape-recorded. Notes were also taken. The interviews were stored, as two taped copies, and as verbatim transcriptions that included a code representing para-linguistic information (Silverman, 1993) that aided interpretation.

Additionally, one participant gave a talk at Lilleshall National Sports Centre regarding elite orienteering techniques. This was tape recorded and transcribed. These data were included in the analysis; this second source of information constituted a triangulation of data (Denzin, 1978). Two participants contributed further, by electronic mail, having contemplated questions from the interview. These data were also included in the analysis.

Ideally, a number of early interviews should be fully coded prior to later interviews for the purpose of theoretical sampling. This is not always possible due to various constraints (Pidgeon & Henwood, 1997). In this case, constraints involved accessing participants: a large number of the participants had to be interviewed in a short amount of time. As a consequence, concepts were identified at various stages: by mental and literal note taking within interviews; during reflection after interviews; whilst listening during the copying of interview tapes; and, for the majority, during transcriptions.

The number of interview issues grew as new lines of investigation were pursued, and as concepts were sampled. Eventually, concepts became saturated; the final interviews became increasingly confirming in nature.

All procedures were conducted with regard to trustworthiness criteria in qualitative research (Lincoln & Guba, 1985): the researcher was engaged for a prolonged period (nine months), persistently observed the participants, triangulated data, engaged in peer debriefing, searched for negative cases, retained one participant s data for referential adequacy, used process and termination member checks, and provided an audit trail and reflexive journal.

Analysis.

All interviews were fully coded and analysed using QSR NUD*IST 4 computer software. This program facilitated the storage of all data, codes, memos and definitions. Automatic storage of information by computer contributed towards an audit trail and reduced the chance of accidental data loss compared with a traditional card system.

Results.

Introduction.

A variety of concepts emerged from the analysis. The properties of each concept and the links between concepts are explained below in terms of the direction and type of influence of one concept to another. As each concept is explained, its context within an overall theory of expert cognition in orienteering is demonstrated in Figure 2 by numbered pathways. A transcript of the interview retained for referential adequacy is found in Appendix 1.

The performance criterion.

The performance criterion in orienteering is time. As Figure 2 demonstrates, all factors in the processing of map information ultimately exert their influence on performance time. An example of the importance of saving time is given below in which the orienteer is discussing the benefit of remembering the control codes in advance.

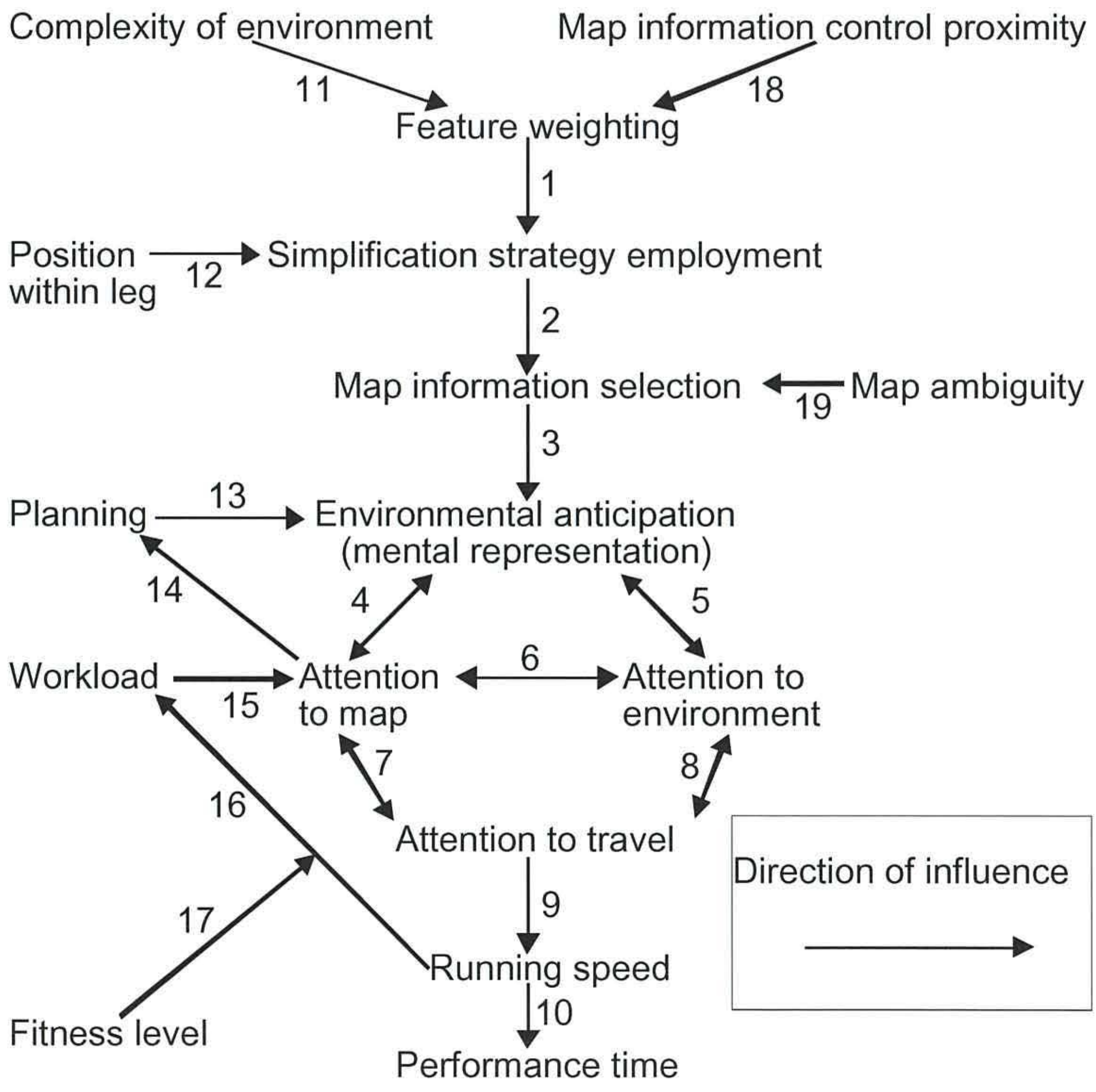


Figure 2: A Grounded Theory of Expert Cognition in Orienteering.

The control code must be checked by the orienteer at his arrival at the control, so that he can confirm his position.

> If you knew you were after 563 you didn t have to open your map up because you ve remembered it, there s a second saved

Also, consider the following quotes as evidence of the importance of time.

> One of the mistakes people make [in orienteering] is that they try and rectify a mistake, they try and catch up for it. You just can t, time is lost.
> If you make a mistake . . . you ve hardly got any time to correct it. If you lose a minute . . . then you can say good-bye to winning.
> [Orienteering is concerned with] looking for the shortest time between two spots [controls].

The fundamental role of the map.

The controls are marked on the map, a printed symbolic representation of the environment. A comparison of both the printed map and the environment must be made in order to find the controls and, in turn, complete the course as quickly as possible. Consider the response from this orienteer when asked whether he believes the navigational skills of the elite orienteer can be developed any further.

> You ve got a map, you ve got a piece of ground, and you have to relate the two together...so long as those two elements are still there I don t see vast changes [in navigational skill taking place].

In addition, consider the following quotes.

> The map isn't the terrain, the map is a representation of the terrain and you have to translate the map in order to be able to use it. I'd turn it into a picture to be able to relate it to the actual terrain that it's supposed to represent.
> If you practice . . . you can see a map and transfer it to what you re looking for on the ground. . . . Likewise, you can look at a piece of terrain and see the subtleties between five different hills to establish that it can only be this hill [on the map] that we re at.

Two methods of comparison.

The elite orienteer has two methods of relating, or comparing, the map and the environment. As the map is only a representation of the actual environment, the orienteer must transform the printed symbols into a mental representation. The transformed mental representation is then compared to the actual environment experienced by the orienteer. This method of comparison is known in orienteering as map-to-ground. Consider the following evidence of this method of comparison. This elite orienteer is anticipating, from the map, what he will experience as he moves through the environment.

> There s three more hills there, I ll skirt around the left of them and then there s that crag and there s a new re-entrant there, but I ve got to be careful because there s another re-entrant to the right of it.

In the reverse method, known in orienteering as ground-to-map, the actual environment is transformed into a mental representation, and, in turn, compared to the map. The following example provides evidence of the existence of this method of comparison.

> If I do see a feature, I ll always want to know where it is on the map...if I see something on the ground that I ve not thought about or not seen on the map yet, I ll want to know where it is [on the map].

The employment of these methods of comparison in the navigational process depends on a number of factors that are discussed later.

The mode of the mental representation in elite orienteering.

Elite orienteers provide unclear evidence as to the mode of mental representation of map information. Compare the following two quotes.

> Some people might [picture the terrain]...it s always described as a mental picture...I don t think you can really do it...you have an idea...of what is acceptable...what the shape of the ground and the nature of the ground may be, and when you see that in the terrain...you re deciding, Does this fit with my idea.
>
> I don t have this picture of what I m looking for but when I see it I can relate it to other experiences I had, so very sharp V-shaped re-entrants, you know, is the type where you have a stream in it, you know, almost like a gully we d call it...that s the important thing I think, is I don t picture what is coming up, I know exactly what I m looking for.

The representations of map information reported by the elite orienteers above appear to be consistent with the notion of a propositional mode of representation. They are more abstract and language-like than the reports of the representations by the elite orienteers below.

> You actually visualise a hill so you've converted the...black, the...ink and paper symbols to [an] actual 3-D image...and there it was...there was the

> hill...so in that respect it's actually...a visual representation of the ground...you've got a picture of the ground...in your mind
> As soon as I look at the map...I can see a picture immediately in my head

These reports appear to be consitent with the notion of an analogical mode of representation; the elite orienteers talk of actually seeing images in the mind. Consider the visual detail reported in the following example.

> This boulder on the side of the hill...I've still got a picture of it [from the map] in my mind now...it was covered in bracken and...the terrain didn't quite match up there was a couple of trees...but it was pretty close I look at the map I convert the ink and paper to a to a full image and it'll be covered in trees and I'd guess it's in colour

This orienteer reports that his mental image was so embellished that he could tell that the map was incorrect. There was a discrepancy in the number of trees between the elite orienteer s mental representation of the environment, transformed from the map, and the actual environment. The orienteer also speculates that his image is in colour.

In summary, the mode of representation in elite orienteering is unclear; evidence of both propositional and analogical representations exists. Regardless of the mode, it is also worth noting that elite orienteers appear to have the desire to form a well-developed mental representation from the map.

Attentional limitations.

In order to move through a continually changing environment the orienteer must attend to both the environment and the map for the purpose of continual comparison. Recall that the performance criterion is time, the orienteer must move as fast as possible through the environment to achieve a good performance. To achieve this goal, the orienteer must also attend to travel through the environment. As the example below demonstrates, elite orienteers can compete in difficult environments.

> Some of it was the most hideous tussocks you ve ever come across in your life and you could neither run in-between them or on top of them because they re kind of grown-over tussocks

When using either method of comparison the orienteer must attend to the map, and to the environment, for the purpose of comparison, and, therefore, cannot concurrently attend to travel. The pressure of time causes a competition of attention between these three stimuli:

1. The map, for the purpose of comparison
2. The environment, for the purpose of comparison
3. Travel, for the purpose of safe and effective running

Figure 2, via pathways 6, 7, 8 and 9, demonstrates the relationship between the three stimuli and the influence of the allocation of attention to travel on running speed.

The orienteer is continually required to allocate attention to one of the three sources of information and calculates where attention will be best invested. When attention is not intelligently allocated the ramifications can be serious.

> After looking at the map for I don t know how long but a very long time to make absolutely sure that I found the control, I realised that I hadn t looked at anything else for far too long, and as I looked up there was a tree. I ran straight into it

The following orienteer demonstrates the effect of allocating attention away from the map.

> It s...a lot easier to move through the terrain when you re not looking at the map

Here the elite orienteer demonstrates his strategic knowledge in orienteering by explicitly planning to allocate his attention.

> As I am approaching a control [I] try to work out the visualisation of what s in the circle so I can go in with my head up rather than trying to read the map and therefore I [haven t] gone right past the control because I m looking down at the map

An optimal balance in the allocation of attention.

As demonstrated, as the orienteer moves through the environment, the map, the environment, and travel all require attention. Allocating as much attention towards travel as possible is the goal, and, thus, allows the orienteer to move through the environment as fast as possible. However, an increase in attention to travel means a decrease in attention to the comparison process, and therefore an increase in the risk of getting lost. This constitutes a trade-off between running speed and the probablility of error. The elite orienteer must allocate attention intelligently to provide the optimal balance in attention between the three suorces of information. An optimal balance will yield the greatest performance benefits. The following quotes provide evidence for these propositions.

> It s very rough [underfoot and] . . . you re glancing at your map, desperately trying to get the information but keeping the speed up, and because it s so rough . . . it s a split second look [at the map], . . . five seconds or three seconds looking ahead, and another glance down [at the map].
>
> What determines how long you look at it [the map] is how long you need to get the information from it, but also how long you can look at it without running into something or falling over or breaking a leg. . . . So you ll be concentrating on looking at the map and you ll just glance up to make sure you re not going to trip into anything you run over.
>
> All the information you re trying to get from the map, . . . it s always got to be balanced against how fast you re running. . . . The faster you re running . . . the less you want to look at detail on the map. It becomes a matter of judging how much you trade off: . . . the amount of detail you re looking for and how much you re running.

The ceiling effect in map reading in orienteering.

Interestingly, due to the problem of allocating attention, performances differences between the genders may become less evident at elite level orienteering, as this orienteer demonstrates when asked how elite orienteering will develop.

> I think you'll notice more of the men s performances don't come down very much and the women s performances catch up because there's never been much depth in women's orienteering I think orienteering has a limitation on how fast you can actually run and still read the map so unlike just running sports there has to be a stopping point with the men where they will no longer be able to run any faster because they've still got to navigate whereas the women we're behind that, we we've still got room to catch up on [the men].

Consider, also, the following quote.

> I think though as people get faster and faster the speed at which you can take in information is always limited to some extent.

The previous quotes suggested that ceiling effect exists whereby the orienteer can only increase running speed to a threshold point, after which attending to the map, for the purpose of comparison, becomes impossible. This would appear to be because at the threshold point too much attention is allocated away from travel in order to look at the map, thereby making running unsafe and ineffective. Also, too much time allocated away from making comparisons with the actual environment may cause information in the environment to be missed, thus increasing the chance of error.

The constraints of work intensity.

The competition of attention is certainly a factor contributing to the ceiling effect. However, this is not the only contributing factor. Consider the following quote.

> I was looking for a very small feature on an open moor land, my legs were completely full of lactic acid and I was in total oxygen debt and I knew roughly I could get myself within fifty metres of the control but the map was blurred I couldn t focus on the map for about ten seconds therefore I know as long as I slow down it s going to disappear and so the focus came back again, then I could start and I could see things and then there it was but I missed, that was forty-five seconds gone and I felt annoyed with myself because it was mainly because I pushed too hard right from the beginning.

The quote above provides evidence that the level of work intensity also dictates the opportunity to read the map. It might be speculated that both factors, the problem of attention allocation, and a high level of work intensity, are additive, in that they both contribute to the ceiling effect.

The level of fitness of the orienteer moderates the limitations on map reading imposed by level of work intensity. If the orienteer becomes fitter, the level of intensity at which map reading becomes problematic is reached at a higher workload. The constraints of the level of work intensity on attending to the map, and the moderating effect of exercise on this relationship, are both demonstrated in Figure 2 via pathways 16, 15, 7, 9, and 17. Consider the following evidence.

> The thing about the physical side is that you need to feel comfortable enough to navigate.
>
> The fitter you are the much easier it is to navigate because you re not tired all the time from running you can pick up things on the map much easier.

The anticipation strategy.

To reiterate, allocating as much attention towards travel as possible is the goal, for this enables safe and effective running, and, thus, allows the elite orienteer to move through the environment as fast as possible. In order to attend to travel the elite orienteer strives to minimise attention to the comparison of the environment and the map. The elite orienteer employs two key strategies to achieve this, the first of which is discussed here. In this first strategy a mental representation of the anticipated enviroment is transformed from the map. This anticipatory strategy therefore utilises the map-to-ground method of comparison. This is noted in this next quote.

> It s a vision of what the terrain s going to look like when I get there. It s not where I am. It s where I m going to be.

This orienteer is not transforming information from the map in relation to his present position; he is manufacturing a representation of the environment that is still some distance from his present location in the direction of his intended travel.

Remembering the information in advance reduces the need to attend to the map for *continual* comparison with features in the environment. Attention can therefore be allocated to comparing the anticipatory mental representation to the environment, and to travel. Consider the following quotes as evidence of this phenomenon.

> You can visualise whole legs [in advance] and then not need to look at the map [as you run the leg], particularly if it s a shorter leg.
>
> You have to have a plan of where you re going. You ve extracted the information from the map that you need, that s ahead of you. [You] go to that [point in the environment] and you don t really need to look at your map again before you get to that [point in the environment].

Figure 2, via pathway 4, demonstrates the relationship of the anticipatory strategy to the need to attend to the map. The following example provides evidence that this strategy increases running speed.

> Just to be knowing what what you re going to see you can just go that bit quicker.

This orienteer demonstrates that anticipation becomes a continuous process.

> Even though you can see where you re going for the next hundred yards ..you re still thinking Right, what s the next hundred yards after that going to be like so that before every section of forest you re working out the next section and you ve got [a] continual cycle of information that you re creating.

Consider the following quote that provide further evidence of anticipation.

> When you are going well you just can t stop yourself knowing what s coming next .You re just looking at the map and you just think Yes that s next, that s next, that s next.
>
> You look at the map and typically you ll visualize a static picture of what s coming up next, a little sort of tableau of on your left a largish hill shaped like a banana, on your right two small knolls [and] a sort of spur sticking out.

Planning ahead and route-choice decision making.

As the evidence above suggests, the mental representation of the environment anticipates the environment that is some distance ahead of the position of the orienteer. The orienteer is continually planning ahead to solve problems concerning choosing a route through the environment and, in turn, to update the manufacture of the anticipatory mental representation.

> It s a big advantage to have a plan, to know what to expect. You have to have a plan for the whole [upcoming] leg which will say I m going to pick up on that, that, that, and then when I get to this point I m going to start fine orienteering to find the control.

The influence of planning on the anticipatory mental representation is demonstrated in Figure 2 via pathway 13.

An early scan of the whole course or of individuals legs that are some considerable distance from the orienteer affords a basic level of information about that area of the environment. As the orienteer travels closer to that area, there is an increase in the number of times the orienteer attends to the map. In this way route choice problems can gradually be solved and more pertinent information can be included in the anticipatory representation. Consider the following quotes.

> You look again, you look again you maybe just build it up in layers I think you glance at the map several times until you re happy with this impression in your head so you ll do that and then you ll look away and you ll think back to it and you ll think No, I haven t got enough for what the situation is and you ll probably look again and after each look you re probably building a layer on to the detail that you have in your mind.
>
> When I m planning ahead I ll be looking more at the next two or three I wouldn t be planning leg fifteen when I m early on.
>
> You always plan the whole leg you tend to look at it in advance, you might even plan the legs two, three, four in advance or at least you ll have

> looked at the whole course probably so I tend to look at the course but in less and less detail [the] further [it is] away from where I am.

There are two cases where the orienteer attends to an area on the map with a frequency greater than normal. These areas are planned in some detail despite being some distance away. Firstly, the following quote provides evidence that the area around the control is given special consideration.

> We were always taught you plan backwards from the control you re going to because the tricky bit is at the other end [where the control is] not at this end I don t really think I do that. I plan and look for a way into it because there s ways that are better to approach a control.

The implications for the development of the mental representation, of the area close to the control, are discussed later in more detail.

Secondly, special consideration is given to long legs where an increased number of route choice decisions have to be made before a representation can be manufactured.

> You might look at all the legs for the entire course [and] establish that that leg at the end is two k [kilometres] and will have a lot of route choice. Route choice takes time because you have to take in [a] big piece of map and there are an awful lot of options to establish whether route A, how much climb it s got, as against route B which maybe a lot further, so right from the start you re planning ahead maybe seventy minutes and you ll remember that if you ve decided you might not make that decision right at word go because you haven t got enough time you might [think] OK I ve established that there are two options just to start off with later on in the course you might try and establish which one is the best option and then once you ve established the best option [at] another point in the course you would establish how you re going to execute it.

Planning opportunities.

As the evidence above suggests, the attention of the orienteer is in great demand. The map, the environment, and travel all compete for attention and as a consequence the orienteer has very few opportunities to plan ahead. Opportunities are afforded when the orienteer has less need to attend to any or all of these three. Consider the following quotes.

> Say if you re doing something very simple where you ll know you ll be switch[ed] off until you get there you can be thinking about [planning].
> Sometimes you get an opportunity to plan ahead legs so say I ve got a 2k track and I m down a track for 1k of it for that k of running [I] look at the map look at the routes ahead depends what your terrain your on if you re on a track then orienteers get very good at running without looking at their feet.
> A lot of this planning ahead will be on roads where you know you re not going to run into stuff or perhaps when you re walking up a hill early on in a race and you can have ten seconds, I d say they re the longest looks is (sic) when you re going up a hill.

Figure 2, via pathway 14, illustrates how attention to the map is necessary for planning ahead.

Supplementary information.

The method of comparison by the elite orienteer is predominantly map-to-ground, and anticipatory, during navigation. However, the elite orienteer also compares information from the environment to the map, by manufacturing a mental representation of the environment. As discussed earlier, this method of comparison is known as ground-to-map and is used by the elite orienteer to provide supplementary information during navigation.

> If I see something on the ground that I ve not thought about or not seen on the map yet, I ll want to know where it is [on the map].

The elite orienteer uses the supplementary information from the environment to confirm his or her position on the map. In turn, positional knowledge can be used by the orienteer to monitor progress, in terms of the distance travelled through the environment, on the map.

> When you[re] actually running the leg you ll find more details on the leg when you re planning ahead you can t really remember all those details so you just really [remember] the big feature that you re [running to] [these extra details are] giving you an idea of [the] distance that you ve travelled.

Despite the benefit of information provided by the ground-to-map method of comparision, the map-to-ground method of comparison predominates as a consequence of the performance benefits this method affords. The next quote demonstrates this.

> If I see something on the ground that I ve not thought about or not seen on the map yet I ll want to know where it is which slows you down because you re having another look at the map but I try to stop myself doing that.

Information retention.

The elite orienteer also appears to retain some mentally represented information regarding the earlier environment in case of a navigational error. This elite orienteer describes an error by stating that the actual environment does not fit his mental representation of the environment transformed from the map.

> It s almost like you ve got a sort of circular bit of memory and this is just moving forward on the course so wherever you are on the course your mind is just working that bit ahead, possibly even a little bit behind just in case you get, things don t fit, and it just carries on sort of rolling along as you move along processing slighty ahead of where you are.

Relocation.

The orienteer becomes aware of navigational error when the actual environment does not compare to the mental representation of the environment. The following quote demonstrates this phenomenon and the repeated use of the term fit .

> You just feel well this isn t fitting there shouldn t, this valley s going off in the wrong direction it s just the feeling that things aren t fitting and you re coming across things that you re not expecting and Hang on a minute I hadn t remembered this, is it that I didn t pick it up from the map, so you go back and check did I just ignore this wall on the map or have I gone wrong.

In the following quote the orienteer describes his mental representation and then demonstrates how the environment does not compare.

> The signs are a patch that isn t all fitting together you come to the road junction and it s a forty-five degree angle in from there and it s a stream and it s downhill, and you come to that junction and you look down hill but there s no stream, and all of a sudden you think, Well hold on a minute there should be a stream here.

When an error has been made the information retained in memory is used to identify the last known point of sucessful comparison. Information from the current environment is also compared to the map using the ground-to-map method of comparison. Both strategies are used to relocate; that is, to identify the orienteer s position on the map. The orienteer can then revert to the anticipatory map-to-ground method of comparison and continue through the environment.

Memorial limitations.

The elite orienteer strives to maximise the anticipatory mental representation, thereby reducing the need for comparison with the environment. However, the following quotes reflect the limitations of the elite orienteer s memory for map information.

> I couldn t remember the whole leg, all the information of it, so you just have to pick out big features.
> When you re planning ahead you can t really remember all the details [from the map], so you just [use] the big features.
> [How much I can anticipate] depends very much on the level of detail in the map. If it s an area like this [referring to an easy area on a map] you can do the whole leg, but in a more complicated area you d maybe end up taking maybe 50 metres at a time.

Further evidence of the elite orienteer s strive to remember as much information as possible is reflected by a training exercise.

> I ve done map memory exercises where I have consciously, you know, you try and remember a leg and run it you just look at a leg for maybe ten seconds, take the map away and try and find the control.

Simplification strategy.

As a consequence of the limitations of memory, and of the strive to minimise attention to the comparison of the environment and the map, a second strategy, simplification, is employed. By selecting minimal but specific map information for comparisons with the environment, orienteers appear to make the most efficient use of the information available. If the simplification strategy is used, resources are freed up and can be allocated to travel, hence running speed can be increased. In addition, if the simplification strategy is used the orienteer need not remember as much information from the map when trying to anticipate a given distance in the environment; that is, simplification aids anticipation. Consider the following quotes as evidence of these propositions.

> The desire to do well in a race creates an imperative that says I need to get everything right I need to do this as quickly as possible therefore I need to know exactly the information that s going to take me around the course but no more the most efficient use of the information available.
>
> When you re running at top speed you re not able to take in all the detail on the map so you have to simplify it, so you re just picking up the major features and navigating by them if you can improve on that you re obviously able to run faster because you don t need to take in as much detail if you took in more detail you d have to be slower to look at the map longer to take it in so that could waste time if you only have to notice one thing then [you can] run to that quicker.
>
> I think though as people get faster and faster the speed at which you can take in information is always limited to some extent people are developing strategies whereby they simplify picking out major features important features so they can run hard.
>
> If it s a very detailed then there s a lot more that your brain s got to process, you ve got much more to try and hold in your head. Whereas if you ve managed to simplify it down to quite big things [that are present in the environment] you ve got less to process, so you can think further ahead.

The following quote provides evidence of how simplification facilitates anticipation b anticipation.

Information selection.

The following examples demonstrate how the simplification strategy affects the selection of information from the map.

> I mean any obvious large contour features, ridges, and obviously preferring the big, obvious, easy features to start with I mean you don t really want to be picking your way too much you want to be able to run fast it d just be picking up the big obvious features unique features.
>
> So the first bit is just really breaking it down into the simplest quickest way of getting near the control and the information you d be looking for would just be the biggest most obvious features on the map things like big hills or roads or whatever.

The last quote provides evidence that the process of the selection of map information is dictated by how distinguishable the information is in the environment. Less distinguishable information is less likely to be selected from the map and transformed into the mental representation used for comparison. Map information evidently lies on a continuum from having no distinguishable or visible properties, to having very distinguishable or visible properties. The selection of information from the map is dictated by the employment of a weighting mechanism. The nearer the information to the latter end of the continuum, the higher the weighting placed on that feature. The higher the weighting, the more likely the information is to be selected. The example below demonstrates the selection process further.

> Trying to simplify things, trying to pick out big things but when you just really can t simplify things you pick out the smaller details and navigate by those.

High-weighted information, in the environment, can be sighted from a distance. This is because running directly to a seen feature negates any recourse to the map, or to making comparisons, and, therefore, attention can be allocated to travel and performance time is improved. Consider the following scenarios.

> As soon as you see the control that s dead time you don t need to read your map from that point on to the control because you can see it just get to it as quick as possible.
> [If] you could see a big feature ahead you could run full, flat out.

Distinguishable information as the determinant of environmental complexity.

In orienteering the nature of the environment can vary both within a course, and between courses and can be more, or less, complex in terms of navigation. It is the presence of distinguishable information in the environment that determines complexity. The more distinguishable information present, the less complex the environment. This orienteer is contrasting high and low complexity environments respectively.

> If you look at it there s absolutely nothing that jumps out at you, it s just a complete mess so you have to look really carefully to pick out information and it all looks pretty much the same, you have to look very carefully to note the slight differences in the shape of the hills whereas some terrain is great big hillsides a network of forest roads, it s dead easy.

Often there is a scarcity of distinguishable features in complex terrain:

> There s like low visibility of where you re running so even if there are features, you can t see them another scenario is there s features but they re not very distinguishable, so [the terrain] might only have a height difference of five metres you ve got contours on it [the map] but you can t tell whether you re on that little wiggle or that on.

In complex environments the simplification process is made difficult due to the scarcity of distinguishable information in the environment. The orienteer is forced to manufacture a representation based on less distinguishable information selected from the map. In turn, in order to navigate more map information is selected in any given distance, and, therefore, less anticipation is afforded in the mental representation. The quotes below demonstrate the effect of environmental complexity.

> If you re looking at the control circle on simple terrain, like a big re-entrant, and you re thinking OK, over the hill, and it s that big re-entrant behind it that s all the information you need. If it s a very intricate area you might be thinking Well, I m going over the first hill, and there s three more hills there, I ll skirt 'round the left of them, and then there s that crag, I ll just get down that, and there s a new re-entrant there, but I ve got to be careful because there s another re-entrant to the right of it which looks very similar, and you know suddenly there s fifteen, twenty items in the [control] circle, rather than just maybe one or two, and you need to be aware of that It would be impossible to simplify it If you just blast in at the same speed as you do in a simple area you ll almost certainly miss [the control].
>
> The more intricate the terrain the shorter you re looking ahead.

Sand-dune topography tends not to vary greatly in height or shape across a given area. Consequently, there are very few distinguishing features.

> These sand dunes if you lost where you were on the map at any time you were lucky to find your way again so you had to keep in contact all the time, so then [it] was really hard to remember the whole leg, you had

to keep checking, every time you went over a dune you had to check which one you were on.

Figure 2, via pathways 11, 1 and 2, demonstrates the influence of the nature of the environment on feature weighting and, in turn, on the employment of the simplification strategy, and, in turn, on the selection of map information.

Position on the leg; implications for simplification and mental representation.

The orienteer s position on the leg also determines the employment of the simplification strategy. The position of the orienteer is also the determinant of the amount of anticipation in the mental representation. When the orienteer is still some distance from the control, any inaccuracy in navigation can be corrected with negligible ramifications. However, the orienteer must navigate more accurately near the control circle in order to locate the small control flag. For this reason, the middle section of the leg is referred to as the rough part, and the area around and including the control circle as the fine part.

In this situation, in order to navigate more accurately, the elite orienteer must include more map information in the manufacture of the mental representation. A reduction in the employment of a simplification strategy causes a concomitant reduction, in terms of distance in the actual environment, in anticipation in the mental representation. Instead, more information is selected within the smaller area of the control circle. Note the limitations of the representation reflect the limitations of the orienteer s memory for map information. The following quotes provide evidence for the differential use of simplification, and the differential nature of mental representation, with a change in position on the leg.

What you do is you visualise the area around the control in detail and the area from the start to the area in the immediate vicinity of the control very roughly

The first bit of the leg at that stage in the leg you re going to be trying to run quite hard, not too much of the detailed information on the map you[re] very much simplifying in that bit, when you come close to the control there s sort of [a] gradient [in terms of] how much detail you do

want at that point you do need all the detail.
When you re doing the first bit of the leg there s more room for correction if you hit a path a few metres up [from where you wanted to be] then you, you know, [it] doesn t really matter too much, but if you re a few metres out from the control [and] you don t see it and you ll waste a lot of time.

Figure 3 demonstrates how the orienteer s position within a leg might affect the level of employment of the simplification strategy and the content of the mental representation in any given distance in the environment. It also demonstrates how these changes may be related to changes in running speed.

Progress monitoring; the mental checklist strategy and the use of supplementary information.

To reiterate, when the orienteer is still some distance from the control, any inaccuracy in navigation can be corrected with negligible ramifications. Here, the elite orienteer employs a mental checklist strategy to monitor progress. As the elite orienteer moves through the environment the mental representation is compared to the environment. Any environmental information recognised is mentally checked off from a list of anticipated information that is the representation. Consider the following quotes.

You might count the number of tracks you cross and you don t worry about anything in between when you look at the leg you think well I ve got to cross three roads, I m going up that valley, I m going to cut across there so then you re checking it off.
Just ticking things off as you go along like you now you ve only got to cross three tracks and then there s a large hill in front of you and you re going to want to go to the right of that.

Together, the mental checklist, and the supplementary information provided by ground-to-map comparisons discussed above, are both strategies employed to monitor progress through a given distance of the a leg. The mental checklist strategy is abandoned when the orienteer reaches the control area, where, as discussed above, the orienteer manufactures a more detailed representation.

Planning opportunities; the effect of the position on the leg.

Earlier, evidence suggested that planning ahead was the early part of the process of manufacturing an anticipatory mental representation. The opportunities to plan afforded to the orienteer were understood to be infrequent, and typically where the attentional demands to any or all of the three key stimuli were reduced. The reduced number of comparisons of the map and the environment afforded by the employment of the simplification strategy, especially during the rough part of the leg, increases the number of opportunities available owing to a freeing up of attention.

In contrast, the control area and complex terrain typically reduce the opportunities to plan because of the increased need to attend to the map and the environment for the purpose of comparison, and a subsequent reduction in the employment of a simplification strategy. Using Figure 2, via pathways 12, 2, 3, 4, and 14, it is possible to observe the influence of the orienteer s position within the leg on the opportunity to plan, through changes in simplification, changes in the content of the representation in any given distance, and a freeing up of attention.

The attack point.

The orienteer frequently selects a final and important piece of information from the map within any given leg. This is typically a high weighted piece of information; that is, it is highly distinguishable. It is often the last item on the mental checklist before the simplification strategy is curtailed and a large amount of information is selected for the area within the control circle. This is known as the attack point and is typically the ultimate goal of any given leg, before finding the control. As discussed, the probability of any error occurring near and within the control circle must be reduced to locate the control. The attack point helps in locating of the control by providing the orienteer with an easily distinguishable objective that is known to be in close proximity to it.

The weighting given to any given piece of map information is, therefore, not only affected by how distinguishable it is in the environment but also by its proximity to the control. Figure 2, via pathways 18, 1 and 2, demonstrates the influence of any given environmental information in terms of its proximity to the control, within the feature weighting mechanism during map information selection. The following quotes provide evidence of the use of attack points.

> An attack point could be anything, it could be something as obvious as a track junction or a wall junction or a stream junction it s a feature that...couldn t possibly be anything else in the vicinity it could be a great big cliff, it could be a pond but basically there s no question in your head, there s nothing else within five hundred metres that could possibly be that, so it s the sort of feature you can absolutely peg it to because you know you cannot miss it, and when you get there you will not confuse it with anything else, and ideally it s close enough to the control that you minimise the time when you re going slowly and carefully into the control.
>
> Generally the attack point s got to be something, some obvious feature as close as possible to the control.

Mental representation and environment synchronisation, and optimal attention allocation.

The capacity of the mental representation is constrained by memorial limitations. Recall that, in a complex environment, the orienteer is forced to manufacture a representation based on less distinguishable information selected from the map. In turn, in order to navigate, more map information is selected in any given distance, and, therefore, less anticipation is afforded in the mental representation. Less anticipation causes an increased need to attend to the map, and to the environment, for the purpose of comparison. This creates a problem of allocating attention and running speed is reduced.

If the environment rapidly becomes more complex within a leg, and running speed is not reduced, a mental representation synchronisation problem will occur. The orienteer can become ahead, in the actual environment, of the furthest position anticipated in the mental representation. Equally, if the environment rapidly becomes less complex within a leg, the orienteer is able to manufacture a representation based on more distinguishable information selected from the map. Less information is selected in any given distance, and, therefore, more anticipation is afforded in the mental representation. More anticipation causes a decreased need to attend to the map, and to the environment, for the purpose of comparison. The problem of allocating attention is reduced. However, if running speed is not increased, the balance of allocating attention is not optimal, it remains weighted towards the map and the environment. The orienteer is making more comparisons than the complexity of the environment demands. These phenomena are demonstrated below respectively.

> A lot of runners who try elite orienteering get very frustrated because they hurtle across the forest and find they ve run twice as far or half as far you have to be able to read the map right I guess you have to know when to slow down as well, know when you re getting ahead of yourself.
> Quite a lot of areas will be quite different in different bits of the map in a way you could say you lose time because you re just running too slowly, you haven t stopped checking off everything because maybe there is [sic] paths or, you know, it s really quite easy so you need to be able to sort of flexible, flexible to what you re seeing, you can waste time without having actually made a mistake.

Mapping ambiguity.

On a map, the environment is represented symbolically with printed graphics. However, ambiguity occurs in the representation of the environment due to a number of factors. Firstly, the symbols on the map cannot represent the infinite variety of the environment. For example, there are five colours representing changes in vegetation. However, these colours cannot represent the exact type of vegetation underfoot, they can only categorise them within a certain bandwidth. It is this variance in the bandwidth of a given symbol that is one source of ambiguity. This causes the orienteer to manufacture an ambiguous mental representation.

> Maps don t always tell you what you can expect, you know, because you have five levels of vegetation maybe if you had ten it would be easier.

Secondly, the same symbol may also represent the environment differently between areas due to the context of the local geography.

> The vegetation shown on the map you know the light green areas and dark green areas which show you the thicker vegetation I mean that varies a lot from area to area, map to map, as to quite how much that s going to impede your running.

Thirdly, the individual or company who make the map decide upon a graphical interpretation of the environment. Their interpretation is subjective, and variance between the cartographers occurs. Consider what this orienteer does when first looking at an orienteering map.

> The first thing I look at is when it was made and who the mapper was.

Consider, also, the following quote.

> A mapper is just one person's representation of the terrain and everybody's got their own style it's like coming to the Lake District this weekend something I noticed yesterday I noticed that there's much more rock detail on the map than I would put on the map I think the rock's really over-mapped in the Lake District you have to be adaptable.

This next quote demonstrates the problems of orienteering on a map made in two sections by two different cartographers.

> An event was actually run on two overlapping maps and if you pick them up you wouldn t have said they were the same just the way he d drawn the contours and things, and the things they ve picked up were quite different it s just how a different mapper will see a different area.

These factors mean that the mental representation manufactured can be inaccurate and confused. In this example the orienteer is trying to plan his route ahead.

> It s usually a bit harder to do it earlier on because there s a period at the start of the running on a map when you re getting used to the way the map is drawn, the way it interprets.

The implication of this third source of ambiguity is that early on in the race the orienteer runs slower. The anticipatory representation manufactured remains flexible because comparisons may initially be problematic. The orienteer receives feedback from the environment, during the map-to-ground method of comparison, as to the nature of the interpretation of the mapper. As the race progresses the understanding of the interpretation increases and the learning process slows. The anticipatory representation becomes more accurate and the comparison process becomes less problematic, and orienteer becomes more confident in the comparison process. As a consequence, running speed can be increased.

Finally, consider the quote above regarding difficulties in planning during the early stages of a leg. Figure 2, via pathway 19, demonstrates the influence of mapping ambiguity on the manufacture of the representation.

Summary.

To summarise, the orienteer must make a comparison of either the map to the environment or the environment to the map in order to navigate through the environment, and does so by manufacturing a mental representation of the map or environment for comparison to the other. Early in a race the orienteer must learn how the cartographer has interpreted the environment. This may cause some ambiguity in the comparison process and a reduced running speed may result. However, as learning takes place running speed may be increased.

If the orienteer is going to win, fast travel through the environment is crucial and attention to travel necessary. This creates competition because three sources of information require attention: the map and environment for comparisons, and travel. The more comparisons that must be made, the slower travel becomes. A number of factors affect how many comparisons must be made. These include the orienteer s position within the leg, the nature of the terrain and the need for an attack point.

However, the orienteer can reduce the number of comparisons that need to be made by selecting only the most distinguishable information from the map and forming a mental representation of the map that is anticipatory in nature. The orienteer can therefore attend to the map less frequently and run faster. On the rare occasions when the three sources of information do not require attention, time is invested in planning ahead and this process aids the creation of the anticipatory representation.

Finally, at high levels of work intensity the orienteer experiences problems in attending to the map. The level of fitness of an orienteer moderates the level of work intensity experienced at any given running speed, and so the fitter an orienteer is, the less problematic attending to the map at speed becomes.

Discussion

The objective of this study was to gain an understanding of expert cognition in orienteering through the detailed identification of the constraints that exist in the sport of orienteering and of the adaptations of the expert orienteer to those constraints. In an attempt to meet this objective, an analysis of interview data using grounded theory was employed to create a detailed theory of expert cognition in orienteering.

Central to the theory, there exists a task constraint in that attention to the map, the environment, and to travel is required to navigate successfully. Evidence suggests that attending simultaneously to these three sources of information is problematic, especially while moving at speed. This finding is consistent with notions of limited attentional resources, upon which many theories of attention rely (e.g., Broadbent, 1958).

If the orienteer were able to remember, from one look at the map, all the information required to complete a course, the burden on resources imposed by this constraint would be drastically reduced; attention could be allocated solely to comparing the environment to the orienteer s mental representation of map information, and to travel. However, evidence suggests that the orienteer s memory for map information is limited. This phenomenon is consistent with notions of limitations in short-term memory capacity (e.g., Miller, 1956). This second limitation appears to compound the demands on attentional resources because the orienteer must attend to the map periodically throughout the course.

However, as consistent with research literature (e.g., Ericsson & Lehmann, 1996), evidence suggests that expert orienteers have adapted to this constraint. They report a number of cognitive skills and strategies that are suggested to result in the management of attentional resources. These include anticipation and simplification. The first strategy involves anticipating, as much as possible, the environment within the course to be covered from the information on the map. Anticipation has been identified as a strategy used by skilled individuals in other dynamic domains (e.g., Abernethy, 1990; Salthouse, 1986; Sloboda, 1984), including those involving navigation; as Norman (1980) suggests, the expert pilot flies ahead of the plane (p. 333, as cited in Aitkenhead & Slack, 1985). The ability to predict future events based on information available from the environment that occurs early in that temporal sequence of events appears to allow experts to prepare their actions and thus essentially circumvent the need for rapid immediate reactions (Ericsson, 1996, p. 18). Consistent with this observation, the use of anticipation by orienteers in this study appeared to allow performers to be less reactionary to, and more in anticipation of, the oncoming environment. The orienteers in this study reported attempts to anticipate the upcoming terrain so as to reduce the need to react to the environment as it was encountered; that is, to reduce the need to refer to the map for the purpose of locating one s self.

As noted, short-term memory capacity limitations appear to allow only a finite amount of information to be anticipated (memorised). As a consequence, expert orienteers also appear to simplify by selecting only the most functional information from the map, and by gating out that which is redundant. Experts in other domains that are rich in information are suggested to reduce the problem space (see Newell & Simon, 1972) to its barest qualitative elements (Kellogg, 1995, p. 210) by recognising critical and, conversely, redundant information in that space (e.g., Annet & Kay, 1956). In orienteering, gating out as much information as possible appears desirable, perhaps because the amount of information, stored in short-term memory, that represents a given distance in the course is reduced. The results suggest that, in turn, increased anticipation is afforded, resulting in decreased attention to the map and increased attention to travel in any given distance. Therefore, it appears that running speed can be increased and performance time improved.

The results also suggest a number of other cognitive strategies that result in a reduction of the burden on processing demands. In essence, expert orienteers appear to intelligently manage attention to the map, the environment, and to travel, to achieve the greatest performance benefits. For example, the results suggest that planning (requiring attention to the map) occurs when attentional demands are low, facilitating the anticipation process which, in turn, may reduce the need to attend to the map during periods when attentional demands may be high, e.g., near the control. Planning strategies have been proposed as a characteristic of skilled sports performers (e.g., McPherson, 2000) and experts in general (Ericsson & Lehmann, 1996). Also, the increased amount of information necessarily selected from the map, when the orienteer nears the control, appears to cause a decrease in running speed. The selection of an attack point, an environmental feature known to be distinguishable in the environment and close to the control, appears to reduce the need to attend to the map until reaching that point.

Such changes in the way attention is managed with practice have been noted in other dynamic domains. For example, Gopher (1993) states that skilled individuals in such domains adapt to task constraints by adopting a selective set, and by dividing, switching, and investing different levels of attention so as to reduce processing burdens and, consequently, reap performance benefits. The expert orienteers in this study provided examples of some of these adaptations. They appeared to adopt a selective set when selecting only distinguishable information from the map for inclusion in the anticipation process, and appeared to know when to switch attention when planning ahead (i.e., by switching attention to the map when attentional demands were low).

To summarise, in terms of the current understanding of expertise, this study provides evidence that the expert orienteer experiences processing limitations unique to the constraints of the task and provides evidence of experts adaptations to task constraints. These adaptations are concerned with complex cognitive skills and strategies that are designed to organise and process information so as to circumvent processing limitations, and, in turn, afford performance benefits. Some of these strategies, such as simplification, anticipation and planning, appear to be related at a general level to strategies observed in experts in other domains (see Ericsson & Lehmann, 1996) and all appear to be related at a specific level to the constraints of the task of orienteering. Chess experts adapt through the use of knowledge-based chunking to circumvent limitations in short-term memory capacity. Fast-ball sport experts adapt through the use of knowledge-based selective attention strategies to circumvent limitations in general reaction time. The evidence from the present study suggests that one way that orienteering experts might adapt is through the use of knowledge-based attention management that circumvents limitations in attention and memory resources.

The theory proposed here also shows many parallels with previous research literature on navigation in domains such as aircraft piloting and way-finding in urban environments. For example, the three sources of information proposed as important in orienteering are observed in a recent review by Wickens (1998). Wickens suggests that the traveller must undertake the action of travelling (our term *travel*) while undertaking navigational checking (see also Schreiber, Wickens, Renner, Alton & Hickox, 1998), i.e., checking that the traveller is where he or she should be through the use of his or her forward field of view (our term *environment*) and the map (our term *map*). The manufacture of some mediating representation between the map and the environment is also suggested in this latter process: the navigation process continues, using some combined representation of map and FFOV [forward field of view] to proceed toward the goal (Wickens, 1998, p. 138).

Also, Wickens (1998) suggests that the rich array of visual information often manifest in both a map and FFOV, must. . . force some selective attention of resources, to process certain features and ignore others (p. 135). In our theory, the strategy of simplification described such a selective attention process and it might be speculated that a task constraint, that of time pressure, creates an imperative to adapt through the use of cognitive strategies that save time, in both aircraft piloting (Wickens domain of investigation) and orienteering. Research also suggests that the information selected from the map and environment for the purpose of navigation is dependent on differentiation; in essence, the equivalent to our term *distinguishability* (Garling et al., 1986; Schulte & Onken, 1995; Warren, 1994). Furthermore, the complexity of a given environment is suggested to depend on the distinguishability of features in that environment (Garling et al., 1986), as we suggest in our theory. Other research literature has reported that the time taken during navigational checking is proportional to the complexity of the environment, as we also propound in this study (e.g., Hickox & Wickens, 1996).

Wickens (1998) also highlights the profound influence strategic control of attention appears to exert on navigational performance (p. 135). The evidence provided by this study concerning a variety of strategies resulting in the management of attention (e.g., simplification, anticipation, planning during periods of low attentional demand, and the use of an attack point) seems to corroborate this statement.

Based on previous research literature (e.g., Ericsson & Lehmann, 1996), it might be speculated that the expert orienteer s strategic knowledge is acquired through experience and practice. To conclude, it appears that, as in many other domains, domain-specific experience and deliberate practice affords an increase in domain-specific knowledge, which, in turn, affords domain-specific changes in the way information is processed to circumvent processing limitations, which, in turn, affords domain-specific performance benefits.

A number of methodological limitations of this study must be noted. First, the use of retrospective introspection is controversial in investigations concerning cognition (Ericsson & Simon, 1980; see also Nisbett & Wilson, 1977). The adaptations suggested here might be just a small number from many that occur with practice; other adaptations that occur may involve processes that are cognitively impenetrable and hence that cannot be reported. Second, readers should note our background as researchers when interpreting our results: these were our constructions of the data; others may have differed in their constructions. However, following this research, we believe firmly in the efficacy of grounded theory in terms of its contribution to fulfilling our original objective; which was to gain an understanding of expert cognition in orienteering.

Third, this study did not employ the traditional expert/novice paradigm. Conclusions regarding changes in skill may only be speculated upon and research at a behavioural level that employs the expert/novice paradigm is required to test aspects of the proposed theory. Recent investigations within our orienteering research program have begun to explore these aspects and have revealed important differences in orienteering performance between skill levels. For example, the evidence from the present study proposed that expert orienteers possess knowledge of when to allocate attention to the map without stopping, such as during periods of low attentional demand. Eccles, Walsh, and Ingledew (in press) have presented behavioural evidence consistent with this proposition in that experienced orienteers, when compared to novice orienteers, were markedly better at attending to the map without stopping. This ability accounted for 45% of performance variance when both groups were combined. The experienced orienteers were also faster, and stopped less and for shorter periods of time.

Also, it was proposed in the present study that if distinguishable information was observed on the map, and was in close proximity to the control, it could be used as an attack point, and hence would be selected from the map for inclusion in the orienteer s anticipatory mental representation of the environment. The result of the identification of an attack point was the facilitation of the simplification of the problem space. Eccles, Walsh, and Ingledew (manuscript in preparation) have presented behavioural evidence consistent with these propositions. Sub-elite and novice orienteers were presented with orienteering legs and asked to plan a route to the control. Process-tracing techniques revealed that the sub-elite orienteers immediately focused attention on map information proximal to the control circle and then planned backwards from there to the start triangle. In contrast, novices employed a weak but intuitive heuristic by planning forward from the start triangle to the control, naive to the importance of prioritising the establishment of an attack point near the control.

Orienteering might benefit from the present study by educating coaches and performers as to natural processing limitations, and the benefits of strategies that might circumvent these limitations. The results of this study also have implications for other sports involving navigation such as hill-walking, mountaineering and sailing, and for other non-sporting domains such as aircraft piloting, car driving, and field operations in the armed forces. Within these domains, consideration of the strategies identified above, that reduce the time required to navigate a given distance, might have life-saving consequences. For example, accidents and navigational errors during car driving have been attributed by researchers (e.g., Burns, 1998) to demands on processing resources caused by task constraints similar to that proposed in orienteering by this study, and in navigational tasks in general by Wickens (1998).

Research is needed to further test the theory at a behavioural level and to continue to establish whether the cognitive skills and strategies identified here account for skill differences in orienteering. With regard to the acceleration of skill acquisition, research needs to investigate the efficacy of training less skilled orienteers, and navigators in general, in the use of these skills and strategies. Our ongoing research program will include such training studies.

The objective of this study was to gain an understanding of cognition in orienteering because such an understanding might have implications for an understanding of expertise, problem solving and navigation, and for the acceleration of skill acquisition within the sport. The results of this study contribute toward fulfilling this objective as they begin to enable the identification of constraints that exist in the sport of orienteering, adaptations of the expert orienteer to those constraints, processes responsible for increases in skill in the sport, applications to other sports and domains, and a number of areas worthy of further research.

CHAPTER 3

VISUAL ATTENTION IN ORIENTEERS WITH DIFFERENT LEVELS OF EXPERIENCE[2]

[2] This chapter has been submitted as a paper to the Journal of Environmental Psychology

Abstract

A proposed task constraint in orienteering is the requirement to attend visually to three sources of dynamically-varying information: the map, the environment, and travel (Eccles et al., under review). This study explored how differences in orienteering experience are related to differences in how attention is allocated to each source. 20 more and 20 less experienced orienteers completed three orienteering courses whilst wearing a head-mounted video camera with microphone. Participants verbalised what they were attending to (map, environment or travel) at any given time. Each recorded film with soundtrack was coded at each point in time in terms of what the participant was attending to and whether he or she was moving or stationary. More experienced orienteers, compared to less experienced orienteers, did not differ significantly in their overall allocation of attention. However, they attended to the map and environment more times per minute and for shorter periods of time, and did this more whilst moving. Participants performance was related significantly to the ability to attend to the map whilst moving. The strategic control of attention by more experienced orienteers is proposed to explain this ability and it is argued that attentional training might enhance navigational performance within and beyond orienteering.

Introduction

The objective of the present study was to identify differences in the allocation of visual attention during orienteering between less and more experienced orienteers. This study is prompted by, and interpreted in terms of, a model of cognition in expert orienteers developed by Eccles, Walsh, and Ingledew (under review). This introduction will: provide a rational for studying perception and cognition in orienteering; review the model proposed by Eccles et al. (under review); review the role of attention in tasks requiring navigation; review the skill and attention relationship; discuss measurement issues in orienteering.

Orienteering has received little research interest within psychology although it is distinctive in terms of possessing both highly cognitive and physical components. Winning is achieved by being the fastest to navigate through points, known as controls, in the environment. The distance from one control to the next is known as a leg. An orienteering course typically comprises 25 legs over 15 kilometres. Controls are symbolised by circles printed on a map, which is presented only seconds before the race begins, and is carried with a compass during the race. An understanding of perception and cognition in orienteering, and of how the perceptual and cognitive processes of the orienteer change with an increase in skill, might have implications for the understanding of perception and cognition in experts, specifically those in domains involving navigation. Also, the identification of those perceptual and cognitive attributes responsible for skill differences might have implications for the acceleration of skill acquisition within and beyond the sport.

The study by Eccles et al. (under review) used a grounded theory method (Glaser & Strauss, 1967) to analyse interviews with elite orienteers. Consequently, a model of cognition in orienteering was proposed. One task constraint central to the model was that successful navigation in orienteering requires visual attention to three sources of dynamically-varying information: the map, the environment, and travel. Attending to the map is necessary because it contains information about the location of the orienteering controls. Attending to the environment is necessary to compare the actual environment with its mapped representation. Attending to travel is necessary to avoid collisions and continue to move without hazard. The qualitative evidence suggested that attending simultaneously to these three sources of dynamically-varying information whilst moving at speed was problematic, perhaps due to natural processing limitations. However, consistent with research literature (e.g., Ericsson & Lehmann, 1996), Eccles et al. s (under review) results suggested considerable adaptations by experts to this task constraint, characterised primarily by a number of cognitive skills and strategies including anticipation and simplification. By anticipating the environment from the map, and by simplifying the information required to navigate, expert orienteers strategically controlled attention, which, in turn, appeared to circumvent processing limitations.

Although orienteering has received little research attention, other studies have investigated the nature of task constraints in domains involving navigation, and the resultant adaptations to these constraints that an increase in skill affords. For example, research on aircraft piloting has revealed that a similar task constraint exists in this domain: the three sources of information proposed as important in orienteering by Eccles et al. (under review) are observed in a recent review by Wickens (1998). Wickens suggests that the traveller must undertake the task of travelling (similar to the source of information we labelled as travel) while undertaking a secondary task labelled navigational checking (Schreiber et al., 1998); in which the traveller checks where he or she should be through the use of the forward field of view (similar to the source of information we labelled as environment) and the map (similar to the source of information we labelled as map). Burns (1998) also highlighted the constraints on processing resources during driving. These constraints were imposed by the need to maintain safe control of a vehicle (similar to our source of information labelled travel), resulting in insufficient resources available for navigating (similar to our source of information labelled environment and, should a map be used, our source labelled map). Furthermore, Burns proposed that many driving accidents were caused by the burden on processing resources from these sources of information.

However, Wickens (1998) highlighted the profound influence strategic control of attention appears to exert on navigational performance (p. 135) in aircraft piloting. Similarly, Gopher (1993) suggested that an important component of navigational tasks such as aircraft piloting and car driving is the ability to allocate attention and processing efforts among multiple, dynamically varying elements (p. 299). He presented evidence that attention control strategies can be learned with experience in high-load attention-demanding tasks, for example, in tasks requiring navigation.

Research suggests that there are a number of adaptations that lead to the strategic control of attention, and, hence, a reduced processing burden. First, there is evidence that skilled individuals in dynamic tasks (as tasks requiring navigation typically are) selectively attend to task-specific spatial and temporal cues (e.g., Abernethy, 1990) by learning to recognise redundancy in their visual environments. Second, it has been suggested that skilled individuals have learnt to divide attention between components within a task, or between tasks (e.g., Spelke, Hirst, & Neisser, 1972). One explanation for this ability is that well-practiced tasks require less attention for a given level of performance (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) and, consequently, attention is freed-up and can be directed to another task, or component of the same task. Also, skilled individuals have been seen to more effectively allocate different levels of attention between components of a dynamic task, or between dynamic tasks, as priorities change (e.g., Wickens & Gopher, 1977). Third, attention can be switched between components of a dynamic task, or between tasks, by skilled individuals in a serial manner as priorities change. Reviews of dynamic domains where task constraints preclude the division of attention between sources of information have proposed that skilled individuals develop an internal model which affords knowledge of when to switch attention between sources (e.g., Moray, 1986). This model ensures optimal sampling.

Traditional methods of investigating expertise have analysed expert behaviour typically through laboratory-based experiments using contrived tasks (e.g., de Groot, 1946/1965). Many such tasks, e.g., in chess studies (e.g., de Groot, 1946/1965), have been suited to static laboratory conditions. However, laboratory-based studies of orienteering would be of low ecological validity; orienteering is a dynamic task that typically takes place in forest. Starkes and Deakin (1984) remarked that the size of the discrepancy between any contrived task and the real task was inversely proportional to the probability of discovering expert/novice differences, owing to the domain-specificity of expertise. Consequently, a contrived task might not reveal the marks of mastership (de Groot & Gobet, 1996, p. 2) that de Groot (1946/1965) found so elusive, even when his domain of investigation was chess. Furthermore, the line of research by Abernethy and his co-workers (e.g., Abernethy & Russell, 1987; Abernethy, 1990) has been criticised for lacking ecological validity by examining the dynamic games of squash and badminton in static laboratory environments (e.g., Summers & Ford, 1995). Orienteering presents a greater measurement challenge again, owing to its nature, and this created an imperative to maintain the natural demands of the task as much as possible in the design of this study.

In an attempt to maintain ecological validity, we measured visual attention in a field setting, i.e., whilst actually orienteering in a natural environment. The study made use of head-mounted video and audio recording equipment to capture the task. This equipment has been shown to be a potentially powerful method of investigating cognition in orienteering (Omodei & McLennan, 1994). Participants were asked to verbalise what they were attending to (map, environment or travel) at any given time. Each film with soundtrack was coded at each point in time in terms of what the participant was attending to and whether he or she was moving or stationary. Using this method, a pattern of the allocation of visual attention within the task could be recorded for each orienteer, while, we believe, the actual task remained relatively unaffected. One caveat to employing this method is the use of introspection (Nisbett & Wilson, 1977). However, Ericsson and Simon (1980; 1993) proposed that verbal reports of information under the current focal attention of the individual would produce a valid reflection of cognition. Furthermore, this process of explication is thought not to change the task process.

The objective of the present study was to identify differences in the allocation of visual attention during orienteering between less and more experienced orienteers. Previous qualitative evidence suggested that attending simultaneously to the three sources of dynamically-varying visual information required to orienteer whilst moving at speed was problematic, perhaps due to natural processing limitations. By anticipating the environment from the map, and by simplifying the information required to navigate, expert orienteers achieved the strategic control of attention and, in turn, increased performance. We hypothesised that such control would be reflected in differences in the allocation of visual attention between more and less experienced orienteers.

Method

Participants

The participants were 20 less experienced and 20 more experienced orienteers. More experienced participants possessed a minimum of three years experience including competition experience and the majority were club-standard orienteers. A minority of the less experienced participants had tried orienteering formerly as a leisure-time activity; otherwise they possessed no experience. The groups were identical in terms of gender: both contained 15 males and 5 females. Participants were aged between 16 and 51 years, and the mean age was 29.88 years. The groups did not differ significantly on this variable when alpha was set at .05 (t (34.43) = 1.94, p = .06). Levene s test of homogeneity of variance was significant and the degrees of freedom were adjusted to make the test more conservative (Winer, 1971).

Fitness was also measured because it was believed that less fit participants would spend more time attending to environment, not because it was necessary, but simply because it took them longer to get to where they were going. Therefore, if fitness differences existed between groups, the pattern of the allocation of attention might reflect fitness, an extraneous variable, and not a propensity to attend to the environment, the variable of interest. Fitness was measured by a timed run over one kilometre in terrain typical of orienteering courses, i.e., comprising rough forest trails through wooded environments. There was no significant difference in the fitness of the two groups when alpha was set at .05. However, the lack of difference was marginal (t (38) = 2.00, p = .053).

Procedures

Access to more experienced orienteers is problematic; only a small population of experienced orienteers exists. This constrained group size, threatening statistical power (Cohen, 1988). To compensate, each participant completed three separate orienteering courses. This served as a repeated measure to reduce measurement error and, hence, increase statistical power (Tabachnick & Fidell, 1996). Each orienteering course comprised ten controls over two kilometres. The venue was a country park; the relief was gently hilly and the terrain was mostly wooded. Each course was a loop shape so the participants ended the course by returning to the start. The start point was the same for each course. Each participant completed the courses in the same order and was allowed five minutes rest between courses. The fitness measure was taken on completion of the three courses. The whole process took approximately two hours.

Whilst performing, participants wore a head-mounted digital video camera with microphone (Sony GV-D900E, Newbury, UK). Participants were asked to verbalise what they were attending to (map, environment or travel) at any given time. Participants practiced verbalising prior to performance and were given freedom to explore methods of verbalising that they found comfortable. A fourth source of information that may require attention was hypothesised to be task-irrelevant behaviours such as tying shoelaces. The participants were not required to verbalise the attention necessitated during these behaviours.

After performance, each film with soundtrack was coded at each point in time in terms of what the participant was attending to and whether he or she was moving or stationary. The unit of time used during coding was one third of a second, the smallest increment of time available from the digital video camera. Two principal cues aided the coding process: the labelling by the participant and the movement of the camera. For example, when the participant looked at the map, typically the word map was heard and, from the angle of the camera, the head was tilted downwards, was kept still, and the top of the map was seen. Similarly, when the participant was looking for a feature in the environment the words looking for stream might be heard and, typically, movements of the head, indicative of scanning during searching, were captured on the film. It was also clear from the film whether the participant was moving or was stationary. Periods of time spent attending to task-irrelevant activities were identified, and were coded as miscellaneous. The researcher responsible for coding (the first author) had practiced coding during a pilot study (with two participants, a total of one hour of film and one day of coding). By these means, it was possible to capture a mutually exclusive and exhaustive pattern of: where visual attention was allocated; whether the participant was moving or stationary. Figure 3 shows a more experienced participant (a member of the British orienteering squad) wearing the head mounted video equipment.

Figure 3: Member of British orienteering squad wearing head mounted video camera equipment.

The validity of the coding was checked in two ways. First, after completion of the courses, the first 10 of the 40 participants were shown samples of the films of their performance, had the coding system explained to them, and were asked to comment on the accuracy of coding. The question asked of them was Is this what you where attending to at this time? Each was asked for their opinion on whether the coding was poor, fair or good overall. All ten responded that the coding was good. Second, an inter-rater reliability assessment was conducted by selecting one film and having two other researchers code it. The mean value of Cohen s kappa (comparing the first author's coding with each of the other researchers' codings) for the coding of attention was .64, and of moving/stationary was .84. A kappa value of .70 is regarded as the minimum requirement for good inter-rater reliability (Fleiss, 1981; Bakeman & Gottman, 1986) and agreement for the attention codes fell below this. On inspection of the tables used to produce kappa values, confusion in coding was found predominantly between environment, travel and miscellaneous codes. Consequently, these data were collapsed, leaving only two codes: map and the collapsed coding renamed other. When kappa was recalculated for these two codes the mean value for the coding of attention increased to .78. Analyses were performed on both the four code and two code versions of the data. The performance time for each participant on each course was also recorded.

Analysis

Exploration of the data was conducted by mixed-model ANOVAs. The between-subject factor was experience (less versus more experience) and the within-subject factor was course (the three separate courses). The within-subject factor was not explored because it served to reduce measurement error. As this was an exploratory study, a variety of dependent variables (73) was explored to ascertain the nature of the differences between the groups. Alpha was set at .05. However, multiple analyses at an alpha level of .05 causes an inflated type I error rate problem. If the Bonniferoni adjustment to the alpha level is used each F ratio would need to be significant at a level of .0007 (.05/73).

Results

The results from the four-code data are reported in Table 1 and from the two-code data in Table 2. Note that although the two-code data contain both map and other codes only the results pertaining to the other code are displayed in Table 2; the results pertaining to the map code are unchanged from those in Table 1. Non-significant differences will not be highlighted below unless they are particularly interesting. To reiterate, if all variables are analysed using separate univariate analyses for each dependent variable (73), the Bonniferoni adjustment to the alpha level yields a value of .0007 (.05/73). Many of the results highlighted below are likely to remain significant given this adjustment. For example, note that many of the variables referred to below fall below the .001 level (the exact level is not known as the computer outputs from the analysis did not provide figures beyond three decimal places). The value for each variable that follows is the mean across participants and courses.

Table 1: Univariate Analyses of Variance for Four Code Dependent Variables between Less and More Experienced Orienteers Over Three Orienteering Routes

		Less experienced group (n = 20)		More experienced group (n = 20)		
	Variable number and name	M	SD	M	SD	F (1, 38)
	Performance time					
1.	Performance time (mins.)	42.08	10.52	21.95	4.39	62.34***
	Attention event data					
2.	Total number of looks	502.77	120.33	361.02	81.98	19.00***
3.	Number of looks at the map	149.83	48.37	122.58	32.68	4.40*
4.	Number of looks at the map as a percentage of total number of looks ((variable 3/variable 2) × 100)	29.93	5.96	34.54	3.73	8.62**
5.	Number of looks at environment	230.52	58.80	168.28	42.69	14.67***
6.	Number of looks at the environment as a percentage of total number of looks ((variable 5/ variable 2) × 100)	45.73	2.22	46.45	3.57	0.59
7.	Number of looks at travel	68.18	27.71	54.90	18.91	3.14
8.	Number of looks at travel as a percentage of total number of looks ((variable 7/variable 2) × 100)	13.23	3.88	14.55	4.48	0.99
9.	Number of looks at miscellaneous	54.23	37.09	6.90	11.30	16.63***
10.	Number of looks at miscellaneous as a percentage of total number of looks ((variable 9/variable 2) × 100)	11.10	7.80	4.44	6.18	8.96**
	Attention time data (absolute)					
11.	Range of times spent looking at map (s)	36.13	10.65	16.74	7.39	44.74***
12.	Minimum time spent looking at map (s)	0.51	0.12	0.56	0.15	1.43
13.	Maximum time spent looking at map (s)	36.65	10.59	17.30	7.34	45.08***
14.	Total time spent looking at map (s)	796.74	260.39	410.15	118.29	36.55***
15.	Mean time spent looking at map (s) (variable 14/variable 3)	5.44	1.04	3.42	.99	39.73***

		Attention time data (absolute)				
16.	Range of times spent looking at environment (s)	60.75	24.27	32.73	10.20	22.66***
17.	Minimum time spent looking at environment (s)	0.33	0.01	0.34	0.02	1.00
18.	Maximum time spent looking at environment (s)	61.08	24.27	33.07	10.20	22.65***
19.	Total time spent looking at environment (s)	1199.22	482.55	636.32	160.01	24.52***
20.	Mean time spent looking at environment (s) (variable 19/variable 5)	5.30	2.06	3.90	1.19	7.33*
21.	Range of times spent looking at travel (s)	27.23	12.23	22.95	9.66	1.51
22.	Minimum time spent looking at travel (s)	0.36	0.06	0.39	0.14	0.67
23.	Maximum time spent looking at travel (s)	27.59	12.22	23.34	9.65	1.49
24.	Total time spent looking at travel (s)	236.61	93.52	167.86	48.84	8.49*
25.	Mean time spent looking at travel (s) (variable 24/variable 7)	3.64	1.03	3.44	1.14	0.32
26.	Range of times spent looking at miscellaneous (s)	41.67	10.18	29.05	11.07	14.09**
27.	Minimum time spent looking at miscellaneous (s)	0.77	0.67	6.53	8.31	9.56**
28.	Maximum time spent looking at miscellaneous (s)	42.44	10.07	35.58	7.68	5.86*
29.	Total time spent looking at miscellaneous (s)	292.33	165.39	102.87	100.10	19.21***
30.	Mean time spent looking at miscellaneous (s) (variable 29/variable 9)	6.69	2.35	14.78	8.09	18.44***

Attention time data (relative)						
31.	Time spent looking at map as a percentage of total course time ((variable 14/variable 1) × 100)	31.45	5.93	31.09	4.20	0.05
32.	Time spent looking at environment as a percentage of total course time ((variable 19/variable 1) × 100)	46.57	9.85	48.14	8.46	0.29
33.	Time spent looking at travel as a percentage of total course time ((variable 24/variable 1) × 100)	9.40	3.77	12.59	3.74	7.18*
Attention time data (relative)						
34.	Time spent looking at miscellaneous as a percentage of total course time ((variable 29/variable 1) × 100)	12.58	7.45	8.17	7.56	3.44
Attention rate data						
35.	Number of times per minute at which map was attended to (variable 3/variable 1)	3.60	0.99	5.83	1.47	30.36***
36.	Number of times per minute at which environment was attended to (variable 5/variable 1)	5.63	1.12	7.85	1.81	21.85***
37.	Number of times per minute at which travel was attended to (variable 7/variable 1)	1.62	0.59	2.46	0.91	11.97**
38.	Number of times per minute at which miscellaneous was attended to (variable 9/variable 1)	1.40	1.10	0.69	1.12	4.11
Movement event data						
39.	Number of stops	68.77	41.86	30.19	21.22	54.08***
Movement time data (absolute)						
40.	Range of time spent moving (s)	130.73	47.67	191.90	60.88	12.51**
41.	Minimum time spent moving (s)	1.38	0.36	3.83	4.93	4.91*
42.	Maximum time spent moving (s)	132.11	47.68	195.72	61.80	13.29**
43.	Total time spent moving (s)	1786.09	456.63	1138.71	207.02	33.35***
44.	Mean time spent moving (s) (variable 43/variable 39)	28.81	8.70	39.03	15.49	16.43***

		Movement time data (absolute)				
45.	Range of time spent stopped (s)	57.64	32.00	20.01	9.78	25.31***
46.	Minimum time spent stopped (s)	0.92	0.21	0.93	0.25	0.03
47.	Maximum time spent stopped (s)	58.56	32.00	20.93	9.83	25.28***
48.	Total time spent stopped (s)	738.80	313.32	178.49	88.06	59.28***
49.	Mean time spent stopped (s) (variable 48/variable 39)	10.37	2.46	5.49	1.46	58.15***
		Movement time data (relative)				
50.	Time spent moving as a percentage of performance time ((variable 43/variable 1) × 100))	72.11	8.21	87.91	4.84	54.92***
		Movement rate data				
51.	Number of stops per minute (variable 39/variable 1)	1.62	0.31	1.30	0.34	10.81**
		Attention time/stopped time data				
52.	Time spent looking at the map while stopped as a percentage of the total amount of time spent stopped	70.54	6.70	69.33	7.48	0.29
53.	Time spent looking at environment while stopped as a percentage of the total amount of time spent stopped	25.09	6.69	26.65	7.33	0.49
54.	Time spent looking at travel while stopped as a percentage of the total amount of time spent stopped	1.06	1.62	1.68	1.50	1.60
55.	Time spent looking at miscellaneous while stopped as a percentage of the total amount of time spent stopped	3.30	2.41	2.34	2.43	1.59
		Attention time/moving time data				
56.	Time spent looking at map while moving as a percentage of the total amount of time spent moving	16.07	7.14	25.68	3.72	28.53***
57.	Time spent looking at environment while moving as a percentage of the total amount of time spent moving	54.76	12.12	51.30	9.46	1.01

Attention time/moving time data						
58.	Time spent looking at travel while moving as a percentage of the total amount of time spent moving	12.86	5.11	14.23	4.17	0.86
59.	Time spent looking at miscellaneous while moving as a percentage of the total amount of time spent moving	16.31	10.09	8.80	8.27	6.63*
Moving time/Attention time data						
60.	Time spent looking at the map while moving as a percentage of the total amount of time spent looking at the map	37.78	15.61	73.25	9.93	73.51***
61.	Time spent looking at the environment while moving as a percentage of the total amount of time spent looking at the environment	84.26	6.85	93.05	3.32	26.66***
62.	Time spent looking at travel while moving as a percentage of the total amount of time spent looking at the travel	96.92	2.95	98.50	1.41	4.66*
63.	Time spent looking at miscellaneous while moving as a percentage of the total amount of time spent looking at miscellaneous	91.38	7.64	93.81	11.38	0.63

Note. Minor rounding errors exist due to the number of manipulations of the raw data required to obtain results.
$*p < .05$. $**p < .01$. $***p < .001$.

Table 2: Univariate Analyses of Variance for Two Code Dependent Variables between Less and More Experienced Orienteers Over Three Orienteering Routes

		Less experienced group ($n = 20$)		More experienced group ($n = 20$)		
Variable number and name		*M*	*SD*	*M*	*SD*	F (1, 38)
Attention event data						
64.	Total number of looks	298.47	95.49	245.68	64.90	4.18
Attention time data (absolute)						
65.	Range of time spent looking at other (s)	105.0	32.76	56.62	14.26	36.72***
66.	Minimum time spent looking at other (s)	0.34	0.03	0.34	0.03	0.00
67.	Maximum time spent looking at other (s)	105.38	32.76	59.97	14.26	36.72***
68.	Total time spent looking at other (s)	1674.41	450.26	869.78	152.15	57.33***
69.	Mean time spent looking at other (s)	12.21	3.76	7.46	2.09	24.39***
Attention time data (relative)						
70.	Time spent looking at other as a percentage of total course time ((variable 68/variable 1) × 100)	67.74	5.92	67.73	4.22	0.00
71.	Amount of time spent looking at other while stopped as a percentage of the amount of time stopped	29.67	6.58	30.50	7.48	0.14
Attention time/moving time data						
72.	Amount of time spent looking at other while moving as a percentage of the amount of time moving	83.90	7.15	74.70	3.71	26.06***
Moving time/Attention time data						
73.	Amount of time spent looking at other while moving as a percentage of amount of time spent looking at other	87.66	5.21	94.43	2.59	27.05***

Note. Minor rounding errors exist due to the number of manipulations of the raw data required to obtain results.
$*p < .05$. $**p < .01$. $***p < .001$.

The more experienced orienteers were clearly faster (variable 1). The less experienced orienteers took 42.08 minutes to complete a course compared to the more experienced orienteers who took 21.95 minutes. More experienced orienteers stopped 1.30 times per minute whereas the less experienced orienteers stopped 1.62 times per minute (variable 51). When the more experienced orienteers did stop it was only for short periods of time. More experienced orienteers stopped for 5.49 seconds compared to 10.37 seconds for the less experienced orienteers in any given stop (variable 49). The maximum time spent stationary during any given stop (variable 47) was nearly three times as long for the less experienced orienteers at 58.56 seconds than for the more experienced orienteers at 20.93 seconds.

More and less experienced orienteers did not differ in terms of the percentage of the overall time they spent looking at the map (variable 31) or the environment (variable 32): both groups spent approximately 31% of their course time looking at the map; more experienced orienteers spent 48.14% of their course time looking at environment, and less experienced 46.57%. The percentage of the time spent looking at travel was greater for more experienced orienteers at 12.59% than for less experienced orienteers at 9.4% (variable 33). More experienced orienteers took fewer looks overall: they looked 361.02 times whereas less experienced orienteers looked 502.77 times (variable 2). However, of those looks, more experienced orienteers took more looks at the map when expressed as a percentage (variable 4) at 34.54%, compared to less experienced orienteers at 29.93%.

Furthermore, more experienced orienteers had a higher rate per minute at which they looked at the map at 5.83, compared to the less experienced orienteers at 3.60 (variable 35). This was also observed with regard to environment: more experienced orienteers looked 7.85 times per minute and less experienced orienteers 5.63 times per minute (variable 36). More experienced orienteers also looked at the map (variable 15) and environment (variable 20) for shorter periods of time: the amount of time more experienced orienteers spent looking at the map in any given look was 3.42 seconds compared with less experienced orienteers who looked for 5.44 seconds; the amount of time more experienced orienteers spent looking at the environment in any given look was 3.90 seconds compared with less experienced orienteers who looked for 5.30 seconds. Furthermore, the maximum time spent looking at the map in any given look (variable 13) was over twice as long for the less experienced orienteers at 36.65 seconds as it was for the more experienced orienteers at 17.30 seconds, and the maximum time spent looking at the environment in any given look (variable 18) was nearly twice as long for the less experienced orienteers at 61.08 seconds as it was for the more experienced orienteers at 33.07 seconds.

A greater percentage of more experienced orienteers movement time was spent looking at the map at 25.68% compared with less experienced orienteers at 16.07% (variable 56) but the groups did not differ in how they spent their time attending when stationary. However, a greater amount of the time that more experienced orienteers spent looking at the map, at the environment, and at travel, was while moving (variables 60, 61 & 62). More experienced orienteers were moving 73.25% of the time they looked at the map, compared to less experienced orienteers at 37.78%; more experienced orienteers were moving 93.05% of the time they looked at the environment, compared to less experienced orienteers at 84.26%; more experienced orienteers were moving 98.50% of the time they looked at travel, compared to less experienced orienteers at 96.92%.

To investigate the possible relationship between performance time (variable 1) and time spent attending to the map whilst moving as a percentage of total time spent attending to the map (variable 60), the two variables were correlated. First, the correlations were conducted separately for each group, and separately for each route. Second, groups were combined and the correlations were conducted separately for each route. Pearson s product moment correlations revealed that there existed no significant relationship between these variables in the less experienced group ($r = -.15$, $p = .52$; $r = -.20$, $p = .39$; $r = -.11$, $p = .66$) but a strong and significant negative relationship between these variables in the more experienced group ($r = -.57$, $p < .01$; $r = -0.48$, $p < .05$; $r = -.58$, $p < .01$). There also existed strong and significant negative relationships when groups were combined ($r = -.69$, $p < .001$; $r = -.71$, $p < .001$; $r = -0.60$, $p < .001$). With regard to the combined-groups analysis, an average of 45% of performance variance was related to time spent attending to the map whilst moving as a percentage of total time spent attending to the map (mean r^2 of three routes = .45). However, checks on scatter-plots between the variables in the combined-groups analysis revealed some potential for a violation of homoscedasity in the data sets of all three routes.

Many of the differences between groups are encapsulated in Figure 4. The graphs depict the pattern of the allocation of visual attention, and movement and stopping, of a less experienced and more experienced orienteer from the start of the first of the three courses to the point at which the first control on that course is reached. These graphs are typical of the differences between groups. For example, the graph of the more experienced orienteer is shorter owing to the faster time in which the first control was reached. Also, note that the majority of the time spent attending to the map is while moving and that short, frequent looks are taken to the map and environment by the more experienced orienteer when compared to the less experienced orienteer.

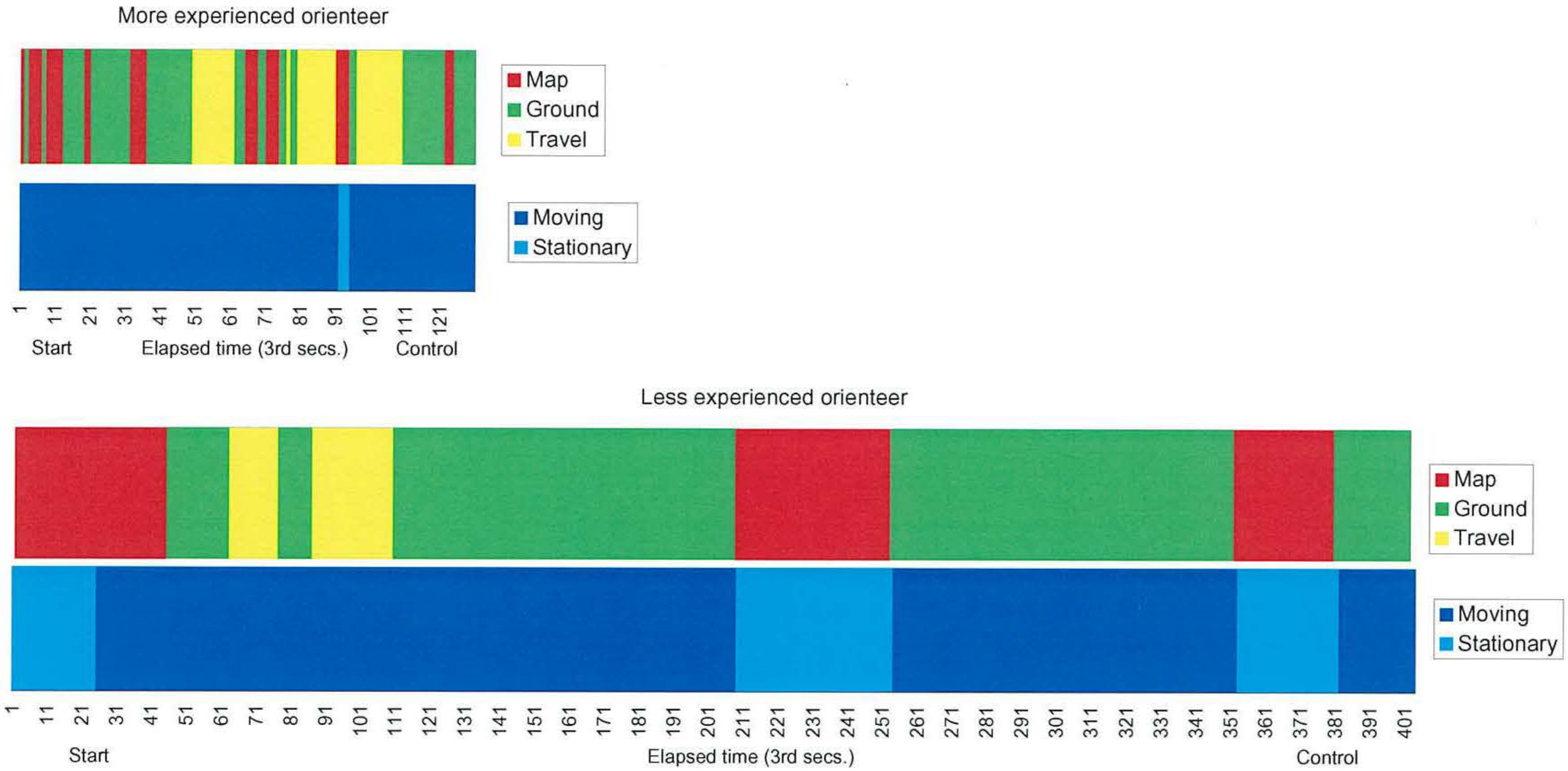


Figure 4. Graphs of the allocation of visual attention, and movement and stopping behaviour, for one less and one more experienced orienteer over one orienteering leg. The differences between these two individuals are representative of the general differences between groups.

Discussion

This study attempted to discover whether more and less experienced orienteers differ in their allocation of visual attention. The main findings are as follows. More experienced orienteers are faster than less experienced orienteers around the courses. Although more experienced orienteers do not differ significantly in their overall allocation of attention when expressed as percentages, they look at the map and environment more times per minute and for shorter periods of time, and do this more whilst moving. When they stop it is only for short periods of time. In contrast, the less experienced orienteers look at the map and environment fewer times per minute, and look at the map very little whilst moving. The majority of the time they spend looking at the map is whilst stationary.

A number of limitations to this study must be noted. Most limitations arose as a consequence of an attempt to conserve the ecological validity of the study by using a field setting. First, attention may be divided concurrently between sources of information and, hence, this division would not be captured by our measurement procedures that coded attention in a mutually exclusive manner. Second, the labelling procedure used constitutes a type of introspection that remains controversial in psychological investigations (see Nisbett & Wilson, 1977). With regard to these two limitations, it may be that only the allocation of attention that was most explicit, in terms of processing, was verbalised (labelled) when attention was divided significantly. Third, while the map code was shown to be reliable across coders during an assessment of inter-rater reliability, the other codes were less reliable. Conclusions regarding these other codes must take this limitation into consideration. This problem may reflect the possibility that attention was being divided concurrently between environment, travel and miscellaneous, and hence presented the coder, who had been asked to code in a mutually exclusive manner, with a more problematic inference regarding the source of information being attended to. Fourth, unlike the participants in the study by Eccles et al. (under review), the more experienced participants in the present study were not elite experts. They possessed more experience and exhibited a greater level of orienteering performance than the less experienced participants but it might be speculated that elite level performers in this sport would perform at a higher standard again.

The more experienced orienteers were faster around the courses. Obviously, time is the performance criterion in orienteering but more experienced individuals are observed generally to be faster and more accurate than less experienced individuals in most domains (e.g., Larkin, 1981). Beyond performance time, one major difference between less and more experienced orienteers was the ability of more experienced orienteers to attend to the map whilst moving. Furthermore, performance appeared to be related to this ability. Individuals experienced in a domain are often able to divide their attention between two sub-components of their task without performance loss on either (e.g., Spelke et al., 1976). Also, experienced orienteers do report the ability to attend to the map while running (P. Palmer, personal communication, September 1, 1998) and attribute performance increases to this ability. Therefore, it might be speculated that this ability causes increases in performance.

A number of adaptations might determine this ability. First, well practiced tasks are seen to require less attention (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Thus more experienced orienteers might not need to attend to travel as much as less experienced orienteers. Surplus resources may then be allocated to reading the map.

Second, skilled orienteers may be able to allocate resources flexibly between the map and travel as each demands more resources; skilled individuals have been seen to allocate different levels of attention, and to switch attention, more effectively between components of a dynamic task, or between dynamic tasks, as priorities change (e.g., Wickens & Gopher, 1977; Moray, 1986). For example, the shorter, more regular map viewing times displayed by the more experienced orienteers may be indicative of the need to attend to travel regularly when looking at the map. Travel accounted for only a small percentage of time spent orienteering in the four-code analysis, however it might be speculated that the orienteer was dividing attention between environment and travel during periods labelled as environment but this would not be captured by our measurement tool. As Figure 4 shows, periods of looking at the map are punctuated regularly by looks up at the environment; it is unlikely that important information regarding travel is not attended to during this period. It is intuitive to think that one way to avoid hazards when moving and reading the map is to look up frequently at where you are going, i.e., to travel. This would be a strategy consistent with research that has suggested that skilled individuals posses an internal model which affords knowledge of when to change the allocation of attention, or to switch attention, between sources. This model ensures optimal sampling (e.g., Moray, 1986). Further evidence for optimal sampling in orienteering was provided by Eccles et al. (under review). Elite orienteers reported that planning occurs when attentional demands are low, such as when running down a level track. Planning ahead during these time reduces the need to attend to the map during periods when attentional demands may be high, such as when crossing difficult terrain. It might be speculated that the pattern of attention exhibited by the more experienced orienteers reflects optimal sampling. This sampling behaviour might contribute to the ability to move and read the map at the same time.

The literature suggests that the various adaptations that occur with practice which facilitate the circumvention of processing limitations may be additive (e.g., Wickens, 1989). More experienced orienteers were observed here to attend to the map for shorter periods of time in any one look and, as suggested above, this behaviour might contribute to their ability to move and read the map at the same time. Clearly, if more skilled orienteers are able to adopt a selective set when attending to the map, information required for navigational checking could be encoded more rapidly. This ability has been found in experienced individuals in many domains (see Ericsson & Lehmann, 1996). The adoption of a selective set might facilitate shorter looks that, in turn, facilitate the ability to move and look at the map.

Evidence for the adoption of a selective set by expert orienteers, when attending to the map, was provided by Eccles et al. (under review). Information was seen to be weighted for selection depending upon how distinguishable it was in the environment; that which was less distinguishable was regarded as redundant. Furthermore, this phenomenon is observed in other domains requiring navigation (Warren, 1994; Wickens, 1998). Also, individuals who are more experienced in a domain have been shown to encode more information from their domain in any given time than those less experienced in that domain (Chase & Simon, 1973a).

The present study presents evidence supporting the notion of an ability of performers to cope efficiently with tasks that require them to divide attention and processing efforts among multiple, dynamically varying elements (Gopher, 1993, p. 299). The difference in the pattern of attention between less and more experienced orienteers may reflect a difference in this ability between these groups. The more experienced orienteers may have developed a more advanced internal model determining the allocation of resources as Gopher (1993) and others suggest (e.g., Moray, 1986). They may be aware of the trade-offs between, and priorities of, the three sources of information required in orienteering and, as Eccles et al. (under review) suggested, have developed skills and strategies to best allocate their limited processing resources. The identification of differences in the pattern of visual attention between less and more experienced orienteers shown in the present study contributes to the body of knowledge about skill differences in real-world tasks involving navigation.

However, there may be an alternative explanation for the ability of the more experienced orienteers to move and attend to the map. This observation may be less a reflection of an ability of the more experienced orienteer and more a reflection of the poor navigational ability of the less experienced orienteers. During coding, the less experienced orienteers were seen to get lost more frequently or were less sure generally of their current position on the map. When this happened they typically stopped and spent time reading the map before continuing. To summarise, it might be speculated that stopping in this situation was less as a consequence of not being able to divide attention, and more because continuing to move would only compound navigational errors. Finally, a third, and more likely, possibility is that both factors contribute to the variance in this particular variable.

There are a number of implications of this study for orienteering, and for other domains involving navigation. Gopher (1993) provides evidence that individuals can be taught to adopt attention control strategies. It might be possible to teach novice, or less experienced orienteers, to behave like more experienced orienteers, and, therefore, accelerate skill acquisition in the former group. For example, a coaching intervention might include an instructional set which specifies trying to move and read the map at the same time, and trying to avoid stopping to read the map even if that means walking slowly. It might be speculated that moving and reading the map feels wrong intuitively to the less experienced orienteer; the former task is not particularly conducive to satisfactory performance on the latter. The information provided by the map is constituted by small and detailed symbols that the orienteer is required to look at with care. This is exemplified by the recommendation of orienteering coaching texts to use a thumb to maintain location on the map when moving (e.g., Palmer, 1997); this saves time when deciding to look at the map for navigational checking. Less experienced orienteers may feel disinclined initially to run and try to extract detailed information from the map. To facilitate this, these orienteers might be instructed to try to take short, regular looks at the map in order to avoid collisions, as the more experienced orienteers have been shown to do in this study. The principle of using models of the attention allocation exhibited by more experienced performers is already evidenced in aircraft pilot training (see Wickens, 1989) but may have applications in other domains involving navigation such as car driving and sailing.

Future research might investigate the efficacy of coaching interventions with less experienced or novice orienteers, based on the identification of the behaviours of more experienced orienteers. Also, research studies might investigate information processing in more experienced orienteers during the short and frequent looks at the map and environment: what are these orienteers doing during these behaviours? Eccles et al. (under review) suggested that a number of behaviours could constitute the navigational checking process such as planning ahead in the course, creating a mental representation of the environment that was anticipatory in nature, and using the current environment to confirm one s position. When and how are each of these strategies employed during these behaviours?

CHAPTER 4

THE USE OF HEURISTICS DURING ROUTE PLANNING BY EXPERT AND NOVICE ORIENTEERS[3]

[3] This chapter has been submitted as a paper to the Journal of Sport Sciences

Abstract

Expert orienteers interviewed by Eccles et al. (in press, a) reported the use of two different heuristics while planning routes on orienteering legs: attending to the start first and subsequently planning forward to the control; and attending to the control first and planning backwards to the start. The objective of this study was to investigate which heuristic experts used, and whether novices use of these heuristics differed from experts. Two methods for tracing attention were employed while 20 expert and 20 novice orienteers planned routes in the laboratory. The data from these methods were used to infer heuristic use. Orienteers were also interviewed about heuristic use. Results indicated that experts generally attended to the control first, and novices to the start first, when planning. There was also some evidence that novices worked forwards from the start to the control, and that experts worked backwards from the control to the start. From the interview results, it appeared that experts knew that the control is the crux of the problem that is the orienteering leg, and, therefore, prioritised this area during planning. These results have implications for an understanding of expertise and problem solving in sport, and for skill acquisition within orienteering.

Introduction

Expert orienteers interviewed by Eccles et al. (in press, a) reported the use of two different heuristics during route planning. The objective of this study was to investigate which heuristic experts predominantly used during planning, and whether novices differed from experts in their use of these heuristics. The results of this study might have implications for an understanding of expertise and problem solving in sport, and for the acceleration of skill acquisition within orienteering.

There are few studies concerned with orienteering within sport psychology (e.g., Gal-Or et al., 1986; Seiler, 1990; Eccles et al., in press, a; Eccles et al., in press, b). However, orienteering is distinctive in terms of possessing both highly cognitive and physical components. Also, 1 million participants enjoy the sport across 58 countries (International Orienteering Federation, 2000). Consequently, it might be a domain of interest to sport scientists. Winning is achieved by being the fastest to navigate through points, known as controls, in the environment. The distance from one control to the next is known as a leg. An orienteering course typically comprises 25 legs over 15 km. Controls are symbolised by circles printed on a map, which is presented only seconds before the race begins and is carried with a compass during the race.

Traditional approaches to expertise proposed that skill was attributable principally to innate aptitudes (e.g., Galton, 1869) but, while this issue remains contentious (e.g., Howe et al., 1998; Ceci & Williams, 1999), a more contemporary understanding is that expertise is attained through experience of, and practice in, a domain, beginning in childhood (Ericsson et al., 1993; Helsen et al., 2000). Knowledge is often proposed as the mediator in the relationship between practice and skill (Gilhooly, 1990). Vast, well-organised and domain-specific knowledge appears fundamental to expertise (Helsen & Pauwels, 1993; Williams, 2000). As a consequence of this knowledge, domain-specific adaptations in information processing during problem solving are afforded, and thus experts are knowledge-driven and novices search-driven during problem solving (Gilhooly, 1990). These adaptations make the expert efficient: the expert is able to reduce processing demands on less adaptable, limited-capacity, basic visual and neural systems (Salthouse, 1991; Ericsson & Lehmann, 1996).

Planning and anticipating are two related strategies that appear general to expertise and skill acquisition (Eccles et al., in press, a; Ericsson & Lehmann, 1996; Helsen & Pauwels, 1993; Kirschenbaum et al, 1998; Kirschenbaum, O Connor, & Owens, 1999; McPherson, 1993, 2000; Williams, 2000; Williams & Krane, 1998; see also Dell, Burger, & Svec, 1997). These strategies are knowledge-driven in experts, and reduce the demands on processing resources by allowing experts to prepare their actions and thus essentially circumvent the need for rapid immediate reactions (Ericsson, 1996, p. 18). As a consequence of their knowledge, experts can adopt a selective set during problem solving (Abernethy, 1990; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996) based on deep , underlying, and abstract aspects of a problem (Chi et al., 1982). This allows selective sampling of meaningful environmental information early in sequences of problem events. This information can then be represented within the expert s knowledge base of prior scenarios, enabling the prediction of later events. Consequently, behaviour can be planned in advance of those events (Allard, 1993; McPherson, 1993). Novices are without knowledge of the underlying aspects of a problem, and therefore must respond to literal, surface aspects of a problem (Chi et al., 1982). Consequently, they cannot adopt a selective set to attenuate the mass of environmental information available. In turn, novices are less able to plan and anticipate, and hence do not benefit from these strategies in terms of performance.

Planning comprises hierarchical processes that structure behaviour during problem solving (Miller, Galanter, & Pribram, 1960). However, the processing involved when planning appears constrained by processing limitations (Newell & Simon, 1972). Rapidly searching the multiplicity of possible solution options within a problem space is often unfeasible given time and processing limitations. Consequently, heuristics are often applied. Heuristics are rule of thumb strategies that provide a short cut from the initial-state to the goal-state of a problem, thereby avoiding a time-consuming search through alternative solution options (Newell & Simon, 1972). Novices typically employ weak heuristics that are applied generally and based on intuition and domain-general knowledge (Chi et al., 1982). Experts are able to better represent novel problems using their knowledge base. Consequently, they employ knowledge-driven heuristics that determine efficient performance (Chi et al., 1982).

Eccles et al. (in press, a) interviewed expert orienteers and developed a theory of expert cognition in orienteering. The requirement to manage attention to the map, the environment, and travel was a constraint identified as central to orienteering. Optimal management appeared constrained by limited processing resources. Planning strategies were identified as potential adaptations to this task constraint. Experts reported utilising periods when the demands on attentional resources were reduced to plan routes ahead of their current position from the map. In turn, they were able to anticipate the oncoming environment. This reduced the need to slow down or stop to refer to the map to make route decisions or locate oneself. Eccles et al. (in press, b) presented behavioural evidence consistent with this proposition: experienced orienteers were markedly better than novices at attending to the map without stopping and were faster, and stopped less and for shorter periods of time. In effect, expert orienteers might be employing planning strategies comprising specialised heuristics to prepare their actions, and thus circumvent the need for rapid reactions, consistent with experts in other domains (Ericsson, 1996).

Despite these advances in an understanding of planning in orienteering, the results from Eccles et al. (in press, a) were unclear with regard to the heuristics used during planning. The 17 experts in this study between them reported 2 different heuristics. Two experts reported using a heuristic in which the start was prioritised first during the planning of any given leg, and the route to the control planned later in a forward direction towards the control. Five experts reported an alternative heuristic in which the control was prioritised first, and the route to the control planned later in a backward direction from the control to the start. The remaining experts provided no evidence of either heuristic, and the results were unclear overall.

This lack of clarity might be due to the methodology employed. First, the interviewer did not specifically probe the heuristics used during planning. Second, interviews rely on verbal reports, thought to be limited to cognitively penetrable processes (Nisbett & Wilson, 1977). In addition, no comparisons across the skill continuum were made and thus differences between skill groups could not be identified. Therefore, the present study used interviews that specifically probed this issue, behavioural methods of investigation, and an expert/novice paradigm, in an attempt to provide converging evidence of the heuristics used by different skill groups during route planning.

The objective of this study was to investigate which heuristic experts predominantly used during planning (start-first, work-forward vs. control-first, work-backward), and whether novices differed from experts in their use of these heuristics. This was because planning appears to be an important component of expertise in sport in general, and orienteering in particular. The results of this study might have implications for an understanding of expertise and problem solving in sport, and for the acceleration of skill acquisition within orienteering.

Method

Participants

The expert group comprised 20 members of the 2000 British orienteering squad (13 men and 7 women; mean age 24.50, $s = 6.01$, years) with international competitive experience. All possessed an average of 13.85, $s = 6.15$, years experience, starting at an average age of 10.65, $s = 3.75$, years. Experts trained an average of 6.50, $s = 2.29$, times per week, equal to an average of 7.18, $s = 2.78$, hrs per week, and, during the competitive season, raced an average of 3.60, $s = 1.02$, times per month. The novice group comprised 20 individuals (13 men and 7 women; mean age 28.35, $s = 7.65$, years) who had little orienteering experience but had all previously orienteered recreationally. The majority of this group (85%) were undergraduate or graduate students. Novices estimated the number of times they had orienteered; the average was 20.95, $s = 32.83$, and maximum was 120. For the purpose of comparison, 120 sessions is approximately the number of training sessions completed in 4 months by an expert in this study (based on the experts average weekly training frequency). Performance on map tasks can be affected by gender (Halpern, 1992), handedness (Coren, 1993) and, intuitively, age and eyesight. Therefore, gender (see above) and handedness (groups contained 17 right-handed and 3 left-handed participants) were balanced between groups, and there was no significant difference in age between groups: $t(1, 38) = 1.77$, $p = .09$. However, groups were not balanced in terms of those with corrected vision: the expert group contained two such individuals, the novice group six.

Apparatus

Two different 5 cm by 15 cm, 1:15000 orienteering maps representing similar terrain were each overprinted with a vertically aligned orienteering leg: a triangle near the bottom representing the start and a circle near the top representing the control. Map 1 was occluded by placing stickers in a 10 (row) by 3 (column) matrix: the first row barely exposed the start, and the tenth row the control. Participants could remove stickers from the map. Map 2 was not occluded. Instead, to accompany map 2, a dummy map and a transparent scoring frame were created. The dummy map was blank except for the vertically aligned orienteering leg. The transparent scoring frame was divided into 11 rows. Participants could place adhesive markers on the dummy map. The researcher could place the transparent scoring frame over the dummy map. When this was done, the first row of the transparent scoring frame overlaid the start of the dummy map, the tenth row overlaid the control, and the eleventh row overlaid the area just above the control. The 10 rows (of stickers) between the start and control of map 1 were congruent with the 10 rows (of the transparent scoring frame) between the start and control of map 2. A video camera (Sony GV-D900E, Newbury, UK) recorded proceedings from a stand directly above the map. Time was controlled using a stopwatch.

Procedures

Three methods were employed with all participants to test for heuristic use: the first heuristic was tested for by seeking evidence of a) prioritisation of the start, and b) forward planning; the second heuristic was tested for by seeking evidence of a) prioritisation of the control, and b) backward planning. Methods 1 and 2 required participants to plan routes and allowed the participants focus of attention to the map to be traced as they planned. In both of these methods, an independent variable was *stage of planning*, that is, the stage of attention to the map from the beginning to the end of planning. In both of these methods, the dependent variable was *focus of attention*, that is, where a participant focused their attention within the leg. Half the participants completed method 1 first; the remainder method 2 first. In method 3, researchers asked participants two questions regarding how they planned routes in general. *Expertise* was an independent variable in all methods (expert vs. novice). Pilot testing was undertaken prior to data collection.

Method 1. Map 1 was used in method 1. Participants sat at a table where the apparatus was arranged and were read an instructional set. They were asked to imagine that they were at the start at a real competitive race and were able to view a map to plan a route before the race commenced (in a real race the map is presented 10 s prior to commencement). Map 1 was then shown to the participants. They were informed that they were able to remove stickers in the order they desired, and in their own time, so as to plan a route. They were also informed that the decision about the second and subsequent stickers they removed might be based on the map information they had previously exposed, or might not, as they desired. They could remove as many stickers as they desired but there was no imperative to remove the fewest. The video recorded the removal of the stickers and, after testing, was played so as to undertake scoring. Stage of planning was quantified as the serial order of sticker removed, from 1 through to a possible 30. Thus, the fifteenth sticker removed was scored as 15. Focus of attention was quantified as the row from which the sticker was removed. Thus, a sticker removed from the row covering the start area was scored as 1, and from the row covering the control area as 10. Consequently, for each participant, one focus of attention score was obtained for each stage of planning. A mean focus of attention score across participants was then calculated for each stage of planning for use in the subsequent analysis.

Method 2. Map 2 was used in method 2. As in method 1, participants were asked to imagine that they were at the start of a race and were able to plan a route before the race. The map was exposed for 10 three-second periods, timed by stopwatch, so that participants could plan. Following each exposure, the map was immediately removed to reveal the dummy map secreted underneath. Participants were asked to indicate on this map all areas of the real map they had attended to using adhesive markers, regardless of whether any information useful for route planning was located there. The video recorded proceedings. After testing, the researcher placed the transparent scoring frame over the dummy map. The video was played so as to undertake scoring. Stage of planning was quantified as the serial order of exposures, from 1 to 10. Focus of attention was quantified as the row in which a marker was placed. Thus, a marker placed in the start area was scored as 1, the control area as 10. Originally, this frame was designed with 10 rows corresponding to the 10 rows of occlusion stickers used in method 1. However, pilot testing revealed that experts attended to the small area of map visible beyond the control, and thus an extra row was added to measure attention to this area. If an individual placed more than one marker following an exposure, his or her mean score across markers was calculated. Consequently, for each participant, one focus of attention score was obtained for each stage of planning. A mean focus of attention score across participants was then calculated for each stage of planning for use in the subsequent analysis.

Measure of ecological validity. An attempt was made to assess the ecological validity of methods 1 and 2. The question asked was: Was the route planning you did in this task like the route planning you do during orienteering? Responses were on a Likert scale ranging from 1 (meaning Not at all) to 9 (meaning Very similar).

Method 3. A short interview was conducted and tape-recorded. Participants were asked: a) can you tell me how you plan routes generally; b) what map information helps you plan? Both questions were open-ended thereby minimising the imposition of the researcher (Patton, 1990). Resulting data were transcribed for analysis.

Analysis

Methods 1 and 2. Chi-square tests with posthoc comparisons were used to test for differences between experts and novices in the frequency distribution of focus of attention at the first stage of planning. Owing to low expected cell frequencies, data indicating attention to areas between the start and control (i.e., scoring from 2 to 9) were collapsed into one category. In method 2, data scoring 10 and 11 constituted attention to the control area, and therefore these data were collapsed into one category. This resulted (for both methods) in a two by three contingency table for chi square tests: two levels of expertise (expert vs. novice) by three positions of focus of attention (start, middle, and control). During posthoc comparisons, the Bonniferoni technique was used to adjust alpha to .016 (.05/3), to reduce the probability of Type I errors, and Yates continuity correction was used. Disproportionately large distributions of a focus of attention to the start area would have been consistent with a general start-first heuristic and, to the control area, a general control-first heuristic.

The correlation between stage of planning and focus of attention was calculated for both methods. A positive correlation would have been consistent with a general work-forward heuristic, and a negative correlation a general work-backward heuristic.

Method 3. Participants qualitative data were examined for evidence of heuristic use by the first author, and subsequently by an independent judge for the purpose of consensus validation. For simplicity, the judge was required to categorise each participant s interview as providing any evidence of either: a) a start-first, work-forward heuristic; b) control-first, work-backward heuristic; or c) neither heuristic. The judge was not told that the interviews were from two different groups. Cohen s kappa was calculated as a measure of agreement between the first author and judge. Chi-square tests with posthoc comparisons were used to test for differences in the reported use of a start- versus control-first heuristic, and a work-forward versus a work-backward heuristic, between experts and novices. During posthoc comparisons, alpha was set at 0.16 (.05/3) and Yates continuity correction was used.

Figure 5: Expert participant is read instructional set.

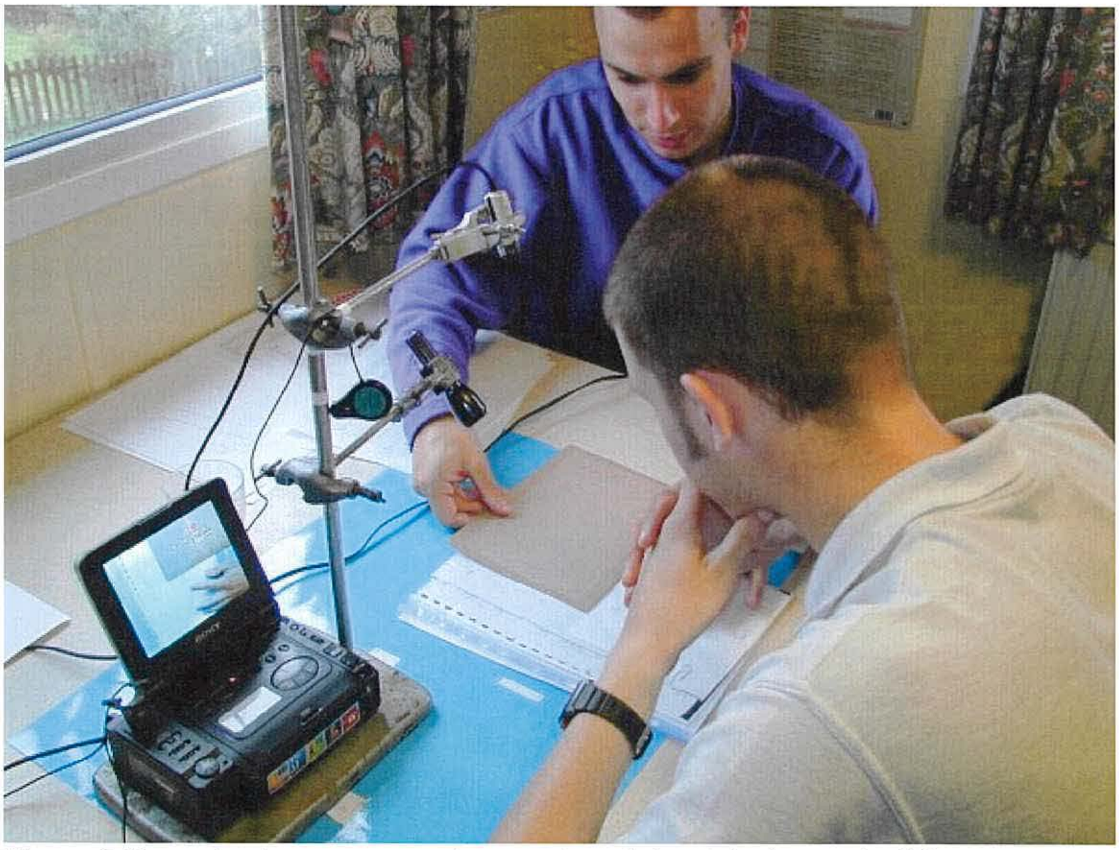


Figure 6: Preparing to expose map to expert participant during method 2.

Results

Measure of ecological validity.

The expert group s mean score was 5.15 (s = 2.16) for method 1, equating to a meaning of A little similar , and 6.99 (s = 1.46) for method 2, equating to a meaning of Quite similar . The novice group s mean score was 5.03 (s = 2.53) for method 1 and 5.15 (s = 2.12) for method 2; both values equated to a meaning of A little similar. With alpha set at .05, a 2 factor (2 skill groups by 2 methods) analysis of variance revealed a significant main effect of method on ratings of ecological validity: method 1 rated lower than method 2; $F(1, 38)$ = 6.75, $p < .01$. The effect of skill and the interaction were not significant.

Methods 1 and 2.

Table 3 displays, for both methods, the percentage distribution of focus of attention for experts and novices at the first stage of planning. This table illustrates, for both methods, that, generally, novices focused their attention to the start, and experts to the control, at the first stage of planning. Table 4 displays, for both methods, chi square tests for, and posthoc comparisons of, differences between experts and novices in the frequency distribution of focus of attention between start, middle and control areas, at the first stage of planning. As the table shows, there was a significant difference between experts and novices in the frequency distribution of focus of attention to the start versus the control in both methods.

The correlation between stage of planning and focus of attention was not significant in the novice group in method 1 (r = .30, n = 30, p = .11) or method 2 (r = .38, n = 10, p = 0.28). This same correlation was significant and negative in the expert group in method 1 (r = -.56, n = 30, $p < .01$; r^2 = .31) but not in method 2 (r = -.11, n = 10, p = .77). In method 1, the scatter plot between stage of planning and focus of attention for novices assumed an inverted-U shape.

Table 3: Percentage Distribution of Focus of Attention at the First Stage of Planning for Experts and Novices in Methods 1 and 2.

	Method 1		Method 2	
Focus of attention	Novices (n = 20)	Experts (n = 20)	Novices (n = 20)	Experts (n = 20)
11 (Control)			5%	25%
10 (Control)	10%	65%	0%	30%
9	0%	15%	5%	5%
8	0%	0%	5%	0%
7	0%	0%	0%	0%
6	0%	0%	0%	5%
5	0%	5%	0%	5%
4	0%	0%	0%	0%
3	0%	0%	5%	0%
2	5%	0%	10%	0%
1 (Start)	85%	15%	70%	30%

<u>Table 4: Chi Square Tests for, and Posthoc Comparisons of, Differences between Experts and Novices in the Frequency Distribution of Focus of Attention at the First Stage of Planning.</u>

	Method 1			Method 2		
Analysis	$\_^{2}$	*n*	*p*	$\_^{2}$	*n*	*p*
Start versus middle versus control	12.03	40	.002	19.67	40	<.001
Start versus middle[a]	0.00	28	1.000	0.00	20	1.000
Start versus control[a]	9.11	32	.003	14.97	35	<.001
Middle versus control[a]	4.38	20	.036	5.47	25	.019

Note: Alpha was set at .05 during the initial test. This level was adjusted to .016 during posthoc comparisons using the Bonniferoni technique. *p* values below .001 were not available from the computer output.
[a]Posthoc comparison.

Method 3.

Table 5 displays for experts and novices the percentage distribution of the reported use of a start- versus control-first heuristic, and a work-forward versus a work-backward heuristic. This table illustrates that, generally, novices reported prioritising the start or did not report prioritising either the start or control, and experts reported prioritising the control. The table also illustrates that only approximately half of the experts, and novices, provided any evidence of either a work forward or work backward heuristic. Of the remainder, all novices reported working forward, and the majority of experts working backwards. Table 6 displays chi-square tests for, and posthoc comparisons of, differences between experts and novices in reported heuristic use. As the table shows, there were significant differences between experts and novices in reports of the following: the prioritisation of the start versus the control; the prioritisation of the control versus no evidence of heuristic use; and working forward versus working backward. Excerpts from the reports of heuristic use by experts and novices are provided in Appendix 2. Recall that the participants responses were undirected. The researcher responsible for consensus validation categorised 80% of participants responses consistent with the first author. Cohen s kappa, measuring agreement between the two parties, was 0.69, where 0.70 is regarded as good agreement (Fleiss, 1981).

Table 5: Percentage Distribution of Reported Heuristic Use for Experts and Novices in Method 3.

Heuristic	Novice (n = 20)	Expert (n = 20)
Start-first	20%	5%
Control-first	5%	80%
No evidence of start- or control-first	75%	15%
Work-forward	45%	15%
Work-backward	0%	35%
No evidence of work-forward or work-backward	55%	50%

Table 6: Chi Square Tests for, and Posthoc Comparisons of, Differences between Experts and Novices in the Frequency Distribution of Reported Heuristic Use.

Analysis	$\_^{2}$	*n*	*p*
Start-first versus control-first versus no evidence	23.04	40	<.001
Start-first versus control-first[a]	8.23	22	.004
Start-first versus no evidence[a]	0.00	23	1.000
Control-first versus no evidence[a]	18.13	35	<.001
Work-forward versus work-backward versus no evidence	10.05	40	.007
Work-forward versus work-backward[a]	7.19	19	.007
Work-forward versus no evidence[a]	0.83	33	.363
Work-backward versus no evidence[a]	4.04	28	.044

Note: Alpha was set at .05 during the initial test. This level was adjusted to .016 during posthoc comparisons using the Bonniferoni technique. *p* values below .001 were not available from the computer output.
[a]Posthoc comparison.

When the results from all methods were considered together, the findings were as follows. Generally, novices prioritised the start in methods 1 and 2, and to a lesser extent in method 3 (four out of the five novices who provided evidence of either heuristic reported prioritising the start). Generally, experts prioritised the control in all three methods. These differences between experts and novices were significant in all three methods.

The evidence concerning whether novices subsequently worked forward from the start or experts backward from the control was less clear. The correlations that tested this were not significant for novices in both methods 1 and 2, and for experts in method 2. However, the data from the novices in method 1 assumed an inverted-U shape. Inspection of the data from method 1 concerning the columns of the sticker matrix revealed that novices typically worked forward up the central column of the matrix, along the centre of the leg, and backward down the two peripheral columns (full description of the column data is beyond the scope of this article). This suggested that novices worked forward initially and backward later. No time restriction was placed on participants in method 1, unlike in real orienteering. Consequently, the novices heuristic might have generally been work-forward in nature, but given extra time they might have worked backwards to obtain extra information. Therefore, this latter behaviour might be as a consequence of the lack of time pressure, and hence an artefact of the design. The data from method 3 were consistent with this: the nine novices who provided evidence of either heuristic all reported working forwards.

The correlation was significant and negative for experts in method 1, suggesting that experts generally worked backwards. The data from method 3 were only partly consistent with this: ten experts provided evidence of either heuristic; of these, seven reported working backwards and three forwards. Despite only approximately half of the novices, and experts, providing evidence of either a work-forward or work-backward heuristic, there was a significant difference between the remainder of these groups in terms of reported heuristic use.

Discussion.

Expert orienteers interviewed by Eccles et al. (in press, a) reported the use of two different heuristics during route planning (start-first, work-forward and control-first, work-backward). The objective of this study was to investigate which heuristic experts used during planning, and whether novices differed from experts in their use of these heuristics.

This study provided evidence that experts generally attend to the control, and novices to the start, first when planning. The evidence pertaining to how experts and novices subsequently plan was less clear. However, there was some evidence that novices work forwards from the start to the control, and that experts work backwards from the control to the start.

Some limitations to this study must be noted. First, this study took place in a laboratory and thus there was a threat to ecological validity. However, participants reported that the planning undertaken in this study was at least quite similar to that undertaken in real orienteering. Consequently, it might be argued that these methods possessed at least some ecological validity. Method 2 was rated as more representative of real planning than method 1. Comments by participants indicated that method 1 did not allow an initial overall impression of the terrain to be gained before stickers were removed, unlike in real orienteering and in method 2. Second, participants in method 1 might have used more time to plan than in reality (as discussed earlier). Third, tracing the focus of attention during planning in methods 1 and 2 was an indirect measure of heuristic use and thus might not have accurately reflected heuristic use. In addition, the correlations that tested the planning forward/backward heuristics were not significant in several instances. However, participants might have all planned in a similar manner overall but group variance in the focus of attention scores between stages of planning might have resulted in meaningless data when the scores where averaged. For example, two novices might have both planned forwards but at very different rates, and thus the mean score might not reflect the overall consistency in these novices strategies. Fourth, methods 2 and 3 relied on self-report, said to be limited to cognitively penetrable processes (e.g., Nisbett and Wilson, 1977). However, there was some evidence that these methods were internally consistent: all three methods provided evidence that experts attended to the control first, and, to a lesser extent, that novices attended to the start first. Finally, this study did not show any causal relationship between heuristic use and performance. To understand the contribution of planning to performance, future research involving teaching novices to use experts planning strategies is needed.

Planning is thought to comprise hierarchical cognitive processes that structure behaviour from the initial- to the goal-state of a problem (e.g., Miller et al., 1960). The results from this study suggest that experts employ qualitatively different planning strategies to novices, consistent with experts in other sports (e.g., McPherson, 2000). The hierarchy of cognitive processes involved in planning by experts in this study appears counter-intuitive. Participants might have been expected to attend to the start first because it was where they were situated (albeit in their imagination), and hence the area in front of the start required attention if they had wished to begin moving through the terrain. However, the experts generally attended to the control area first, which was a considerable distance from their location. Attending to the control first appears to be a higher-order process in the hierarchy of processes that comprise planning by experts in orienteering.

An examination of the qualitative data from this study and from Eccles et al. (in press, a) revealed possible explanations for the experts heuristic. First, navigational errors that occur near the control area, in contrast to earlier in the leg, can negatively affect performance. However, for any given leg, there appears to be a route into the control area that facilitates the location of the control. Identifying such a route appears to be the crux of the problem that is the orienteering leg. Experts are known to recognise the essential properties (Simon & Barenfield, 1969, p. 474) of a problem and thus can rapidly simplify a problem to its barest qualitative elements (Kellogg, 1995, p. 210; see also Thomas, French, & Humphries, 1986). This is said to reduce the burden on processing resources (Ericsson & Lehmann, 1996). The optimal route into the control appears to influence how the remainder of the route is planned. This might explain why some of the experts seemed to work backward from the control towards the start.

Also, planning ahead as much as possible appears to allow performers to anticipate the oncoming environment and hence reduce the need to refer to the map for the purpose of locating oneself and making route-choice decisions (Eccles et al., in press, a). Consistent with this, Eccles et al. (in press, b) provided evidence that experienced orienteers stopped infrequently and for short periods of time compared to less experienced orienteers. Anticipation has been identified as a strategy used by skilled individuals in other dynamic domains (e.g., Abernethy, 1990; Sloboda, 1984; Salthouse, 1986), including those involving navigation; as Norman (1980) suggests, the expert pilot flies ahead of the plane (p. 333, cited in Aitkenhead & Slack, 1985).

These explanations would imply that the heuristics used by expert orienteers are knowledge-driven. Expert orienteers might have acquired domain-specific knowledge, through practice and experience, resulting in the use of specialised heuristics during planning (Chi et al., 1982). Consequently, behaviour can be guided in a manner that causes performance benefits. In contrast, the unpractised and inexperienced novices are unlikely to have acquired any domain-specific knowledge that might result in the use of specialised heuristics (Chi et al., 1982). In turn, behaviour is not guided in a manner that determines performance benefits. The evidence from this study might reflect adaptations to task constraints by experts (Ericsson and Lehmann, 1996). For example, the expert orienteer might have adapted by acquiring a planning heuristic that prioritises the identification of an optimum route into the control, and thus allows the crux of the problem to be solved with the minimum of time and processing resources, resulting in more efficient orienteering.

A training programme for novices based on the planning behaviour of the experts in this study might improve performance. Previous research has provided evidence that skills such as locating and using specific cues in the environment can be trained (e.g., Singer et al., 1994). Therefore, training novices to attend to the control first, in order to establish a route into the control area, might be feasible. Various other factors influencing route planning were elicited from the interview questions in this study. These included the presence of linear features, the amount of ascent, and the difficulty of the terrain underfoot. Future research needs to establish the contribution of these other factors to route planning. Planning remains a relatively under researched area in psychology (Ward & Allport, 1997). Given the suggested importance of the role of planning in sport and expertise (e.g, Ericsson & Lehmann, 1996), further research into the use of heuristics by sports performers during planning is required.

Expert orienteers interviewed by Eccles et al. (in press, a) reported the use of two different heuristics during route planning. The objective of this study was to investigate which heuristic experts predominantly used during planning, and whether novices use of these heuristics differed from experts. This study provided evidence that experts generally attend to the control first, and novices to the start first, when route planning. The evidence concerning how experts and novices subsequently planned was less clear. However, there was some evidence that novices work forwards from the start to the control, and that experts work backwards from the control to the start. These results have implications for an understanding of expertise and problem solving in sport, and for skill acquisition within orienteering.

CHAPTER 5

GENERAL DISCUSSION

Summary of main thesis findings.

The objective of the first study was to gain an understanding of expert cognition in orienteering. The British elite orienteering squad was interviewed and grounded theory was used to develop a theory of expert cognition in orienteering. In this theory, the orienteer must make a comparison of either the map to the environment or the environment to the map in order to navigate through the environment, and does so by manufacturing a mental representation of the map or environment for comparison with the other. Early in a race the orienteer must learn how the cartographer has interpreted the environment during the map-making process. This might cause some ambiguity in the comparison process resulting in a reduced running speed. However, running speed is increased as the orienteer learns the how the cartographer has interpreted the environment.

The theory also suggests that fast travel through the environment is necessary in order to maximise orienteering performance. However, an increase in running speed requires an increase in attention to travel. This results in three sources of information requiring attention: the map and environment, for the purpose of comparisons, and travel. However, as more attention must be allocated to travel as running speed is increased, fewer attentional resources are available for making comparisons between the map and environment. Similarly, when more comparisons between the map and the environment are necessary for navigation, fewer attentional resources are available to allocate to travel. Consequently, running speed is reduced and performance decreases. Additionally, a number of factors affect the amount of comparisons that are necessary for navigation. These include the orienteer s position within the leg and the complexity of the terrain.

However, the orienteer can reduce the amount of comparisons necessary by simplifying navigation. Consequently, running speed can be increased and performance improved. Simplification is achieved by selecting only information from the map that is known to be distinguishable in the environment. An example of this strategy is the use of an attack point . An attack point is a feature in the terrain that is in close proximity to the control and is easily distinguishable, and, therefore, easier to locate than the control itself. Location of the attack point reduces the distance in the terrain within which the orienteer must accurately navigate before locating the control, and therefore reduces the number of comparisons to the map and environment. Another strategy that reduces the number of comparisons between the map and environment that need to be made entails forming a mental representation of the map that is anticipatory in nature. This is often achieved by attending to the map during periods when the demands on processing resources are low, such as whilst running down a track. By anticipating as much of the upcoming terrain as possible, the orienteer can reduce the need to attend to the map for continual comparison with features in the environment. Instead, the orienteer can simply compare his or her mental representation of the map information to the environment.

Finally, the theory suggests that attending to the map at high levels of work intensity is problematic. The level of fitness of an orienteer moderates the level of work intensity experienced at any given running speed, and so the fitter an orienteer is, the less problematic attending to the map at speed becomes.

To reiterate, in study one it was proposed that attention to the map, environment, and travel was a task constraint central to orienteering. Based on this proposition, the second study was an investigation, conducted at a behavioural level, into how orienteering experience affected the allocation of visual attention to these three sources of information. The main findings were as follows. Although more experienced orienteers did not differ significantly from less experienced orienteers in their overall allocation of attention when expressed as percentages, they looked at the map and environment more times per minute and for shorter periods of time, and did this markedly more whilst moving. When experienced orienteers stopped it was only for short periods of time. In contrast, less experienced orienteers looked at the map and environment fewer times per minute, and looked at the map very little whilst moving. The majority of the time they spent looking at the map was while stationary. The use of planning strategies was suggested as one explanation of the superior ability of the experienced orienteers to read the map without stopping. Elite orienteers in study one reported planning ahead during periods of low attentional demand so as to avoid stopping. According to the theory proposed in the first study, the advantages of planning were to solve upcoming route choice decisions and to be able to anticipate the upcoming terrain. Consequently, this made the orienteer less likely to stop later in the course to make decisions or relocate his or her position.

Given the suggested importance of planning to orienteering performance, the objective of the third study was to identify the use of heuristics during planning by expert and novice orienteers. The qualitative evidence from the first study indicated that two heuristics might be used during planning. In the first heuristic, the start was prioritised first during the planning of any given leg, and the route to the control was planned later in a forward direction from the orienteer s present location. In the second heuristic, the control was prioritised first during the planning of any given leg, and the route to the control was planned later in a backward direction from the control to the orienteer s present location. The use of these heuristics was tested for in expert and novice orienteers at a behavioural level in the laboratory. Participants were also asked specific questions about their use of heuristics during planning. The main findings were as follows. There was evidence to suggest that experts generally attended to the control, and novices to the start, first when route planning. The evidence concerning how experts and novices subsequently planned was less clear. However, there was some evidence that experts worked backwards from the control to the start, and that novices worked forwards from the start to the control.

Limitations of the research.

A number of limitations to this research must be noted. The first is concerned with the internal and ecological validity of the research. Orienteering is a dynamic task that is undertaken over a large area in the outdoors. Consequently, it is difficult to observe an individual as they orienteer throughout an entire course. For example, orienteering coaches typically rely on feedback from orienteers for performance-related information because they cannot observe their orienteers performance (Omodei & McLennan, 1994; Omodei et al., 1998). Consequently, the nature of the sport presents problems for researchers of the sport. One criticism of laboratory-based studies of human behaviour is their lack of ecological validity (Martens, 1987); real-world behaviour occurs in real-world settings and, hence, not in laboratory settings. This problem is particularly relevant in studies of expertise because expertise appears domain-specific (e.g., Ericsson & Lehmann, 1996). Therefore, any experimentally-contrived situation that is not representative of the expert s domain might reduce the chance of observable expert performance. Starkes and Deakin (1984) remarked that the probability of discovering expert/novice differences is inversely proportionate to the size of the discrepancy between any contrived task and the real-world task. This creates an imperative to conserve the natural context and demands of the task as much as possible.

However, studies conducted in the laboratory have the advantage of control over potentially extraneous variables. For example, a field setting in orienteering occurs in a forest or on open moor or fell land. A researcher in these environments would have little control over environmental factors such as changes in climate, light level, season, and forestation. Random extraneous variables such as these might affect scores on dependant variables of interest, and thus increase error variance and decrease effect sizes (Cook & Campbell, 1979). Therefore, a trade-off is apparent between internal and ecological validity in studies of orienteering. While this trade-off is ubiquitous in research, it is accentuated in domains that occur in environments that are dissimilar in nature to laboratory environments. For example, the game of chess, a domain that is frequently investigated in cognitive psychology, is played by seated, static participants, is slow to proceed, is easily observable, and takes place in an indoor environment. Therefore, this domain is relatively conducive to laboratory study and, consequently, there is less trade-off between internal and ecological validity in chess studies. As discussed, orienteering is a dynamic and complex task that takes place outdoors. Cook and Cambell acknowledge this problem: In many complex field settings [control over extraneous variables] . . . will be very difficult to implement (p. 44). The orienteering environment is not conducive to laboratory study. The search for contrived experimental tasks that can be studied under controlled laboratory conditions but remain representative of real tasks (see Ericsson, 1996) is much more problematic in orienteering than in chess.

Therefore, the behavioural studies conducted in this thesis share both the advantages and disadvantages of the context in which they were conducted. For example, Seiler (1990) asked elite orienteers to plan and then execute a route within an orienteering leg. He observed that orienteers did not always follow the route, when actually orienteering, that they had planned previously. Seiler concluded that route planning requires information available in the environment during actual orienteering, not just the information available on the map that was provided during planning. Therefore, by being conducted in a laboratory setting, the third study was characterised by the control of many extraneous variables, and thus was high in internal validity, but owing to a lack of available environmental information during route planning, was potentially lower in ecological validity. In contrast, the field study (study two) was higher in ecological validity, but less control over extraneous variables was possible in this study.

A second limitation is concerned with establishing cause. All three studies in the thesis were examples of descriptive research, and the second and third studies were survey studies. No true experiments or quasi-experiments were conducted, that is, no variables were manipulated and there was no random allocation to groups. The problem with descriptive research is that it is difficult to establish cause. For example, although expert orienteers reported that they used various strategies to improve performance, and the ability to read the map while moving was shown to correlate significantly with performance, it can only be established that these phenomena are related to performance, not that they cause increases in performance. Research is now needed into whether the strategies used by expert orienteers are of benefit to other groups of orienteers (discussed below). Studies employing true experimental designs, in which novices are randomly assigned to groups receiving training in different strategies (and to a control or placebo group), would more firmly establish causal relationships.

A third limitation is the use of methods relying on self-report. All of the studies in this thesis relied on self-report methods to some extent: the first study relied entirely on interview data, the second study required participants to verbally label their focus of attention, and participants in the third study reported where they focussed their attention on the map using adhesive markers. Data elicited by methods of self-report are often thought to be limited to cognitively penetrable processes, that is, mental processes to which there may be no access at all (Nisbett & Wilson, 1977, p. 255). Nisbett and Wilson (1977) described an experiment in which they asked participants to choose a favourite item from a selection presented. Nisbett and Wilson were able to determine that participants actual choices were not always consistent with their reported reasons for these choices. Therefore, participants were not able to report the reasons for their behaviour accurately. Nisbett and Wilson proposed that individuals often verbalise reasons for actions based on implicit, *a priori* causal theories, and, hence, verbalise much more about the reasons for their behaviour than they actually know. Phrased alternatively, the individual will often offer justifications for actions that they believe are accurate but in reality are not. Consequently, the limitations of self-report methods must be taken into consideration when interpreting the results of the studies in this thesis. The limitations of self-report methods in this thesis were revealed when the elite orienteers in study one tried to describe their mental representations of map information. Elite orienteers reported trying to build up an idea of what the terrain would look like from the information available on the map because anticipating in this way was reported to be beneficial to performance. However, the orienteers often experienced difficulty describing how they represented this knowledge: some reported explicit attempts to form pictures of the terrain but others simply reported being aware of what to expect without forming a picture. This ambiguity might be due to these mental representations being cognitively impenetrable, making verbal reports inaccurate and incomplete.

Another limitation is concerned with the samples used in the studies. The novice samples from studies two and three typically comprised undergraduates from sport and exercise degree programmes, and these samples were similar in terms of their orienteering skill. Therefore, it might be proposed that generalising the results from one novice sample to another is not a problem. Studies one and three both involved samples of expert orienteers that comprised members of the British orienteering squad, but study two involved a sample of experienced orienteers that comprised club standard orienteers. It is tempting to generalise the results from the expert samples to the experienced sample. However, the skill level of these samples is undoubtedly different, and therefore the behaviour of the experts in studies one and three might not be the same as the behaviour of the experienced orienteers in study two. For example, in study two, evidence was presented of the experienced orienteers superior ability to read the map while moving, compared to the inexperienced orienteers. It is tempting to assume that the experts from the other studies would behave similarly. Furthermore, given the experts higher level of skill, it might be speculated that they would spend more time reading the map while moving than the experienced orienteers in study two. However, this is an assumption; the samples are different and, therefore, the strategies used by the samples might be different, resulting in different behaviour. Consequently, some caution is necessary when generalising the findings from the sample of experienced orienteers in study two to the samples of expert orienteers in studies one and three.

Theoretical Implications.

The findings of this thesis are compared here with the results of the previous psychological studies on orienteering. Gal-Or et al. (1986) reported that one of the most frequently used cognitive strategies in orienteering was imagery but did not discuss how imagery was used. The results from the first study of this thesis suggested that one way elite orienteers make use of imagery is by trying to form the best image possible of the upcoming terrain. The manufacture of a representation of map information pertaining to terrain that was some distance ahead of the present position of the orienteer was proposed to aid anticipation. Consequently, orienteers could plan ahead and prepare their actions and thus essentially circumvent the need for rapid immediate reactions (Ericsson, 1996, p. 18), as experts in other domains have been observed to do (Ericsson, 1996). For example, in many dynamic sports, such as squash (Abernethy, 1990), football (Williams & Burwitz, 1993), volleyball (Wright, Pleasants, & Gomez-Meza, 1990) and tennis (Jones & Miles, 1973), much of the experts advantage in reaction time has been shown to be a consequence of the use of cues available in the environment in advance of events occurring. The appropriate preparations can be made for those events based on the information available in these cues (for a review see Williams, Davids, & Williams, 1999).

Similarly, the expert typist, when compared to the novice, is always looking ahead in the text compared to what is actually being typed so as to prepare finger movements required for upcoming words (Genter, 1983, 1988; Salthouse, 1984, 1986). A similar situation occurs in music: expert sight readers, compared to novices, look ahead in music scripts compared to what is actually being played so as to prepare movements (Bean, 1938; Sloboda, 1984). Furthermore, it is interesting to note that Dell et al. (1997) discovered that skilled orators tend to make anticipatory errors in speech in that they confuse the word they are saying with a word they are about to say. In contrast, less skilled orators tend to confuse the word they are saying with one recently said. This suggests that the skilled orators are anticipating what is about to be said when compared with less skilled orators, and this anticipatory behaviour might be a component of their skill. Similarly, Whitaker and Cuqlock-Knopp (1995) reported that one strategy used during navigation by their sample of off-road navigators, which included orienteers, was that of using the information from the map to predict the upcoming terrain (however, the use of an imagery as the mode of the mental representation of this knowledge was not mentioned).

The representations (images or ideas) of environmental information described by the orienteers in the first study seems consistent with the notion of a cognitive map (Tolman, 1948), in that they encoded, stored (mentally represented), and recalled information about a particular environment (Moore & Golledge, 1976). However, the orienteers were unclear as to the nature of their imagery. Some reported explicit attempts to form pictures of the terrain as if seen through the eyes. In contrast, others reported simply being aware of what to expect but not forming a picture-like image. As discussed earlier, this ambiguity might be because mental representations are possibly cognitively impenetrable, making verbal reports inaccurate and incomplete. Although highly speculative, the former account of imagery seems consistent with an analogical mode of mental representation, while the latter account a propositional mode of representation. Given the suggested frequency with which orienteers use imagery, and the proposed performance benefits of the use of imagery, it might be of interest to discover what mode of representation is used, and how this mode changes with an increase in skill acquisition. For example, recent research into child development has indicated that the nature of the mental representation of environmental information changes with age and maturation. Evidence has been provided of a reliance of younger children on analogical representations. Younger children do not seem to be able to create, and thus utilise, propositional representations. However, older children are able to use both types of representation (e.g., Fenner et al., 2000).

Robbins et al. (1996) attempted to discover what mode mental representations took in chess players, and how this changed with an increase in skill. Robbins et al. tested this by adopting Baddeley s (1986) working memory theory. This theory proposed that working memory has three separate sub-components: the central executive, phonological loop, and visuospatial sketchpad. The phonological loop is said to be responsible for the storage of textual and language-like information, consistent with the notion of propositional representations, and the visuospatial sketchpad for visual and spatial information, consistent with the notion of analogical representations. These authors employed a recall paradigm (and other methods not reported here) whereby participants were required to reconstruct temporarily observed chessboards on which the pieces were arranged in positions typical of the middle of a game (cf. de Groot, 1946/1965; Chase & Simon, 1973a). The phonological loop and visuospatial-sketchpad were separately suppressed using secondary tasks during memory and recall phases of the chess experiment in an attempt to ascertain which sub-component of working memory was predominantly responsible for storage of chess position information. Recall performance was observed as each sub-component was suppressed. Suppression of the sub-component responsible for the storage of chess information should have caused the worst recall performance, allowing the mode of representation of chess information to be inferred. Robbins et al. used differing skill groups in an attempt to ascertain how the mode of representation changed with an increase in skill. A replication of this experiment in which orienteers of different skill levels are required to remember and recall map information might reveal the mode of representation predominantly used in orienteering, and how that mode changes with an increase in skill. The results of such an experiment would have implications for how best to structure map memory exercises and imagery training.

Many of the elite orienteers in studies one and three reported that they tried to make as complete an image as possible of the upcoming terrain. Although speculative, attempts to form a complete picture of the terrain appear consistent with the notion of trying to create a survey-based representation, regarded as the most advanced knowledge an individual can possess about an environment (Seigel & White, 1975). The advantages of a complete image in orienteering might be similar to the advantages of survey-based representations. For example, adults who possess only route-based representations have been observed to get lost more easily during wayfinding (e.g., Lawton, 1994). This is because route-based representations are useful only while on the route. In contrast, survey-based representations are global representations of the environment and are not linked to any particular route, or orientation of an individual. Individuals who have acquired survey-based representations are also able to identify short cuts between points in the environment more easily than those with route-based representations (O Keefe & Nadell, 1978).

Hancock and McNaughton (1986) proposed that fatigue had a negative effect on visual information processing (e.g., map reading) in orienteering. The results from the first study appeared consistent with this. Orienteers reported that being as fit as possible allowed the map to be read more easily while moving.

Seiler (1990) proposed that the elite orienteer reduces physical and/or technical expenses (p. 40). The results of the first study of this thesis are consistent with this: elite orienteers reported simplifying the task as much as possible and the result of this was suggested to be a reduction of the burden on processing resources. This might be regarded in essence as a reduction in what Seiler refers to as technical expenses . Whitaker and Cuqlock-Knopp (1995) reported a strategy that effectively resulted in simplification, known as aiming off. This involved navigating to a large and hence distinguishable linear feature proximal to the actual desired location (e.g., the control). The linear feature could then be used as a hand rail to guide the navigator towards the desired location, thus reducing the possibility for error. This strategy is similar to the strategy of using an attack point reported by the elite orienteers in study one, and both appear to have the same effect of simplifying the amount of information required to navigate. The result of simplification, and Seiler s notion of a reduction in physical and technical expenses, is likely to be a more efficient orienteer; that is, an increased level of performance for the same cost to energy and processing resources.

Seiler (1990) also reported that control difficulty was a factor influencing route choice but did not elaborate to explain how this factor influenced route choice. The results from studies one and three of this thesis indicated that the control site was the essence of the problem that is an orienteering leg. Small inaccuracies in navigation that occur before the control area are reported to have a small or negligible cost to performance and, therefore, the elite orienteers in study one seemed prepared to trade off some accuracy for the benefits an increase in speed provided. However, the cost of error near the control was reported to be much greater than earlier in the leg. Here, accurate navigation was paramount to the location of the control; the control is a small feature that can be missed easily. The cost of missing the control was reported to be a considerable loss in time, the performance criterion. There was behavioural evidence in the third study that expert orienteers prioritised the control when planning. In addition, the elite orienteers in the third study reported that that the selection of a route that maximises the probability of finding the control influences how a route to the control is subsequently planned, and some behavioural evidence of a backward planning heuristic consistent with this notion. A difficult control might be one where establishing an optimal route to the control is problematic. Experts are thought to be able to rapidly recognise, and hence more accurately categorise, the difficulty of a given problem, and thus can allocate resources accordingly (e.g., Chi, 1978; Chi et al., 1982; Chi et al., 1988).

Considering this, the findings of studies one and three, and those by Seiler (1990), it might be speculated that the expert orienteer attends to the control first to identify its difficulty in terms of identifying an optimal approach. If it is difficult the orienteer might spend longer (invest more resources) considering alternative approaches to identify an optimal approach. Whether the control is difficult or not, the rest of the route would then be planned backwards from the control after an optimal approach is identified (however, note that the backwards planning heuristic received only partial support in the third study of the thesis).

Seiler (1990) suggested that other factors influenced route. For example, he suggested that avoiding hindrances was more important than running speed; that is, running speed would be traded off if it meant avoiding hindrances. Perhaps the cost of hindrances, in terms of time, was greater than the loss of running speed, a similar phenomenon to that reported in study one whereby the cost of missing the control was considered greater than the loss in running speed required to accurately locate the control. Seiler also reported that the amount of ascent, the difficulty of the terrain underfoot, and the presence of linear features, influenced route choice. The qualitative evidence obtained in the first and third studies also indicated that other factors, including the presence of linear features, influenced route choice. Whitaker and Cuqlock-Knopp (1995) reported a strategy known as aiming off, discussed above. This involved navigating to a linear feature that could then be used as a hand rail to guide the navigator towards the desired location, thus reducing the possibility for error. It might be speculated that this is the reason that the orienteers in the study by Seiler and in study three of this thesis reported the presence of linear features as a factor in route choice. Future research might include the construction of a model of route choice decision-making by expert orienteers and, subsequently, experiments might be designed to test aspects of the model at a behavioural level.

Omodei et al. (1998) reported that the orienteers in their study were often shocked to discover how often, and for how long, they stopped running to check the map. The results from study two indicated that experienced orienteers spent markedly more time looking at the map while moving than while stopped compared to inexperienced orienteers. Omodei et al. also reported that the orienteers in their study were shocked to discover how often, and for how long, they spent searching for controls. The results from studies one and three suggest that the control is the essence of the problem that is the orienteering leg, and that attention to planning an optimum route into this area is prioritised. It might be speculated that orienteers want to improve their skills and would benefit from being made aware of where time is wasted by stopping to look at the map, and by searching for the controls, using a head mounted video camera protocol. Furthermore, they might also benefit from strategies reported by elite orienteers that help overcome these two problems. For example, learning to read the map while moving (e.g., by planning ahead when demands on attention are low) might reduce the incidence of stopping to read the map, whilst learning to prioritise the establishment of an optimum route into the control might reduce time wasted searching for controls.

The findings of the three studies of this thesis might be explained by an adaptations approach to expertise and skill acquisition (see Ericsson & Lehmann, 1996). An individual s performance at a given task can be affected negatively by burdens on processing resources. These burdens are often caused by constraints inherent in a task. In the first study of this thesis, the requirement to attend to three sources of environmental information, the map, the environment, and travel, was a task constraint identified as central to orienteering. This constraint was suggested to result in a burden on processing resources. However, environmental factors, such as deliberate practice in, and extensive experience of, a specific domain have been suggested to cause an increase in declarative and procedural knowledge of that domain, leading to changes in information processing, a circumvention of processing limitations, and ultimately, increases in performance (Ericsson & Lehmann, 1996). The orienteers in studies one and three were highly practised and experienced. For example, the orienteers in study three had an average of 13.85 years experience, and trained for an average of 7.18 hrs per week. If it were assumed that they had trained for this duration per week over their entire orienteering careers, their total amount of practice time expressed in hours would equal 5171.04 hrs.

Simon and Chase (1973) proposed that becoming an expert in any domain required 10,000 hrs of practice over a 10 year period. The hours of practice estimated above for elite orienteers fall well below 10,000 hrs but do extend over 10 years. There might be several explanations for the deficit between the amount of practice calculated for the orienteers in study three and that suggested by Simon and Chase. First, the reported level of practice might be inaccurate. Second, the calculated figure does not include time spent competing, or doing any other activity such as mental rehearsal, which might be considered time spent practicing. Third, there exist absolute and relative levels of expertise (Ericsson, 1996). The orienteers in the samples in studies one and three represent the highest levels of performance in Britain but orienteering remains a sport in which few elite performers are able to train on a full-time basis. For example, an orienteer within the expert sample in study three received some funding from the government for orienteering. He had also moved from Britain to Sweden; one reason for this move was that the type of terrain that orienteers need for training is easily accessible in Sweden, so training times could be maximised. Despite these advantages, this orienteer still needed to work part-time to fund himself fully, thereby limiting the amount of time he could train. Somebody who has been able to accrue 10,000 hrs of practice over 10 years must train for at least 19 hours per week. It might be speculated that this amount of time is not possible for a part-time athlete given the amount of time required for rest. Consequently, although this expert represents a world class level of performance, this standard is only relative to that which could be achieved if full time training was an option available generally to orienteers. This option is not currently available for the vast majority of orienteers worldwide.

Despite this, the expert orienteers in study three had amassed an average of over 5,000 hrs practice in orienteering and over 10 years of competitive experience. This level of practice and experience is likely to have caused a large increase in the declarative and procedural knowledge base of these experts, specific to the domain of orienteering (Ericsson et al., 1993; Helsen & Pauwels, 1993). Experts knowledge is known to facilitate the adoption of domain-specific cognitive skills and strategies that cause changes in the way information is attended to, perceived, and stored in working and long-term memory (represented). The experts in studies one and three reported various skills and strategies that appeared to cause changes in the way information was processed. Furthermore, the behaviour by expert and experienced orienteers in studies two and three could be explained by these strategies. Furthermore, it is proposed that through practice and experience, expert orienteers have acquired knowledge of skills and strategies that cause performance benefits. It is proposed that these are adaptations to task constraints.

For example, evidence from study two indicated that experienced orienteers attended to the map much more while moving, as distinct from while stationary, compared to less experienced orienteers, and this ability accounted for 45% of performance variance when both groups were combined. One possible explanation for this ability is that the experienced orienteers possessed more attentional resources and thus could allocate attention to both the map and travel simultaneously to avoid stopping to read the map. However, based on the evidence provided in this thesis, there are several other explanations for this ability that are more consistent with the notion of adapting to task constraints. These are described here.

First, the elite orienteers in study one reported attending to the map to plan ahead when the demands on attention from the map, the environment and travel, concerning their present position, were low. Knowledge of when to plan ahead allowed the elite orienteers the opportunity to solve route choice options and anticipate the upcoming terrain. In turn, this might have allowed a reduction in the burden on attentional resources during later sections of orienteering courses that would have otherwise been characterised by high attentional demands, such as the area near the control. For example, elite orienteers in the first study reported that the control area required more attention to the map and environment because more accurate navigation was required in this area. However, orienteers also reported using periods of orienteering when attentional demands were low, such as running along a flat road, to plan a route out of the control and perhaps into the next control. Consistent with this, expert orienteers in study three appeared to use a heuristic when route planning that involved attending first to the control area, despite being asked to imagine that they were at the start triangle located some distance away from the control. In contrast, novices attended first to the start triangle. According to the theory proposed in the first study, orienteers could avoid stopping to make route choice decisions and to locate themselves by planning ahead during periods of low attentional demand.

Second, the elite orienteers in study one also provided evidence of simplifying the information required to navigate. This strategy involved selecting only specific information from the map for comparison to the environment. This information constituted features in the environment known to be highly distinguishable, thereby maximising the possibility of the easy location of features, and, concomitantly, minimising the potential for navigational error. If highly distinguishable features could be easily identified on the map along a given leg, the information between these features could be ignored; orienteers could run from one easily locatable feature to another. Consequently, fewer comparisons between the map and the environment would be needed to successfully navigate any given distance. Therefore, processing resources freed up by this reduction in comparisons could be reallocated into planning ahead and anticipating the upcoming terrain. In turn, planning and anticipation would prevent the orienteer stopping to read the map. In effect, simplification increased the incidence of periods of low attentional demands. As described above, elite orienteers exploit these times to attend to the map to plan ahead.

Third, the experienced orienteers in study two were shown to attend to the map and environment more frequently but for shorter periods of time compared to the less experienced orienteers. It might be speculated that this behaviour allowed the orienteer to encode a small amount of map information with each period of attention, but that each period of attention was short enough in duration to allow the orienteer to look up at the environment so as not to miss important features, but also at travel so as to avoid collisions. In study two, travel accounted for only a small percentage of the time spent orienteering. However, as discussed in study two, it might be speculated that the orienteer was dividing attention between environment and travel during periods verbally labelled by the orienteer as environment; the measurement tool used in the study would not have captured this. It is unlikely that important information regarding travel was not attended to during this period. It might be speculated that one way to avoid hazards when moving and reading the map is to look up frequently at where you are going, that is, to travel. By acquiring knowledge of this technique, experienced orienteers might have been able to facilitate the ability to read the map while moving. Skilled orienteers might be able to allocate resources flexibly between the map, environment, and travel as the demands on resources from each source of information change. Skilled individuals have been observed to allocate different levels of attention, and to switch attention, more effectively between components of a dynamic task, or between dynamic tasks, as priorities change (e.g., Wickens & Gopher, 1977; Moray, 1986). This would be a strategy consistent with research that has suggested that skilled individuals have acquired an internal model of when to change the allocation of attention, or to switch attention, between sources so as to achieve the greatest performance benefits. This model ensures optimal sampling (e.g., Moray, 1986).

Fourth, it is self-evident that reading detailed information from a map is not an easy task to undertake while running. It might be speculated that novices are unlikely to want to do both simultaneously without being made explicitly aware of the performance benefits this behaviour causes. From an inspection of the film data from study two, it was common to observe novices running without reference to the map, and then stopping to read the map. Presumably, novices would plan ahead while stationary and then run to some remembered, pre-planned location, or until they were unsure of their location, and then refer to the map once again to plan the next discrete section, or to relocate themselves. By contrast, the elite orienteers in the first study reported varying their running speed according to the need to attend to the map. For example, they reported slowing running speed down when nearing the control. It might be proposed that this was because the cost of missing the control was considered greater than the loss in running speed required to accurately locate the control (discussed earlier). From an analysis of the interview data in study one, it appeared that elite orienteers are seldom prepared to run faster than the proposed ceiling level, whereby reading the map became impossible.

Planning ahead during periods when attentional demands were low, simplifying, attending to the map for short periods before looking up, and not running too fast to make map reading impossible, are all proposed as adaptations by elite orienteers to a particular task constraint: the requirement to attend to the map, environment and travel. The result of these adaptations is the ability to read the map without stopping; essentially, a circumvention of processing limitations (cf. Ericsson & Lehmann, 1996). Ultimately, performance is increased. Of course, genetic, inherited factors might contribute to orienteering skill. However, on the basis of the strategies identified in this thesis, there is a sound rational for investigating whether novices can benefit from learning these strategies, in terms of orienteering performance.

Applied Implications.

Theories of the expert performance of a task can be used to inform training programmes for less skilled performers with the aim of accelerating skill acquisition in this population (Abernethy, 1994). Therefore, the findings from this thesis might be used to inform a training programme for novice orienteers. One aim for a training programme might be to encourage novice orienteers to read the map while moving, given the suggested performance benefits. Novice orienteers might be encouraged to move through the terrain at a speed that is conducive to reading the map, even if that means, initially, running slowly or walking. The elite orienteers in study one reported placing a thumb on the map in the position of the orienteer s current location and slowly moving it across the map as the orienteer moves through the terrain to keep its position constantly updated. This meant that whenever the orienteer needed to look at the map the thumb was in the correct location, and, hence, no time or attentional resources were wasted in finding the orienteer s present location. The map can also be folded to make holding it while moving the thumb easier.

Second, orienteers might be encouraged to think ahead during periods where the demands on attention are low. For example, imagine that a novice identifies a bridge they have been looking for, some distance away in the terrain, and the approach to the bridge is a flat track. No attention to the map and the environment is needed because navigation is not required until the bridge is reached. Also, the requirement to attend to travel is minimal because the conditions underfoot are obstacle free. Consequently, the spare time available between the novice orienteer s present position and the bridge can be used to plan a route ahead of the bridge and anticipate the upcoming terrain. It is proposed that because the novice is aware of the performance criterion, time, they believe they must always be running and hence opt to increase speed, requiring attention to travel, rather than invest spare attentional resources in planning ahead. Alternatively, novices might not exploit this period at all; that is, they might neither speed up nor plan ahead during this period. Both scenarios would be due to a lack of knowledge by the novice about the benefits to performance of planning ahead. However, by moving at a speed conducive to reading the map, the orienteer might be able to plan ahead and prevent having to stop to decide where to go next, once the bridge is reached.

Third, orienteers might be advised to take short but regular looks at the map as they move. This might allow orienteers to look at the map as they move to plan ahead but also to periodically look up from the map to avoid collisions and missing environmental information necessary for navigation.

Finally, novice orienteers might be made aware of the effects of the other skills and strategies identified in this thesis that are suggested to afford performance benefits. For example, they might practice the following: simplifying and identifying distinguishable features for use in this strategy from the map, identifying an attack point and an optimal approach to the control early in a given leg, gaining familiarity with the mapping style of the cartographer responsible for mapping areas used in competitions, training for aerobic fitness to facilitate attending to the map without stopping, and practising map memory and imagery exercises in an attempt to anticipate as much of the upcoming terrain as possible with recourse to the map. Furthermore, orienteers might benefit from some understanding of how these strategies could improve performance, in terms of how they reduce the burden on processing resources. A simple explanation of the limitations of human processing resources would be useful in achieving this. For example, the author has used the analogy of a large apple pie during applied consultancy work with elite junior athletes for this purpose, with the explanation that the more one has to remember, and the more one has to attend to, the less pie there is available to eat. This could then be followed by an explanation of how the use of each strategy reduces the amount resources used, and how having some spare resources can be used elsewhere. Understanding why strategies work in terms of a simple explanation of brain functioning might increase the interest and motivation of the learner, and the efficacy of strategies.

The techniques and strategies used by expert orienteers might have applications in other domains involving navigation such as field manoeuvres in the armed forces, vehicle driving, hiking and mountaineering, sailing, and aircraft piloting. In these domains, use of these strategies could decrease the burden on processing resources, time, energy and fuel, and, ultimately, save lives. For example, mountaineers might be taught to simplify the information required to navigate. Although time is not of direct importance to mountaineering performance, as it is in orienteering, mountaineers only have a finite amount of daylight with which to complete summits, and climatic conditions can be extreme. Therefore, reducing the amount of time required to navigate a certain distance could potentially reduce the number of fatal accidents in mountaineering. Also, knowledge of the constraints inherent in orienteering, and the adaptations by skilled orienteers to those constraints, might be useful in creating an expert system of navigation in off-road environments (as recommended by Whitaker & Cuqlock-Knopp, 1995). A computer program that could simulate the behaviour of an expert off-road navigator might have applications for robotic devices or remotely controlled vehicles used, for example, in military scenarios.

Future Research Directions.

A number of areas of future research were established in this thesis. First, the theory of expert cognition in orienteering proposed in study one needs to be tested further at a behavioural level. This theory was induced from qualitative data, and behavioural testing of separate aspects of the theory might provide converging evidence for phenomena proposed.

In study one it was suggested that the orienteer s position within the leg affected the amount they simplified and, in turn, anticipated. This was because more accurate navigation was required as the orienteer neared the control area. Study three also provided evidence that seemed to converge with the proposition that experts prioritise planning the control area. Further behavioural testing might provide further evidence of this phenomenon. For example, the results of study one also indicated that orienteers were likely to slow down as they neared the control. This might form a hypothesis that could be tested in the field using a head mounted video camera protocol similar to that used in study two. The theory also proposed that complex terrain constituted an area containing few distinguishable features. As a consequence, an orienteer moving from an easy to a complex area is less able to simplify navigation, and thus must make more comparisons. An increase in the number of comparisons would cause a decrease in attentional resources available to be allocated to travel, and running speed would decrease. Provided that a suitable change in the complexity of an area of terrain could be identified or contrived, the effects of a change in complexity might be measurable. Measures might include frequency of comparisons (measured from using a head mounted video camera protocol), mental workload (self-reported) and running speed (obtained using an accelerometer).

The outcomes of testing the theory at a behavioural level would be an increase in an understanding of the task constraints of orienteering in terms of the workloads imposed on the orienteer. Knowledge of where demands are highest could be used to direct the use of strategies that reduce the burden on processing resources, with the aim of increasing performance.

Future research should also be directed at ascertaining whether the strategies reported by the elite orienteers contribute to performance. One limitation of this thesis is that the strategies proposed have not been shown at a behavioural level to cause increases in performance (see above). For example, the expert orienteers in study three attended to the control first during the planning of orienteering legs, suggesting that the control was important area and therefore required prioritisation during planning. It might be assumed that the experts prioritised the control because this strategy causes performance benefits. However, this is inference and cause has not been established empirically.

Finally, future research should also be directed towards designing training programmes for novice orienteers, as discussed above. Longitudinal designs whereby novices are randomly assigned to different training programmes, and that include a placebo group, should be used to test the efficacy of using the findings regarding adaptations by skilled orienteers in training programmes for other groups of orienteers. One criticism of the findings of this thesis might be that some of the techniques, skills, and strategies identified here as possible adaptations already appear in orienteering texts. For example, Hale (1997) describes trying to simplify the information needed to navigate during orienteering, and trying to build up pictures of the upcoming terrain. However, few studies have been directed at providing evidence of the use of these strategies by elite orienteers, or have attempted to explain how these strategies might be supported by psychological theories. As yet, no studies have been directed at testing the efficacy of any of these techniques. Are these techniques actually responsible for skill increases? More importantly, no studies have been directed at establishing the efficacy of teaching any of these techniques. Can these techniques actually be taught or are they acquired only after extensive experience?

Conclusion.

Research into orienteering from a psychological perspective is limited. Therefore, the first objective of the research programme was to begin to explore the constraints of the task of orienteering from a psychological perspective, and the problems these constraints impose on the performer. This thesis has begun to address these objectives. Data from the first study were interpreted as indicating that a task constraint central to orienteering was the requirement to attend to the map, environment, and travel. In the second study, inexperienced orienteers were observed to stop frequently, and for longer periods of time, in order to read the map, when compared to experienced orienteers. The cause of these problems was consistent with the notion of a burden on the processing resources of the novice imposed by the task constraint identified in the first study. In contrast to the inexperienced orienteers, experienced orienteers attended to the map markedly more while moving, and stopped infrequently and for shorter periods of time. Furthermore, there was a significant relationship between the ability to read the map while moving and orienteering performance.

The second objective of the research programme was to begin to identify any adaptations by experienced orienteers to the constraints of the task that appeared to reduce the problems imposed by these constraints, and, in turn, account for performance increases. This thesis has provided evidence consistent with the notion of adaptations: one explanation for the differences between the less and more experienced orienteers, in terms of the ability to read the map while moving, was that experienced orienteers have learned to adapt to the requirement to attend to the map, environment, and travel. Elite orienteers in the first study reported a number of strategies that appeared to reduce the burden on processing resources including planning ahead during periods of low attentional demand, anticipating the upcoming terrain, and simplifying the information required to navigate. Consistent with the reports of planning ahead, elite orienteers were also observed to generally attend to the control area first when planning routes from orienteering maps, despite being instructed to imagine that they were at the start. In contrast, novices generally attended first to the start. Instructing novices to adopt the skills and strategies used by the elite orienteers in this thesis might increase their ability to read the map without stopping, and, thus, potentially improve performance.

REFERENCES

REFERENCES

Abernethy, B. (1990). Expertise, visual search, and information pick-up in squash. *Perception, 19,* 63-77

Abernethy, Burgess-Limerick, & Parks (1994). Contrasting approaches to the study of motor expertise. *Quest, 46,* 186-198

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

Aitkenhead, A. M., & Slack, J. M. (Eds.). (1985). *Issues in cognitive modeling.* London: Lawrence Erlbaum Associates

Allard, F. (1993). Cognition, expertise, and motor performance. In J. L. Starkes and F. Allard (Eds.), *Cognitive Issues in Motor Expertise,* (pp. 109-134). Amsterdam: North-Holland

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

Anderson, J. R. (1985). *Cognitive Psychology and its Implications.* New York: W. H. Freeman

Annett, J., & Kay, H. (1956). Skilled performance. *Occupational Psychology, 30,* 112-117

Anzai, Y., & Simon, H. A. (1979). The theory of learning by doing. *Psychological Review, 86,* 124-180

Appleyard, D. (1970). *Styles and methods of structuring a city.* Environment and Behavior, 2, 100-116

Arthur, P. & Passini, R. (1992). *Wayfinding: People, signs, and architecture.* New York: McGraw-Hill Inc.

Baddeley, A. D. (1986). *Working memory.* Oxford: Clarendon Press

Bakeman, R., & Gottman, J. M. (1986). *Observing interaction: An introduction to sequential analysis.* Cambridge, Eng.: Cambridge University Press

Bartlett, F. C. (1932). *Remembering.* Cambridge, England: Cambridge University Press

Bean, K. L. (1938). An experimental approach to the reading of music. *Psychological Monographs, 50,* 1-80

Bedard, J., & Chi, M. T. H. (1992). Expertise. *Current Directions in Psychological Science, 1,* 135-139

Beek, P. J., & Meijer, O. G. (1988). On the nature of the motor-action controversy. In O. G. Meijer and K. Roth (Eds.), *Complex Movement Behaviour: the motor-action controversy,* (pp. 157-185). Amsterdam: Elsevier Science

Bechtel, W., & Abrahamsen, A. (1991). *Connectionism and the mind: An introduction to parallel processing in networks.* Malden, Mass: Blackwell Publishers

Blades, M., & Spencer, C. (1987). How do people use maps to navigate through the world? *Cartographica, 24,* 64-75

British Orienteering Federation (1999). *Advertisement posters.* British Orienteering Federation: telephone number 01629 734042; website www.cix.co.uk/~bof/whatbof.html

Broadbent, D. E. (1958). *Perception and Communication.* London: Pergamon Press

Burns, P. C. (1998). Wayfinding errors while driving. *Journal of Environmental Psychology, 18,* 209-217

Ceci, J., & Williams, W. M. (1999). *The nature-nurture debate: the essential readings.* Oxford: Blackwell Publishers Ltd.

Charmaz, K. (1995). Grounded theory. In J. A. Smith, R. Harre & L. V. Langenhove (Eds.), *Rethinking methods in psychology.* London: Sage Publications Inc.

Charness, N. (1988). Expertise in chess, music, and physics: A cognitive perspective. In L. K. Obler & D. Fein (Eds.), *The exceptional brain: Neuropsychology of talent and special abilities* (pp. 399-426). New York: The Guildford Press

Chase, W. G., and Ericsson, K. A. (1981). Skilled memory. In J. R. Anderson (Ed.), *Cognitive Skills and Their Acquisition.* Hillsdale, NJ: Erlbaum

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

Chase, W. G., & Simon, H. A. (1973b). The mind s eye in chess. In W. G. Chase (Ed.), *Visual information processing* (pp. 251-281). New York: Academic Press

Chi, M. T. H. (1978). Knowledge structures and memory development. In R. Siegler (Ed.), *Children s thinking: What develops?* (pp. 73-96). Hillsdale, NJ: Lawrence Erlbaum Associates

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., Glaser, R. (1989). Self-explanations: how students study and use examples in learning to solve problems. *Cognitive Science, 13,* 145-182

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

Chi, M. T. H., Glaser, R., & Farr, M. J. (1988). *The nature of expertise.* Hillsdale, NJ: Lawrence Erlbaum

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. J. Sternberg (Ed.), *Advances in the psychology of expertise* (Vol. 1, pp. 7-76). Hillsdale, NJ: Erlbaum

Chiesi, H. L., Spilich, G. J., Voss, J. F. (1979). Acquisition of domain-related information in relation to high and low domain knowledge. *Journal of Verbal Learning & Verbal Behavior, 18,* 257-273

Chomsky, N. (1957). *Syntactic structures.* The Hague: Mouton

Cohen, G. (1996). *Memory in the real world* (2nd ed.). Hove: Psychology Press

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* San Diego, CA: Academic Press

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: design and analysis issues for field research.* Boston: Houghton Mifflin Company

Coren, S. (1993). *The left-hander syndrome: The causes and consequences of left-handedness.* New York: Free Press

de Groot, A. D. (1946). *Het denken van den schaker [Thought and choice in chess].* Amsterdam: North Holland

de Groot, A. D. (1965). *Thought and choice in chess (Trans.).* The Hague: Mouton. (Original work published 1946).

de Groot, A. D., & Gobet, F. (1996). *Perception and memory in chess.* Van Gorcum: Assen

Dell, G. S., Burger, L. K., and Svec, W. R. (1997). Language production and serial order: a functional analysis and a model. *Psychological Review, 104,* 123-147

Denzin, N. K. (1978). *Sociological methods.* New York: McGraw-Hill

Detterman, D. K., Gabriel, L. T., & Ruthsatz, L. T. (1998). Absurd environmentalism. In M. J. A. Howe, J. W. Davidson, & J. A. Sloboda (Eds.), Innate talents: reality or myth? *Behavioral and Brain Sciences, 21,* 399-442

Devlin A. S., & Berstein, J. (1997). Interactive wayfinding: map style and effectiveness. *Journal of Environmental Psychology, 17,* 99-10

Devlin A. S., & Berstein, J. (1995). Interactive wayfinding: use of cues by men and women. *Journal of Environmental Psychology, 15,* 23-38

Downs, R. M., & Stea, D. (Eds.). (1973). *Image and Environment.* Chicago: Aldine Publishing Company

Dunker, K. (1926). A qualitative (experimental and theoretical) study of productive thinking (solving of comprehensible problems). *Journal of Genetic Psychology, 68,* 97-116

Dunker, K. (1945). On problem solving. *Psychological monographs, 58,* (Whole no. 270)

Egan, D. W., & Greeno, J. G. (1974). Theories of rule induction: knowledge acquired in concept learning, serial pattern learning and problem solving. In W. G. Gregg (Ed.), *Knowledge and cognition.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Ericsson, K. A. (1998). Basic capacities can be modified or circumvented by deliberate practice: a rejection of talent accounts of expert performance. In M. J. A. Howe, J. W. Davidson, & J. A. Sloboda (Eds.), Innate talents: reality or myth? *Behavioral and Brain Sciences, 21,* 399-442

Ericsson, K. A. (1996). The acquisition of expert performance: An introduction to some of the issues. In K. A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports, and games* (pp. 1-50). Mahwah, NJ: Lawrence Erlbaum Associates

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102,* 211-245

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

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology, 47,* 273-305

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

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87,* 215-251

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. 1-39). Cambridge: Cambridge University Press

Evans, G. (1980). Environmental cognition. *Psychological Bulletin, 88,* 259-287

Eysenck, M. W. (1993). *Principles of cognitive psychology.* Hillsdale, NJ: Lawrence Erlbaum Associates Ltd.

Eysenck, M. W., & Keyne, M. T. (2000). *Cognitive Psychology. A Student s Handbook.* (4th ed.). Hove: Psychology Press

Fenner, J., Heathcote, D., & Jerraoms-Smith, J. (2000). The development of wayfinding competency: asymmetrical effects of visuo-spatial and verbal ability. *Journal of Environmental Psychology, 20,* 165-175

Fitts, P. M. (1964). Perceptual-motor skill learning. In A. W. Melton (Ed.), *Categories of human learning.* New York: Academic Press

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

Fleiss, J. L. (1981). *Statistical methods for rates and proportions.* New York: Wiley

Gal-Or, Y., Tenenbaum, G., & Shimrony, S. (1986). Cognitive behavioural strategies and anxiety in elite orienteers. *Journal of Sport Sciences,* 4, 39-48

Galton, F., Sir (1869). *Hereditary genius: An inquiry into its laws and consequences.* London: Friedman

Garling, T., Book, A., & Lindberg, E. (1986). Spatial orientation and wayfinding in the designed environment. *Journal of Architectural and Planning Research, 3,* 55-64

Genter, D. R. (1983). The acquisition of typewriting skill. *Acta Psychologica, 54,* 233-248

Genter, D. R. (1988). Expertise in typewriting. In Chi, M. T. H., Glaser, R., Farr, M. (1988). *The Nature of Expertise.* Hillsdale, NJ: Erlbaum

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

Gilhooly, K. J. (1990). Cognitive psychology and medical diagnosis. *Applied Cognitive Psychology, 4,* 261-272

Gilhooly, K. J., McGeorge, P., Hunter, J., Rawles, J. M., Kirby, I. K., Green, C., & Wynn, V. (1997). Biomedical knowledge in diagnostic thinking: The case of electrocardiogram (ECG) interpretation. *European Journal of Cognitive Psychology, 9,* 199-223

Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research.* New York: Aldine

Gobet, F. (1998). Expert memory: A comparison of four theories. *Cognition, 66,* 115-152

Gobet, F., & Simon, H. A. (1998). Expert chess memory: Revisiting the chunking hypothesis. *Memory, 6,* 225-255

Golledge, R. G. (1987). Environmental cognition. In D. Stokols & I. Altman (Eds.), *Handbook of Environmental Psychology* (pp. 131-174). New York: John Wiley & Sons

Golledge, R. G., Smith, T. R., Pelligrino, J. W., Doherty, S. E., Marshall, S. P. (1985). A conceptual model and empirical analysis of children s acquisition of spatial knowledge. *Journal of Environmental Psychology, 5,* 125-152

Gopher, D. (1993). The skill of attention control: Acquisition and execution of attention strategies. In D. E. Meyer & S. Kornbaum (Eds.), *Attention and Performance XIV,* (pp. 299-322). Cambridge, Mass.: MIT Press

Greeno, J. G., Simon, H. A., (1988). Problem solving and reasoning. In Atkinson, R. C. (Ed), *Stevens' handbook of experimental psychology, Vol. 2: Learning and cognition* (2nd ed.), (pp. 589-672). New York: John Wiley & Sons

Hale, S. (1997). Advanced techniques. In P. Palmer (Ed.), *The Complete Orienteering Manual.* Crowood Press, Wilts.

Halpern, D. F. (1992). *Sex differences in cognitive abilities.* (2nd ed.). Hillsdale, N.J.: Lawrence Erlbaum Associates

Hancock, S., & McNaughton, L. (1986). Effects of fatigue on ability to process visual information by experienced orienteers. *Perceptual and Motor Skills,* 62, 491-498

Handford, C., Davids, K., Bennett, S., & Button, C. (1997). Skill acquisition in sport: some applications of an evolving practice ecology. *Journal of Sport Sciences,_15,* 621-640

Hart, R. A., & Moore, G. T. (1973). The development of spatial cognition. In R. M. Downs, & D. Stea (Eds.), *Image and Environment,* (pp. 246-288). Chicago, IL: Aldine

Helsen, W. F., Hodges, N. J., Van Winckel, J., & Starkes, J. L. (2000). The roles of talent, physical precocity and practice in the development of soccer expertise. *Journal of Sports Sciences, 18,* 727-736

Helsen, W., and Pauwels, J. M. (1993). The relationship between expertise and visual information processing in sport. In J. L. Starkes and F. Allard (Eds.), *Cognitive Issues in Motor Expertise,* (pp. 109-134). Amsterdam: North-Holland

Hickox, J., & Wickens, C. D. (1996). Navigational checking: a model of elevation angle effects, image complexity, and feature type. *University of Illinois Institute of Aviation Technical Report* (ARL-96-4/NAWC-ONR-96-1). Savy, IL: Aviation Research Laboratory

Hirtle, S. C., & Heidorn, P B. (1993). The structure of cognitive maps: Representations and processes. In T. Gaerling and R. G. Golledge (Eds.) et al. Behavior and environment: Psychological and geographical approaches. *Advances in psychology, Vol. 96,* (pp. 170-192). Amsterdam: North Holland

Holyoak, (1995). Problem solving. In D. N. Osherson (Ed.), *An invitation to cognitive science* (2nd ed, pp. 267-296). Cambridge, Mass.: MIT Press

Howe, M. J. A., Davidson, J. W., & Sloboda, J. A. (1998). Innate talents: Reality or myth? *Behavioral and Brain Sciences, 21,* 399-442

International Orienteering Federation (2000). *Biennial report, 2000,* Radiokatu, Helsinki: International Orienteering Federation

Jensen, K., Johansen, L., & Karkkainen, O. P. (1999). Economy in track runners and orienteers during path and terrain running. *Journal of Sports Sciences, 17,* 945-950

Jones, C. M., & Miles, T. R. (1978). Use of advance cues in predicting the flight of a tennis ball. *Journal of Human Movement Studies, 4,* 231-235

Jongman, R. W. (1968). *Het oog van de meester [The eye of the master].* Amsterdam: Van Gorcum

Kaplan, S. (1973). Cognitive maps in perception and thought. In R. M. Downs, & D. Stea (Eds.), *Image and Environment,* (pp. 63-86). Chicago, IL: Aldine

Kellogg, R. T. (1995). *Cognitive Psychology.* Thousand Oaks, CA: Sage

Kelso, J. A. S. (1995). *Dynamic patterns: the self-organization of brain and behavior.* Cambridge, MA: MIT Press

Kirschenbaum, D. S., Owens, D., O Connor, E. A. (1998). Smart golf: preliminary evaluation of a simple, yet comprehensive, approach to improving and scoring the mental game. *The Sport Psychologist, 12,* 283-299

Kirschenbaum, D. S., O Connor, E. A., and Owens, D. (1999). Positive illusions in golf: empirical and conceptual analyses. *Journal of Applied Sport Psychology, 11,* 1-27

Kohler, W. (1927). *The mentality of apes (2^{nd} Ed.).* New York: Harcourt Brace

Kohler, W. (1940). *Dynamics in psychology.* New York: Liveright

Kosslyn, S. M. (1980). *Image and mind.* Cambridge, MA: Harvard University Press

Kuhn, T. S. (1977). *The essential tension: selected studies in scientific tradition and change.* Chicago: Chicago University Press

Larkin, J. H. (1981). Enriching formal knowledge: A model for learning to solve textbook physics problems. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition.* Hillsdale, N. J.: Lawrence Erlbaum Associates

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. Models of competence in solving physics problems (1980). *Cognitive Science, 4,* 317-345

Lawton, C. A. (1994). Gender differences in way-finding strategies: relationship to spatial ability and spatial anxiety. *Sex Roles, 30,* 765-779

Lawton, C. A. (1996). Strategies for indoor wayfinding: The role of orientation. *Journal of Environmental Psychology, 16,* 137-145

Lemmens, W., & Jongman, R. W. (1964). Unpublished manuscript.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry.* Beverly Hills: Sage

Lynch, K. (1960). *The image of the city.* Cambridge, Mass.: MIT Press

MacDougall, J. D., Ward, G. R., Sale, D. G., & Sutton, J. R. (1977). Biochemical adaptation of human skeletal muscle to heavy resistance training and immobilization. *Journal of Applied Physiology, 43,* 700

Maier, N. R. F. (1931). Reasoning in humans II: the solution of a problem and its appearance in consciousness. *Journal of Comparative Psychology, 12,* 181-194

Marr, D. (1982). *Vision: a computational investigation into the human representation and processing of visual information.* San Francisco, CA: W. H. Freeman

Martens, R. (1987). Science, knowledge, and sport psychology. *The Sport Psychologist, 1,* 29-55

McClelland, J. L., Rumelhart, D. E., & The PDP Research Group (1986). *Parallel distributed processing: Vol 2. Psychological and biological models.* Cambridge, MA: MIT Press

McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin, 86*, 889-918

McLeod, P. (1987). Visual reaction time and high-speed ball games. *Perception, 16,* 49-59

McLeod, P., Plunkett, K., & Rolls, E. T. (1998). *Introduction to connectionist modelling of cognitive processes*. Oxford: Oxford University Press

McNamara, T. P. (1994). Knowledge representation. In R. J. Sternberg (Ed.), *Thinking and problem solving.* London: Academic Press

McNamara, T. P., Ratcliff, R., & McKoon, G. (1984). The mental representation of knowledge acquired from maps. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 10,* 723-732

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

McPherson, S. L. (2000). Expert-novice differences in planning strategies during collegiate singles tennis competition. *Journal of Sport and Exercise Psychology, 22,* 39-62

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63,* 81-97

Miller, G. A., Galanter, E., and Pribram, K. H. (1960). *Plans and the structure of behavior.* New York: Holt, Reinhart, and Winston

Moore, G. T., & Golledge, R. G. (1976). *Environmental knowing: theories, research, and methods.* Stroudsburg, PA: Dowden, Hutchinson, & Ross

Moran, A. P. (1996). *The Psychology of Concentration in Sport Performers: a Cognitive Analysis.* Hove, East Sussex: The Psychology Press

Moray, N. (1986). Monitoring behavior and supervisory control. In K. Boff, L. Kaufman, & J. Thomas (Eds.), *Handbook of Perception and Performance* (Vol. 2, pp. 40.1-40.51). New York: John Wiley

Newell, A., & Simon, H. A. (1972). *Human problem solving.* Englewood Cliffs: Prentice-Hall

Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: verbal reports on mental processes. *Psychological Review, 84,* 231-259

Norman, D. A. (1980). Twelve issues for cognitive science. *Cognitive Science, 4,* 1-33

O Keefe, J., & Nadel, L. (1978). *The Hippocampus as a Cognitive Map.* Oxford: Oxford University Press

Omodei, M.M., & McLennan, J. (1994). Studying complex decision making in natural settings; using a head-mounted video camera to study competitive orienteering. *Perceptual and Motor Skills, 79,* 1411-1425

Omodei, M. M., McLennan, J., & Whitford, P. (1998). Using a head-mounted video camera and two-stage replay to enhance orienteering performance. International *Journal of Sport Psychology, 29,* 115-131

Palmer, P. (1997). *The Complete Orienteering Manual.* Crowood Press, Wilts.

Passini, R. (1984). Spatial representations, a wayfinding perspective. *Journal of Environmental Psychology, 4,* 153-164

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (3rd ed.). Newbury Park, CA: Sage Publications Inc.

Piaget, J., & Inhelder, B. (1967). *The child s conception of space.* New York: Norton

Pidgeon, N., & Henwood, K. (1997). Using grounded theory in psychological research. In N. Hayes (Ed.), *Doing qualitative analysis in psychology* (pp. 245-274). Hove, England: Psychology Press

QSR NUD*IST 4 [Computer software]. (1997). Melbourne, Australia: Qualitative Solutions & Research Pty Ltd.

Robbins, T. W., Anderson, E. J., Barker, D. R., Bradley, A. C., Fearnyhough, C., Henson, R., Hudson, S. R., & Baddeley, A. D. (1996). Working memory in chess. *Memory and Cognition, 24,* 83-93

Rumelhart, James L. McClelland, and The PDP Research Group (1986). *Parallel distributed processing: Vol 1. Explorations in the microstructure of cognition.* Cambridge, MA: MIT Press

Salthouse, T. A. (1984). Effects of age and skill on typewriting. *Journal of Experimental Psychology: General, 13,* 345-371

Salthouse, T. A. (1986). Perceptual, cognitive, and motoric aspects of transcription typing. *Psychological Bulletin, 99,* 303-319

Salthouse, T. A. (1991). Expertise as the circumvention of human processing limitations. In K. A. Ericsson and J. Smith (Eds.), *Towards a general theory of expertise* (pp. 286-300). Cambridge: Cambridge University Press

Saltin, B. (1969). Physiological effects of physiological conditioning. *Medicine and Science in Sports, 1,* 50

Schank, R. C., & Albenson, R. P. (1977). *Scripts, plans, goals and understanding*. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82,* 4

Schmidt, R. A. (1988). *Motor control and learning*. Englewood Cliffs, NJ: Human Kinetics

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84,* 1-66

Schreiber, B., Wickens, C. D., Renner, G., Alton, J., & Hickox, J. (1998). Navigational checking using 3D maps. *Human Factors, 40,* 209-223

Schulte, A., and Onken, R. (1995). Empirical modelling of pilot s visual behaviour at low altitudes. In *Proceedings of the International Federation of Automatic Control: Man-Machine Systems Conference.* Oxford: Pergamon Press

Seigel, A. W., & White, S. W. (1975). The development of spatial representations of large-scale environments. *Advances in Child Development and Behaviour, 10,* 9-55

Seiler, R. (1990). Decision making processes in orienteering. *International Journal of Sport Psychology, **21**,* 36-45

Shannon, C. E. & Weaver, W. (1949). *The mathematical theory of communication.* Urbana, Il.: University of Illinois Press

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84,* 127-190

Silverman, D. (1993). *Interpreting qualitative data. Methods for analysing talk, text and interaction.* London: Sage publications

Simon, H. A., & Barenfield, M. (1969). Information processing analysis of perceptual processes in problem solving. *Psychological Review, 76,* 473-483

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

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

Singer, R. N., Cauraugh, J. H., Chen, D., Steinberg, G. M., Frehlich, S. G., & Wang, L. (1994). Training mental quickness in beginning/intermediate tennis players. *The Sport Psychologist, 8,* 305-319

Skodak, M., & Skeels, H. M. (1949). A follow-up study of 100 adopted children. *Journal of Genetic Psychology, 75,* 85-125

Sloboda, J. A. (1984). Experimental studies in music reading: A review. *Music Perception, 22,* 222-236

Sloboda, J. A. (1996). The acquisition of musical performance expertise: deconstructing the talent account of individual differences in musical expressivity. In K. A. Ericsson (Ed.), *The road to excellence* (pp. 107-127). Mahwah, NJ: Erlbaum

Spelke, E. S., Hirst, W. C., & Neisser, U. (1976). Skills of divided attention. *Cognition, 4,* 215-230

Starkes, J. L., & Deakin, J. (1984). Perception in sport: a cognitive approach to skilled performance. In W. F. Straub & J. M. Williams (Eds.), *Cognitive Sports Psychology* (pp. 115-128). New York: Sport Science Assoc.

Summers, J., & Ford, S. (1995). Attention in sport. In T. Morris & J. Summers (Eds.), *Sport psychology: Theory, applications and issues.* Chichester: John Wiley

Tabachnick, B. G., & Fidell, L. S. (1996). *Using Multivariate Statistics.* New York: Harper Collins

Thomas, J. R., French, K. E., & Humphries, C. A. (1986). Knowledge development and sport skill performance: directions for motor behavior research. *Journal of Sport Psychology, 8,* 259-272

Thomas, P.R, Murphy, S. M., & Hardy, L. (1999). *Journal of Sports Sciences, 17,* 697-711

Thorndyke, E. L. (1911). *Animal intelligence.* New York: Macmillan

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55,* 189-208

Voss, J. F., Greene, T. R., Post, T. a., & Penner, B. C. (1983). Problem-solving skill in the social sciences. *The Psychology of Learning and Motivation, 17,* 165-213

Wallman, J. (1994). Nature and nurture of myopia. *Nature, 371*, 201-2

Ward, G., & Allport, A. (1997). Planning and problem-solving using the five-disk tower of London task. *The Quarterly Journal of Experimental Psychology, 50A,* 49-78

Warren, D. H. (1994). Self-localization on plan and oblique maps. *Environment and Behavior, 26,* 71-98

Whitaker, L. A. & Cuqlock-Knopp, V. G. (1995) In P. Hancock and J. M. Flach (Eds.), *Local applications of the ecological approach to human-machine systems*, Vol. 2. (pp. 234-254). Hillsdale, NJ,: Lawrence Erlbaum Associates, Inc.

Weber, R. P. (1985). *Basic Content Analysis.* California: Sage Publications Inc.

Wickens, C. D. (1989). Attention and skilled performance. In D. Holding (Ed.), *Human skills* (pp. 71-105). New York: John Wiley

Wickens, C. D. (1998). Frames of reference for navigation. In D. Gopher & A. Koriat (Eds.), *Attention and Performance XVII,* (pp. 113-144). Cambridge, Mass.: MIT Press

Wickens, C. D., & Gopher, D. (1977). Control theory measures of tracking as indices of attention allocation strategies. *Human Factors, 19,* 349-365

Winer, B. J. (1971). *Statistical principles in experimental design (2nd Ed.).* London: McGraw-Hill

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

Williams, A. M., & Burwitz, L. (1993). Advance cue utilisation in soccer. In T. Reilly, J. Clarys, & A. Stribe (Eds.), *Science and football II*, (pp. 239-244). London: E & F Spon

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport.* London: E & F Spon

Williams, J. M., & Krane, V. (1998). Psychological characteristics of peak performance. In J. M. Williams (Ed.), *Applied sport psychology: personal growth to peak performance* (3rd ed., pp. 270-295). Mountain View, CA: Mayfield

Wright, D. L., Pleasants, F., & Gomez-Meza, A (1990). Use of advanced visual cue sources in volleyball. *Journal of Sport and Exercise Psychology, 12,* 406-414

APPENDICES

Appendix 1: Interview with SN, member of the 1998 British orienteering squad, in Stirling on the 22nd February 1998.

This interview is from study 1 and is unanalysed for the purpose of providing referential adequacy. Paralinguistic symbols have been removed from the text to make reading easier.

D: Ok erm interviewing S err it s the twenty second of the second ninety-eight in Stirling and it's err nineteen minutes past five ok err let's have a look hereerm first sort of question in what areas of err the sport of orienteering do you think developments will come sport is progressing and moving on and times are coming down in all areas of sport within orienteering how are those gains going to be made

S: Probably the only way is physically I think someone who wins the world championships is having the perfect run doesn't miss any time at all and so the only time for the for that for the winning time to be better is to find some way of physically fitter there's no more secrets to be found from route choice or through well I don't think through orienteering more quickly err feasibly I guess people might come up with different approaches to orienteering which could enable them to r to run more quickly but I think when people with a World champion ( ) running flat out the entire time and so there's there's not much room there for someone to improve err

D: When you said approaches erm running style or or erm navigation

S: Yeh

S: Navigation and ( ) they way they navigate erm currently people run flat out on

D: Right

S: compass and stray try and stay in constant contact which is optimal if you're running in a straight line and you always know where you are then you're gonna go straight through the flags and that always ( ) seconds erm but that'sthat's the best approach and people are doing it well at the moment er certain areas you can't do that and and you have to slow down which is where I guess navigation takes a lead then (and then) how much you slow down is dictated by how skilled you are at navigating erm perhaps though that there's room for improvement there so that of people to improve that err that scenario to improve their navigation skills they have e.g. running dead straight on a compass bearing just through whatever knowing you're gonna hit the control and err I guess if someone designed a compass which enabled you to run with a incredible level of accuracy current current compasses get you within plus or minus ten per cent so if you had a system that could make you run as straight as an arrow ((last word said with laughter)) through the flags then you know that's that'sthat's a definite area that you could improve I guess erm so I'm probably probably saying yeh there's room for improvement the technology erm mentally the more experienced you are the quicker you orienteer but the current world champions have err incredible experience they've been doing it for three or four decades erm they're old chaps they're thirty-five you know ( ) erm they've always said it's well known that you need tons of experience to be able to to do well in orienteering erm you might be able to do well on one particular area one particular type of terrain with only a few years experience erm but to be a general all round World cup champion or World Champion then you need to have many many different skills which which relies on the built up the experience from the past physically there must be room to (doubt) I mean well ok Carston Jurgenson's the European cross country champion ((last word said with laughter)) at the moment so maybe that's just as fast as you can get but every year you see track times improve (don't you) and so sure

D: ( )

D: Emm

S: Improved physical training is gonna take seconds off kilometres

D: Erm you mentioned erm staying in constant contact

S: Emm

D: H-how h can you describe that phenomenon ( )

S: It's whenalright

S: Err constant contact means ((last word said with laughter)) at a really reasonably regular int it doesn't mean knowing exactly where you are all the time but it means knowing where you are as much of the time as you want to know where you are I mean it it it's sort of you could say it could be every hundred metres being able to pinpoint your place so every hundred metres you spot a boulder that's unique and you spot exactly where you are that'sthat's almost constan constant contact erm that might be slightly more than a hundred or slightly less than a hundred metres all always knowing where you are in relation to the control do you can zero in

D: What processes determine always knowing where you are

S: Erm it has to knowing constant contact means looking at the map looking up and spotting something on the ground that says yeh that's what it should be it's not ground to map it's map to ground as soon as you start going ground to map you've lost it you're loosing time but so it's being ahead of the game isn't it if you if you know where you are err if you knew where you were just a short while ago then you can look at the map and say oh (yeh) I'm expecting to see thisthis this this and when you look up again you see them but they might be a hundred yards ahead in an open area they might be five hundred yards ahead

D: Em-hem

S: if you're going there but it in effect you know where you're going so maybe constant contact means you know exactly where to go next you it does doesn't matter where you are precisely at that point in time it's just sort of put your direction

D: Ok erm and you also mentioned there about terrain predicting erm the speed of and err rapidity through the terrain er how does terrain predict your speed

S: Erm oh there's different types I don't know what you're getting at quite there I mean different types of terrain you get a different speeds

D: Right

S: Erm if you're running through green you'll go less fast than if you're running through an open field

D: Right right

S: Ahh but what what we needed you need an o the skill of orien a level of orien our navigational skill

D: Em-hem

S: That means you can run flat out through the green

D: Right

S: ((Stuttering)) if you didn t have a map err and also it s flat out (the other field) of course as if you didn t have a map that s that s that s the required level of navigational skill

D: Erm

D: Em-hem

S: which was planning ahead it s just just being slightly ahead of the game before you get there knowing what you ll see before you get there

D: Right

D: Always that anticipatory

S: Yeh anticipation a lot of the orienteering I do I mean I I know my orienteering skills I ve got lots of gaps in them erm but I m very aware of how I orienteer its very jumpy its oh I m looking for the next thing ah there it is I m looking for the next thing there it is that s map to ground and and the more obvious things you can see the better err (I-I m gonna run in the area) the Norwegian champs last year lots of unique features a big boulder a crag black I mean black

D: Right

S: things tend to be unique because there s not that many of them contours are less unique I mean you ve got to have an extremely high level of skill to make a contour unique but because it s subject a drawing the contours is very subjective I don t really think there s a unique contour so it it s not like um a um map a bit of black on the map or a a bit of different area of green on the map or a path obviously a path or a marsh thing is those things can be very unique

D: Right

D: Right

S: Erm and so eyeing it up orienteering for me is easy when you ve got these these non-brown things which you can just jump from A run from one to another erm and the brown things are just icing on the cake you know that just means I mean I can see the boulder which means that must be the re-entrant and that must be the hill

D: Right

S: and then everything s makes perfect sense which is very satisfying form of orienteering what you aim at and you can do it in Scandinavia and places with lots of you ve got the black super-imposed on the map to enable you to to always be you know always use these marks or you know there there sort of a bench marks around you

D: Em-hem

S: Erm and then you you can understand the contours under underlying this and go that way er so some a some areas like sand-dune areas don t have any black at all you ve only got brown all right

D: Emm

S: and because contours aren t unique because of their inherent sort of subjectivity you need to have a prior recollection ((stumbling)) you you you try and always get ahead of the game (   ) orienteering map to ground ahead of the game knowing what to see see next but I but you also need much better memory of what s just happened erm just just like twenty yards ago

D: Em

S: to enable that that process to happen erm and if you forget where you ve just been then it s very difficult after you ve run thirty yards to look at your map again till oh yeh I ll know what to expect next because lost of what you you lost where you are

D: Em-hem

S: Erm so the level of err memories greater for those (brown) rolling areas sand-dune areas I m talking about this because I ve just come from s-sand-dune areas ((last two words said with laughter))

D: Emm em m

S: Err in Spain

D: H-how had I mean err in respect of what you ve just said how did you get on (0.5)

S: Err I now I m er alright I mean I hold my own in sand-dune areas erm but they re not they re not my my strength they re they (technical) they re harder and everyone finds them harder erm probably for that reason err they tend to be more runnable er er er sand-dune areas tend to be open you run on compasses quite a lot

D: and they re harder f because of the erm

S: because there s a lack of other information on the map you ve just got these these contours which require a much higher level of skill to understand and they re wacky shapes as well they re not ((stuttering)) the information on the maps is unusual so you can t say oh yeh that s gonna be a ridge of the typical shape because there is no typical shape you have to look at the map and think oh yeh it s a ridge with all these different bits around it that make up it s shape which ok should make it unique but it doesn t because ((mumbling)) it s erm less effective because of err what the mapper s done erm you know it s orienteering in Scotland land shapes the the geography a the geology I mean I guess topography is fairly predictable

D: ((laughter))

D: Em-hem

S: You get familiar with the nature nature of the features so they re not that sort of err you you you can apply your own knowledge to the map whereas sand-dune areas you don t get that unique (for this) you need shapes coming out

D: and those erm shapes ahh and ho ho how are they be linked to erm how much experience you ve got at recognising those

S: Err it helps having ((stuttering)) it helps having experience because then you have an open mind erm and you when you look at something on the map it could be up or could be down so tag lines often you know people don t make many mistakes when they run and they normally make mistakes because of something unusual something unusual on the map something unusual happens to them I m talking about elite orienteers now I mean maybe they ll only make two mistakes on the course and both have arisen because of something abnormal happening and they haven t reacted to it properly and one reason for example is er where you don t see a tag line on the map in in the area looking at so you don t know what s up and what s down it s a classic this so

D: Right

S: you re expecting something to be going up as you re running along cos you you can t see the tagline ( ) erm but it turns out to be down of course and so when you re running along

D: Emm

S: it throws up what s this and if you re not open minded enough fresh enough to thnik ahh I ve got to run it s down it s not up erm you you you know you you veer off a bit and loose ten seconds or turn that into a minute mistake and then you know it s it s a major major major mistake then erm and so that comes from

D: ((laugh))

S: experience you know oh yeh yeh I ve fallen for that one before it s how people learn form their mistakes then they can rationalise it in their head they can go into a race with all these possibilities in their head and they ll just be very open minded erm as they go in to confirm things or or even make Ideally when you re looking at the

D: Emm sure

S: map before you get there looking for the tag or or piecing it together from some other there maybe a bit of blue a hundred metres to the right and indicate

D: Yeh the tags is a is a contour is it

S: No of I I I thought you nodded so I thought you knew what the tag meant erm

D: No sorry

S: C with con ((stuttering)) the tag is simply err you get them on contours car-cartographers put them on contours where it s not obvious which way s down and which way s up so

D: Ahh

S: a contour line err wiggles along and the tag points down the hill so

D: Right

S: in the sand dune areas say you might get a mass of contours and everything s up and down and all over the place you know there s no blue on the map to indicate what sort of valley and so they use tags

D: Oh excellent ( )

S: So every now and again ( ) but sometimes they don t put tags on where they should sometimes they forget to put tags on so what you think is a depression to put the tags on these are the sorts of things that create mistakes sometimes imperfect maps err ( ) everybody s got the same map so it s kind of a level playing field isn t it but

D: Yeh

S: Erm that that s the idea but tags were just an example I was just

D: Emm y eh sure yeh

S: ( )

D: grappling with the terminology sometimes

S: Yeh

D: Erm and in terms of erm you said you you difficult to recognise the sort of sand-dunes err erm in Spain but you recognise erm typical Scottish erm

S: Yeh err you know we think our people will have a home advantage in the coming championships up here in that we re very familiar with err the terrain er ok no ones ever been on the terrain before

D: Em-hem

S: but because we know generally where better l the better line of running is and navigationally we re very confident and even when you look at the look at the Scottish map it s you can but it s good I doubt if there ll be any surprises if it s mapped in in a normal way

D: Erm erm

S: by the normal Scottish mappers

D: Yeh (good luck) ( )

S: ( ) familiarity yeh

D: Yeh yeh

S: ( ) in a hundred minute race

D: Yeh

S: ( )

D: Excellent ok erm err when you re first faced with erm a map how do you decide what information is pertinent err how do you decide what information ( )

S: So you re on the start line looking at the map

D: Yeh

D: Ok yeh

S: That s that s the only situation that s the only situation we find ourselves in orienteering you get the map when you start

D: Erm

S: You ve got to make the decision straight away err well it s a race situation so you wanna s get number one clean first time around

D: Em-hem

S: And if there s a major championship I would do probably do nothing but concentrate on getting to number one cleanly and not even dare look anywhere else

D: Em-hem

S: This is just ((stuttering)) and that develops specifically for major championships big races you have to hit number one cleanly err if you re not gonna make any mistakes that s the idea but you certainly don t want to blow the first one

D: Em-hem

S: Cos of all the ((stuttering)) you don t want to spend your time looking around the rest of the course erm I just look for the easy route establish a good route and get on with it and then navigate the route very very carefully for the first I ll probably look at the control first this is the right way to pick a route you should look at the you look at the control you re going to first

D: Em-hem

S: check out what the best way in is you don t want to miss it so it s there s always an easier but normally an easier way in than any other way and then just work backwards

D: Right

S: and yeh work back to where you are look look wide before you narrow it down I Scandinavia you d probably just narrow it down straight away if you run along the line all the way but on the Continent look wide check the path options

D: Yeh

S: Erm check the runnablility err then link it up to where you are and tie it together and off you go but you wouldn t you wouldn t spend more than two or three seconds doing it and it s just that you get get cracking

D: Right

S: Oh you you got you certainly got five seconds on the run out probably so you the whole process it wouldn t take very long erm World championship this year I got it wrong actually yeh

D: Wrong

S: Wrong yeh

D: Right

S: There there was about twenty second run out I just went for the wrong er I should of I should of done the old ah (when out) there was a gagging route to the right the planners do it to trick you planners if I was planning a course I would be doing it you try and trick people into taking the wrong route so you reward the good guys by picking the right route and normally it won t make much of a difference like thirty seconds or a minute but good courses have these tricks in them so you re

D: Emm

S: you re tempted by an option up front yeh an easy path takes you off to the right which sets you up horribly to get into the flag

D: Emm

S: Erm like on a big hill or through some green or just a very tricky angle navigationally very tricky with no features whereas erm the the route off to the left doesn t look so enticing the first kilometre but the last three hundred yards is a dream down a path or something and gets you in erm tha-that s the sort of thing you want to look out for cos they do it all the time ((last word said with laughter))

D: Yeh

D: And erm when you actually look at the map information itself how do you actually decide what s relevant from that

S: Err I think the first thing you obviously are the paths so it depends on the area again if it was continental err any area the paths will jump out straight away but fundamentally to get the right route you ve got to look at the hills imagine where the hills are big hill there a big hill there I think that s your picture and once you ve got the paths and the hills that s your picture and that s most of what you need to pick the route apart from ge-getting an easier way in erm but there s so many areas thought there s so much so much orienteering virtually all of Scandinavia you just take a bearing and run like hell just on the bearing it s straight line orienteering and it s if you loose where you are it s you know ((stuttering)) you just carry on on your bearing ((cough)) (revise) the whole thing so route choice tends to be overstated yeh very rarely is route choice gonna make a big difference ((stuttering)) it s only when the plan is very good or it s a Continental area route choice gonna win or loose races normally we ve done loads of exercises where people err you know you run in gangs sort of half a dozen of you in the forest you all take different routes but everybody arrives at the control at the same time p p part from the poor guy who had to take the really way out route choice ((last four words said with laughter)) which you would never do it would be a realistic one erm the the key to orienteering is just moving it s not so much the route choice you you take a feasible route but running it really quickly not hesitating just picking it getting on with it and screaming round

D: Ok ((cough)) erm had something to do with my third question here erm you mentioned you said there s you there s you re picture

S: Emm

S: Emm

D: I mean I mean er d you d you try and form a picture

S: Err it s so automatic now I probably I used to when I was before I really got into orienteering when I was fourteen fifteen sixteen I was just getting into it then erm I used to a have this picture idea of orienteering (   ) manually do do it explicitly I used to sort of try and draw contours on a bit of paper what I saw you know sitting in a sitting in a classroom draw the contours outside while sitting in a van draw the contours you can see or draw from memory I mean I walked on Dartmoor a lot when I was young draw Dartmoor draw the contours and that and that I mean I was doing it because I quite like doing it but also you know I was trying to do it to help me understand contours to try and (   ) erm but now er it s it s very automatic you don t you don t think picture y- you to a certain extent if you re looking at something hard you re trying to like like you you you re faced with a moo the moonscape the sand-dunes

D: Em-hem

D: Em

S: You re trying to go to jump out into 3-D so you could pic picture what s up what s down what s a good route can you see a nice line so I gu er I guess there is a certain amount of picture trying to trying to make the picture but it s it is very automatic and it s only on the most technical areas where the maps completely overloaded with information do you really have to strain to make a picture but most any Scottish area m-most of the areas round here the the picture you you re looking at a map you know you you don t need to think think 3-D let s find out let s really concentrate to m-make things turn into into something more meaningful erm and it is it is very err

D: Emm

S: you don t always need the 3-D picture you can just navigate on the easy things the obvious paths with a compass bearings er the black you know the there a they re if you know the symbol you know what to look for obviously only contours that you need the pictures that spring out on the map

D: Right right

S: You need a you need a lot of imagination sometimes as well I mean erm its just mapping styles you need to understand the mapping style how the mapper thinks wh-wh- different

D: Right

S: countries have different mapping styles

D: Ok

S: Erm whenever you re when you re checking out a new area or a new type of area for races and stuff you need to try and home in on the symbols the mapper s used to portray certain things or if there s any unusual feature that erm that you can use to navigate that you re used to using at home err so typically err things like just the colour like rough open I-I-is the rough bit is the rough open going to be young trees that are here that some people will hope that they re gonna be sort of shoulder high erm that some people might mark as that in Scotland we might mark that as dark green but in Denmark they might mark it as yellow erm and that s that s another area people make the biggest probably people make the biggest mistakes in orienteering and this is at elite level as at any other level I ve seen it happen loads of times at elite level just cos they get the colours wrong the colour system wrong and they ( ) they look at the terrain I m sure this happens at like it happens also I m sure it happened to Heather at the Nordics she would she d virtually won the classic she should have won it she was fourth but the final day she was gonna win the short the Nordic championships but she made a five minute mistake on the way to number one which was just colours and then she just looked at the ground and the colours weren t what she expected err I think err you have to ask of her err I think so it s happened to me though on JK race big races I ve been running along and I look ahead and I think ah that must be yellow cos it s a green field but the the the for some reason (don t know) maybe cos there s a few trees in it the map was blue or white and you look at your map you re looking for yellow and cos you re slightly tired you can t make you can t make the connection oh I ve got that wrong you re just fixed on it oh you think oh I haven t gone far enough and you plough on and nothing suddenly nothing fits and so a big (map) or anything like that you can get wrong and it can really really screw you up sort of massive mistake so you re ( ) many minutes mistakes erm rather than small things erm to colours yeh I mean colours something that s critical on the map to understand what colours what that s probably one reason why I first started orienteering I used to find it hard

D: Emm

D: Yeh there s white on the map as forest

S: but I mean err I appreciate that being a walker myself you using OS maps which are which are great I love them

S: Yeh (me too)

D: Twenty fives and

S: Yeh

D: Erm yeh I can see it s just so alien when you see white is is forest ( )

S: Yeh it is strange they used to actually mark er for a while in Scandinavia er probably to do with the printing or anything sort of technically they couldn t mark different colours but they had forest always as white whatever felled areas

D: Right

S: Thick areas everything was white and that must have been quite orien quite simple orienteering in a way you know you didn t worry you didn t have the er the colour information to worry about so you couldn t go out and say ( )

D: ((laughter))

(on the back of that) I mean there there s certainly less information to navigate on ((cough)) but it made you concentrate on the contours

D: ((laughter))

S: err it may may have been better contour readings as a result

D: Yeh

S: ((cough))

D: Interesting thing you said there er it doesn t fit erm what did you mean by that when you say it doesn t fit

S: Right

S: oh that that that just mean when you hit when you look up and expect to see the next thing you don t see it err you you happy going from map to ground running flat out and everything s ding ding ding ding ding and suddenly dong oh know that s not it

D: ((laugh))

S: and it doesn t fit

D: Ok

S: And normally re-recover is you you ve got a bearing and you re running flat out on the bearing if you just keep going to the next bit and you and you re ding you know ((last two words said with laughter)) and you spot it but if you haven t got a bearing and you can t remember where you were last then that could develop into a mistake ( ) but if you don t sort it out quickly then you have as you re running along

D: Right

D: Erm when when you go ding ding ding ding ding where do you where d you recover each ding from the map d you do it all initially or d you do it gradually or

S: Yeh

S: Err you do it continually ( ) you look you probably look you must I would imagine people will look at their I d certainly think I look at my map every err thirty yards it should be that it should be you can t look at it all the time

D: Emm

D: Emm

S: Cos you ve got to check what you re doing with your feet (though you re continually) grabbing grabbing glances at it so you you know when you look at it you need a system to know where you where you just were just have your thumb on it or something

D: Right

S: So you can at a glance within the nanosecond you can say oh yeh I was there and I m I m about to go there I m about to do that err an-and I don t think your memory spans much more than can t be more than twenty seconds cos you you d you re so much would happen by then and you you re probably looking at it every thirty yards which could be certainly every ten seconds just checking things out ( ) ok I m talking in terrain if you re on a track that you might just have a look at your map till you get to the next junction

D: Emm

S: bit dangerous but yeh you you might look at the ( ) ( )

D: but then you d have that junction in memory ( )

S: in memory (until you get there) yeh

D: Right

S: But that s very the longer you leave it the more likely you ll make a mistake err and so yeh yeh one thing that certainly we train as juniors one thing I I always self-trained was well I don t want to make mistakes it just means look at the map more simple as that if you don t you want a perfect run just look at the map more that s is a very easy rule erm err ( ) the more you look at the map the more you have to

really force yourself though because it s a discipline thing especially if you re tired or you know it s easy to put your map down and just run for a bit erm but it you know but the less you leave it the more likely you are to make a mistake quite simple I-I don t <u>really</u> think people develop memory ability to that they they can actually change their memory ability to be able to take less frequent looks at the map I think different people have different different abilities to remember things err and certainly I ( ) probably agree with people who couldn t remember any any of these any of these details maybe cos like they re not familiar with them or they re just you know just not innate innately good at doing it erm and for them the the only solution was to look at the map the entire time

D: Erm

S: erm but then the other hand at the other level there s probably people that have a very well developed and innately very good quality memory which means they can get away with every thirty seconds er but I I don t think the range would be that big one way to check is to just see who you re running with various people clock how long they look at their map ((last five words said with laughter))

D: Emm

S: and try and relate that to how often they make mistakes ((last word said with laughter))

D: ((laughter)) see if there s a correlation

S: Yeh

D: Well that really leads onto the the next question erm from what you said a bit controversial but how d you remember the information

S: Ahh ((sighing))

D: (0.2) ((laugh))

S: How do you remember it I forget it sometimes one thing one thing you used to try and train certainly would control tags are one thing you ve got to remember you re control tag to go through it quickly so you can check it so if you have to check it at the control this is just two numbers twenty-one er whatever AB erm when you get to the control if you have to check you re number you have to unwrap you re map a bit have a look and that ll take a second or two which is a lot lot of time wasted round the whole course and so er certainly for a while er or certainly some people say you should before you get to the control you should have everything sorted out in your head where are the flags going to be on the feature and what the control code is and I normally try that but I virtually always forget I m very bad I look at it (at) what during the course when I ve got the time and it might be a minute or two before I get there might be a bit longer erm but by the time I get there I can never remember what it was ((last four words said with laughter)) and I always end up having to double check it but now that s a problem that s redundant cos you tend to get descriptions on your wrist or have your control card so you when you see the flag you just have a quick look as you re running in so it doesn t matter erm so er that s one that s one thing ah which shows I haven t got a very good memory for for numbers err as for features erm I think it s just err if you you don t need to remember it cos the maps in your hand and you can look at it whenever you like so you don t need to err

D: As that picture

S: Yeh I think ( ) sometimes you do a certain style of orienteering that does mean you don t want to have a look at your map cos you re running so flat out but that s not real that s not orienteering I m just thinking of an exercise we did err a few days ago when we were out in spain we were training as a big group and we called it trains erm th en

D: Call called it what

S: We call it trains

D: Trains ((said laughing))

S: It s just an interval training type exercise where the first chap goes off with a twenty second

D: Yeh

S: lead and then after the twenty seconds everybody else goes off at ten second intervals

D: Right

S: and the aim is to catch up the next person and eventually the driver but it s thick forest s you can t just run you ve got to navigate but the the way you navigate changes it s not normal orienteering what you do is you you glance at your map a lot at the beginning and then just run like hell just navigating by your fingertips because you can just remember a few things you c you you know if you look at your map you re gonna loose half the er half the ( ) perhaps erm and you might you know you might sometimes see see their back and so the the the thing is there it s your very much erm relying on that memory of what s coming up which which you may have got right at the start cos you just look you know

D: What this this ding ding ding ding ding ( ) list of

S: Erm well yeh you you but you re you probably rely on far less information cos you re is tra it s not like err you re a it s not so important to hit all the flags er ( ) you got you got you got your compass bearings but you it s not not like a race a race you can t afford to make a mistake so you re a bit more careful and you by yourself so you do you do the ding a ding frequently and it s to make sure

D: Emm

S: everything s right but that that just a form of training that was physical and so you would have a ding every third s every third di ng

D: ((laughter))

S: You will only pick up every third feature err cos you re running flat out and you know that you either get picked up by the guy behind or you ll catch the guy up in front and it s so it s just err it s just simplified orienteering in a way err but you you need to when you re running flat out you just have a few things in your head and as long as you as long as they work your plan works which might be something like over the open hill on my bearing

D: Emm

S: and I should see a pond in my map and there s gonna be a a knoll or something just to the right and the flag s there very very simplified err if you can get away with that then then you re orienteering at your fastest you can just concentrate on running flat out just on trying to remember these things look there s the hill oh there s the pond just a bit further and (I m almost) there found off to the next one

D: When you when you do that erm erm are you remembering literally just the sort of language based over the hill on the left would you picture those as well

S: No I m language based (I th ink)

D: Yeh

S: Err I don t err I might yeh might be a bit more explicit open hill err uncrossable marsh with with a bit of a thicket nearby you know there might be a little bit more but I I don t don t think err it s it s really pictorial totally pictorial

D: Emm emm

D: Em-hem

S: it s gotta be to an extent erm but on the whole it s it s just that s a hill it doesn t matter what the shape is that s the hill and if there s something simple on it like something like a boulder that makes it unique fine erm but er it s quite a highly developed sk-sk-skill to say that s the hill which has got a kink in the contour on

D: Emm

S: the left hand side or even just saying that s a cigar shaped hill I mean ok you probably do that but err just refining the shape s quite difficult you nee d a very well developed level of skill probably better in the Scandinavian orienteers S and S or maybe the mappers like John Musgrave

D: Em-hem

S: these guys might have a have a a more developed contour skill as

D: Emm

S: as that s the orienteering they ve been doing more erm the mappers must surely have a more pictorial view of things but it doesn t come through in the results I mean you don t it s harder you hardly ever ever ever does it come d you need that level of skill to be able to run around the course flat out without making any mistakes you ( ) efficient on the map to accommodate a variety of skill levels or approaches to to enable you to run around cleanly not missing anything

D: This is good seeing the differences quite interesting excellent ok erm and err possibly going to overlap here erm how how do you use the information from the map to navigate then really we ve we ve cover ed a lot of that but anything anything more you can tell me there

S: Em em

S: Compass bearing

D: Yeh

S: ( ) you ve always got your direction doesn t if it means you can t take you can keep running flat out on the compass bearing it s got to be an accurate compass bearing well that s with out a compass evrybody would slow down by ten percent ((last word said with laughter)) twenty per cent and mistakes would be horrendously (made) erm (err I don t think I ve got much to add

D: Emm ok erm another slight one again slightly overlapping possibly how do you monitor your progress er through the terrrian

S: Erm

D: Navigationally

S: Y eh

D: Navigation progress I think I d probably err I thumb it I ha the way I do it on a map is I thumb it on the map if it s very technical and I might even have the map in two hands very close and so (all) that reason why I ve got it on two hands is so that I can be right on where I am erm but normally I just (I —I have the line) of the compass I have my compass on the map and so where I am it s just slightly to the right of the edge of the compass and it might be be bear the err ((stuttering)) down the bottom of the compass and always in the same place of course erm the position of the compass is normally dictated where the nearest magnetic areas on the on the map you ve got to have it suffi the housing sufficiently close to a a magnetic line so you can get the get the angle I always turn the housing everyday just turn the housing make sure I don t make a mistake that way erm so I use a I use a known spot ( ) on the map in relation to my compass and to see where I am erm

D: Emm

S: What was the what was the question it was

D: ((laugh)) er how do you monis monitor your progress through the terrain

S: I got sidetracked

S: The through the terrain err actually through the terrain through the forest it s just in relation to your known points erm

D: ( ) the points that you picked up

S: You the points you expected to see and of course when you you probably ( ) because as you re running along you do see things I-I ve emphasised map to ground so much cos that s the best way to orienteer

D: Em-hem

S: but of course it doesn t always work like that and you frequently frequently see what you thinks on the ground you think oh what s that take you by surprise where s that on the ma p which of causes you to look at your map again and a lot of the time it s actually information you don t need so you re already decided

D: Yeh

S: what you do need but you know maybe it s a bit of a time waster maybe you should ignore it it s always nice to get err another confirmation that everything is going as planned

D: Emm

S: That s that that s that

D: Em-hem

S: Err if you re orienteering very badly that s the whole way round you go the whole the whole course if you do the whole course in that manner always thinking oh what s that oh there it is and I m sure people bad orienteers orienteer like that don t they err just constantly on the hop ((last word said with and followed by laughter)) varying round from one thing they recognise to another but I mean it s it s not a good way cos you need to you need to be able to it s using a pictorial skills a lot isn t it cos you see something on the ground then you have to turn that that feature into something you ve got to look at it just like how the mappers looked at it and turn that into the same

D: Emm

S: 2-D impression on the map and the contour that s incredibly difficult I need a very good level of skill for for that erm but with things like boulders it s just oh is that a big boulder would it be on the map if it was just is that a small boulder oh it won t be on the map that s the sort of decision your making crag same thing is it a big uncovered crag or not erm you you need to know what the mapper may have put on and what hadn t err so yeh you you you know where you are on the ground by by that combination of leaving a known point together with seeing something and thinking oh yeh that s that er cos it s it s between the two points I m going from and that s all I ve got to say

D: Ok yeh yeh erm this is a good one good bit of analyses on how do you know when things are going wrong what causes your navigational errors actually that s a separate question

S: Emm

D: how how how can you tell

S: Emm

D: when things are going wrong

S: Err

D: ((cough))

S: Well you when you re at risk when things aren t cropping up as expected you re not everything s not perfectly in place things you can you can be taken by surprise suddenly that might just be cos the whole map s slightly er out and it might all be out slightly and so things aren t you ve got to have allowed for that or just get into the new mapping style and then once you re into the new mapping style you can put it right erm you know when you re you could know when you re about to make a mistake when you re running flat out and suddenly things aren t fitting erm but you keep running flat out I mean the right thing to do is to keep running flat out because might end up in the control circle and keep going cos normally you ll just pickup something else and off you ca you carry on going and you never made a mistake erm that probably happens tons of tons of the time but you .hh are so confident you can just just go straight through it cos you know you can pick things up erm you wanna minimise that err you know when you re making a gonna make a mistake cos of the sinking feeling when you suddenly think oh the flag s not there you know you pop round the boulder and this not there ((last two words said with laughter)) erm and you think ahh what is it in that situation if you re right in the control circle and it s not there you can just it s a question of looking at your map for an extra five seconds and then you realise of there s two boulders on the map well there s you know you just made it a small error maybe it s the next one and you can er work it out and that might involve very little time wasted erm I don t think you can detect at the start of a race I m gonna have a bad run I don t think there s anything like that (0.4) I certainly don t experience it if there is it must be only psychological it s just like oh gonna have a bad run so you g o and do it but I err I m not familiar with that sort of experience erm physically I guess you could be feeling very very knackered and tired in which case you know physically you re not going to be (0.5) going that quickly (0.6) erm but you can still orienteer incredibly well being physically tired and get a good result I don t think you want to feel fresh at the start line

D: Emm emm

D: Erm and and what are the determinants what causes navigational errors d you think

S: It s concentration it s ter it s just the level of concentration

D: Em-hem

S: When I when I said how often you look at your map well that s that I-I implicitly mean you re concentrating as well cos you re saying oh I look t the map look at the map actively thinking yep looking at the map I m here I m looking for other things I m checking out options doing all these things in your head and so err the most fundamental skill in orienteering once you ve got the basics a you ve learnt what a map is and you ve learnt how to read a compass bearing it s just how able you are to concentrate solidly all the time the better you are at concentrating the better orienteer you ll be erm I in a really big races I m sure my mind is super na I I think personally I when I m in I ve never blown the World Championship I ve always done in really big races I ve done alright and I think the reason why is I m concentrating super hard my mind s going at flat out a hundred and ten per cent and I'm covering all the possibilities I m terrified of ma missing a missing a control and making a mistake it s just too important I can t do it (as I ran) in the British Championship you can t possibly make a mistake erm so you re looking at the map and you you re using all your known experience all the things you ve done in the past and making sure you re not doing them checking out possibilities ((last word said with laughter)) in your head saying I can t I m not going to make that many you actively say I m not going to make a parallel error I m not gonna make one and you think am I making one no good I m not fine ahh err you go through your list of types of mistakes you could make I m not going to make a one eighty am I making a one eighty on a compass you know running in the wrong direction no I m not thank God you know I ((last word said with stutter)) did that five years ago I blew out you know so you gotta you ve gotta have made these mis-mistakes in the past to be able to

D: Right

D: ((cough))

S: ( ) down your vocabulary of mistakes and say I m not gonna make that I m not gonna make that I m not gonna make that but there s a cert there s an element of that going on when you re running the running the course erm

Interruption while tea is made

S: Erm (0.7) so it s concentration it s so that s the that s the ( ) I can t rely on myself enough if you get lazy that s just the other side of the coin is if you get lazy or I know this area or can t be bothered today err or ( ) it s easy the then you you make mistakes cos you know you re just not

D: Emm

D: Complacency yeh

S: Yeh putting the required amount of err effort in yeh all the other guys that it s just concentration the ability I I ve I I m sure I ve got I ve got a strange phenomena people go people say erm when you do exams you re too tired to navigate or you re ((stuttering)) mentally you re too tired they say of you shouldn t

D: Emm

S: shouldn t race they tell the students this oh what people doing A levels (you know) don t do any races during your exams cos you re you re be you re make mistakes you ll be tired this sort of stuff you won t be able to train properly

D: Right

D: Emm

S: My own experiences having just done five years worth of actuarial exams I ( ) when you do exams you re really sort of honing your level of concentration I think so you can perform on the day mentally phenomenally well and you re cramming loads of information in as well but it s all it s all about a being able to concentrate if you orienteer around that sort of time then I think you re gonna you could do very very well cos you re you re able to concentrate (sort of level) it s sort of freshness as well but your body s used to concentrating very very hard erm the mind I d say it s a strange idea but you know ((last to words said with laughter)) I I just I just I think that simply because I I hear so many so many times people saying ooh he s just done his exams you know that s why he s done badly is that is that that that s supposed to be the excuse

D: Em-he m

S: in my experiences ( )

D: All right very interesting ( ) probably a training effect you know if you if you having to concentrate

S: Yeh yeh I t s yeh training the mind

D: Yeh

D: You re just training it you know

S: Yeh there s a number of way I mean yeh education s training the mind isn t it

D: Yeh

S: Er m tra there s specific ways of training the mind in orienteering by looking at maps at home making route choices

D: (Something like that)

D: Emm

S: rehearsing but another way to train the mind is to is to run lots lots of (orienteers) I think is to go running with a map of a course a good course Scandinavian course a or a different country somewhere just run for an hour and do the course in your head and pick you know em do make all the decisions you ll make on the course that what am I going to see next what what s the route choice I am going to make just rehearsing it all in your head that s that s training the mind to to orienteer but er at a higher level I think training you doing exams aca all all the oreinteers are academically successful I suspect or yeh they all are erm and it s all cos they ve got the learnt how to do exams ( ) be able to train their minds in a school environment ( ) there must be a correlation.

Tea is served. Side A ends, Side B begins.

D: Yeh what strategies erm techniques exercises do you practice err to improve your map reading and navigation

S: Erm probably er recently it s only two things err I think when I was younger I had a number of strategies erm but the only thing I ve been doing in the past say three or four years is er say er say a World championship in Sweden or whatever wherever the country is get maps of that area ( ) or similar areas err and run in terrain through a forest a normal forest with the map and the course and rehearse it all in my head just go through all the err the things I would do you get the perfect run of course you never make a mistake so it doesn t doesn t it doesn t erm help you practice putting mistakes right err which hopefully you ll never be in that position to do in the race but it enables you to to make all the right a do the active concentration bit making all the right decisions forcing yourself to pick the things you re going to navigate on err so that s that s one very easy way to train once you ve got the maps erm and the other way is simply to err go orienteering and is Scotland we re quite lucky

D: Emm

S: Even with the tre the trespass law you just run in areas without permission just do loads and loads of orienteering err if there s any events on on Saturdays or Sundays ( ) it s quite easy to go orienteering on week days ( ) and just do the real thing I spent a year in Sweden in ni eighty-nine actually

D: Em-he m

S: and er it was mainly my approach is is partly dictated by that because when we were there we went orienteering virtually e-every second or third day we went orienteering (whereas) in Britain you go orienteering ay weekends only and probably only a Sunday because I came from down south and that was what it was it was you orienteered once a week on Sundays and if there wasn t an event on that weekend you didn t go orienteering

D: ((laug h))

S: So you never

D: ((cough))

S: I mean that was your big sport but you never actually did it very much and that was a silly way very silly way to be how limited you know certainly erm ( ) ( ) ( ) erm so when I came back from Sweden I just I just made the effort you know just thought some people say if you orienteer to much you get stale you know or there s a certain amount you can do and then you err if em if they re from down south they only go orienteering once on weekends they might only orienteer forty times in a year ((last word said with laughter)) err and so the they might think I honestly in my my opinion you can ((stuttering)) orienteer a little bit cos otherwise you get stale but having been in the Swedish environment you can orienteer every day ((laugh)) you get better and better and do fine that s my attitude to I should apply that up here lots of erm sponsoring I don t go into sitting on the sofa looking through maps much I don t think there s much value in that erm I don t do any other exercises ( ) textbook type exercises to practice orienteering when you re not in the right forest I just just err stick to the real thing as far as possible

D: You mentioned erm a few earlier erm running with a partner and

S: Yeh that s that sort of thing yeah go on big (you can have lucky) in big groups then there are but they re physi er they re physical things I mean err err they re like the trains exercise that s purely physical you re running flat out you re not dealing with orienteering

D: Yeh

S: Cos you re you re simplifying it all and and just doing what you re doing a five by mile interval session that s really what you re ending up with but in terrain that makes it quite special I guess erm I-I over my time I ve done most exercises in the book and there s a whole variety of them but the best the best training weekends we ever go on are the training weekends where you ve suddenly got an orienteering course like a short course it might be a long course in a race environment which is timed and you just hare around and make sure you don t miss anything try try not to miss anything it s the best training

D: Emm

D: Ok how has your map reading and navigation changed and developed over your orienteering career

S: ((laughs)) erm well I guess it was err dictated by my circumstances I came from from Dorse er I was down in Dorset when I started emm there the nature of the orienteering was very much part of the orienteering with featureless forest in between and so the the the safest the best way to orienteer down there was to hammer all the way round the paths ( ) I was a track runner cross country runner so I used to hammer round the paths and just leap into the forest for a little bit to get the control and hammer round again and that lead lead to great success erm erm well when I got onto the junior squad and started doing a bit more orienteering abroad I found out that you need a few other skills as well and it became never run on thepath always run straight on the line but it still get very good results down south but you get even better results abroad doing that oh up in Scotland just running err straight straight as you can between controls erm and not using the paths very much and then when I went to Scandinavia err what I went out there cos I knew that I couldn t handle orienteering up in Scotland or I couldn t handle Scandinavian orienteering cos it s such a high the-the-there was so many more skills I needed to pick up so when I went out there that was tr-terrific erm ((ringing telephone)) that s answer phone ( ) picked up

D: Erm

S: I d say in Scandinavia erm I-I think I had all the skills I need to orienteer round most courses

Break in conversation regarding phone call

S: So over the last four year five years like that six years now seven years I ve been er just just physical it s just getting yourself in shape I can handle most courses most of the pro-problems err to navigational problems it was just a question of getting in shape it s good to brush up though erm you know I m not I couldn t just turn out at a race in any particular area you need to brush up before the race there might mean two or three weeks training a month before or three months before in the relevant area which brush up the skills

D: Ah

D: What erm you said there are many more skills to learn can you give me

S: Em

D: any examples of those

S: Em erm before I went abroad erm I didn t I didn t have the ability to recognise land shapes contours erm I didn t I I I didn t have the there s a there s d a few different types of orienteering there s sort of down south continental type orienteering I had that skill but the other mainstream orienteering in Scandinavian orienteering which is mainly learning how to run very accurately on the compass and learning how to recognise contour shapes they re in together those two things erm I don t think I had that and that s actually much harder to develop it s a much harder skill to err to get and you should you don t get it from living down south or even living living in Scotland you don t really get it there s not enough of that type of orienteering erm but it s er it s a very it s the most com it is the type of orienteering out in Sweden and Norway Finland so it s very well practiced erm and it and it it s just a question of going out and learning how to do that that s that s err that s the two different it happens the other way if you speak to sort of Scandinavians and they say oh we we don t we can t do continental orienteering and and that s their broad term for reading rou route choice orienteering reading roads and paths erm looking for big hills and things just running running round things simple ((stuttering)) you know ((stuttering)) be able to run with a compass without any contour detail to an extent and that s thats continental orienteering doing things like putting putting your map down and just running flat out for a while cos you re on a path and you don t need to know

D: Emm

S: anything until the next junction wh ich is

D: Right

S: a kilometre down the path you know a long err which is Scandinavian orienteering they don t (don t) (do) things like that at all

D: Ok excellent erm how would you intend to how do you intend to improve your navigation and map skills erm

S: What s the next big race coming up Lake District and Ireland well to prepare for them I just need to have it s physi it s physically err I need to remember to concentrate so that there s no further skills I can develop for those ra those races

D: Right

S: I think if you picked a race at so somewhere unusual like Finland there s World cups in in October I need to develop my skills cos I haven t run in Finland much they ve got a few unique err f-features out there just mapping styles and things I need to practice them so I ll go out twice erm I ll get couple of weeks out there before the races erm so that is just running in areas nearby ( ) so you can apply that general principle in any race just just go out and perform get used to it

D: Erm so it s a question of being able to recognise

S: Yeh

D: features new and unusual

S: Yeh learning how to recognise features ( ) one here here s and example that s quite err quite unusual (but prominent) in Czechoslovakia we had places out in Czechoslovakia the world championships there in ninety-five one feature of the orienteering out there were these great limestone stacks that could be thirty forty foot high and they re just black dots on the map and so when you look at the map there could be lots and lots of black on it but not unusual shapes of black and they re usually just pillars of limestone or sort of ridges of limestone which were towering above you and you d be running in between them all and that s that s very unusual orienteering and so you have to go out and practice learning how to find your way around a-and knowing that quite often you could be within ten yards of the control but it s just round the other side of these great big pillar and to find it and so there s plenty of other examples I guess out there ( ) you just need to know how to do it (cos) in a race you re talking about ten seconds twenty seconds that s really important so if you can get any advantage at all err then it s going to make all the difference the most basic thing is just being familiar with the terrain

D: You were saying also erm erm that you can you need to be familiar with the or you are now familiar with problems

S: Em

D: Erm you re familiar with problems here and you went out you re unfamiliar with problems abroad I mean do you find you can recognise classic problems ( ) you know categorise ( ) oh that s a classic classic

S: Erm

D: problem or

S: Yeh there s probably a certain amount of erm knowing what to expect at the beginning I talked about the tricks the plannners play on you they there are well known ways of tricking you and you look for that a bit yeh you you get caught out a number of times then you know er like for example the best route is always going back out the way you came in or can be that way if you if you re waying up two routes and one means going back out the way you came in chances are the planner made sure that that was the best route people just don t like doing that they like just running straight through and keep going and it that s because they re not prepared really sloppy orienteering just running through on your bearing punch and carry on running emm so knowing knowing the sort of tricks they play planners look for the weaker weak spots erm that you know if there s a down hill but the route that starts off down hill initially then that that will probably be the wrong route to take you want to go up hill initially cos the planner knows he s trying to trick people err so that s one type of problem the planning that s that s a route choic(ing) as planning erm but yeh there s other there s other there s other problems and tricks you know erm taking controls from certain angles are wrong like er a control on a slightly if you try and take it diagonally you re far more likely to miss it than if you take it err either contouring or head on straight down straight up or ( ) there certain way of you just know a good way to find a flag and a bad way err possibly erm a crag the control s always if I could mention the foot of the crag never at the top so if you wanna take a crag you take it from below cos you re gonna see the crag and the control should be at the foot of it you don t take it from above what you re just looking for a a precipice you know and then you ve got to check if it s the right precipice when you get there the there s hundreds of things like that so give you examples

D: Yeh that s fine that s excellent erm ((cough)) and err really a final one erm sort of put the ball in your court wha what else can you tell me about how you navigate and and use maps that you think could better erm somebody outside of orienteering ( ) want to understand how map information is used to navigate

S: Emm I can emphasise it s very discrete it s not continual it s just jumping around it s jumping from A to B to C to D that s err that s what it is and that s because the mapper s not perfect if the map was perfect and you like always know where you are but generally there s holes in it all over the place and he s less likely to get certain things wrong the way they make maps ( ) they they get the boulder in the right place from the crags that look down and they can pinpoint it right but the the the filling in in between things they draw by hand when they re not looking down might actually be wrong and so when are you going from A to B to C you you use the most reliable things first or the unique things erm erm just jump and the more fre the quicker you can jump the safer it is back it up with a bearing and you re sort of invincible combination you re not going to go wrong at all you you re just running on the line ticking off everything as you go the compass can t be overstated we certainly haven t talked about it enough but the the compass just removes the need for a map almost em (for all the time) ((stuttering)) some people used to say oh you can have this approach to orienteering (treflite) approach where you run flat out till your within a hundred yards of the control and then you just relocate just by it cos you ve got cos you know you run so accurately on the compass erm and I m just go into the control ( ) I don t think of anybody who does that type of orienteering they probably bull-shit if they do erm because it s a very high risk method of orienteering and it s kind of unnecessary cos you can run flat out and still look at your map and look up so you don t get much advantage from it so em it s not that that you don t go to that extent but you do combine running flat out with a compass and and continual contact looking ahead look at the map pick up everything erm running another thing about orienteering is you don t orienteer like a cross country race where you run flat out always pushing well I mean I err I guess ((stuttering)) a lot of cr a lot of cross country runners but it s not a series of sprints it s it s where you run within your aerobic threshold and if you re running if it s going very well everything s in control erm you re not rushed you re not sprinting at all you re just running at a steady pace the whole time

D: Em-hem

S: and things are coming up as expected and you finish the course and you re gonna do very well indeed

D: Right

S: and it it it s not and to be ( ) when you train fitness you re training your fitness level so that you can run comfortably at at a slightly higher level the more you train that comfortable cruising speed s gonna be slightly higher it s a it s a cruising speed it s not sprinting

D: Emm

S: It s a cruising speed at the end of the race you ll be shattered cos you ve been at your optimal cruising speed the whole way round

D: Em-hem

S: Erm but it hasn t been a case of err just running flat out (sort of people go run in the short races) it s they think the cruising speed it s actually higher if it s a short race but it s not really cos short races tend to be a bit more technical cos the controls are all much closer so you re cruising speed s slightly lower erm so you can cope with the navigational

D: Em-hem

S: Erm to an extent so I guess that means you re navigation s slowing you down but it it s not really like that I don t think navigation slows you down that much erm but what you you don t want to get ahead of yourself that s why it s a cruising speed you just you just you just make sure you don t get ahead of yourself if it is obvious like there s an open area then you you turn the cruising speed right up to cross country speed almost and that would be the cups in Ireland it will be cross country racing almost because it will be really easy there won t be there won t be too much cruising

D: Ok thanks erm emm what do you attribute to er good day

S: A good day err preparation I think yes confidence preparation I just think try and think about my own re err recent

D: ( )

S: passed year or two trying to think of good races

D: Ok a good day ( )

S: Yeh

D: You mean a good day orienteering or just like a good race or a good day and

D: Sorry I mean a good good race good good performance

S: The race yeh

S: Yeh

D: not necessarily a good race but when you re out there and you you know you re orienteering well wha erm

S: It s just that super alert thing you know you re concentrating a hundred and ten percent

D: Yeh

S: Super alert super fresh you know sup massively conscious when you re running throughout the course erm it it it so when you re running you re just thinking the whole time check check check check check everything you re checking everything all the time ticking off things behind you in front of you around you covering options going through you re menu of em mistakes you could possibly make making sure you re not doing any of them

D: Yeh

S: Erm it might be that I mean I think this is a common feature when you get to the finish you can t remember where the hell you ve been or you know you get to the finish almost instantly you you start off and before you know it you re at the finish and it s cos you re so preoccupied with everything going on (that you re not preoccupied with it) you re you re concentrating so hard err that it all happens in all there s a before you know it you re at the finish it s a hundred minute race

D: That s right you re not trying to stand back and experience anything are you you just get on with it

S: No

S: Yeh totally engrossed totally engrossed in it ((mumbling)) you do it with work don t you a really good day at work before you know it it s

D: I can see (   )

S: five o clock (and time to go home)

D: That s right totally

S: Emm

D: Yeh but you know you ve done a lot

S: Emm

D: but you can t really think what you ve done ((joint laughter))

S: yeh that s right yeh

D: Yeh I know what you mean right err and err the other side of the coin em you know what what kind of things do you attribute to a bad day what makes for a bad day

S: I think it s just mistakes ((laugh)) you finish the course and think oh shit when you make a mistake you mustn t contemplate think about it again put it behind you in the course and never r think about it again it s only when you get to the finish you think ahh ahh no I have three mistakes or ten mistakes whatever I ve made all these mistakes ahh and that was a big one and that was a big one

D: What are the determinants determinants of mistake making do you think

S: Erm oh I wish we wish we knew it s not you know it s not it think that s an easy question err just think

D: Ahh

S: They re the extreme things I guess like not sleeping the night before I guess and that could not always but then you know m-most people don t sleep alot of them don t sleep the night before the World championships but still do very well oh but erm just something in the preparation leading up to it that can upset you err t physically hurting yourself when you re in a race

D: Yeh sure

S: Erm err I don t know there s any men mental one s having said that I used to try and I used to for a short while I thought I was superstitious (of) think of biorhythms cos I got some exceptionally good runs every four weeks

D: Right yeh

S: (   )

S: and I thought maybe there s something here and I got these (   ) to see but it obviously it was a load of bollocks (   ) and I was spending more time getting

D: ((laugh))

S: superstitious with lead on like that

D: ((laugh))

S: I don t like to think there s anything that I think I like to think that when you get to the start line at any race or at any day or any situation you can think right I m gonna do really well now and off you go and do it

D: Yeh

S: And that s generally I mean that s all the all the top guys they re consistent hopefully I think they re all consistently good and they re all you know any race at any particular day they can turn up and navigate cleanly

D: Yeh

S: Physically they might be ups and downs you know (they might get) injured or whatever (   ) they ve not had a good winter or whatever but erm it s just then they they can arrive at start line and say right ((possibly slaps table)) I m not going to miss anything go off run a clean course

D: Yeh (   ) ok erm and just a few questions about levels of experience and things how many sort of err international level comps have you have you been in now then

S: Erm well I ve I ve senior level

D: Yeh

S: Well I was running in the since eighty-nine now I ve got first first year I was a senior

D: Since eighty-nine ok (   )

S: (   )

S: Yeh the races so I m I m at the other end of the at the experienced end

D: Right fine yeh

S: Yeh

D: Err wo when did you first start orienteering

S: Emm fifteen I think fifteen at school

D: And can I ask what age you are at now

S: Thirty twenty-nine

D: Twenty-nine

Yeh so that s

D: Ok

S: Fourteen years of

D: Right ok that that s that s everything

General conversation follows. Interview length 45 + 25 = 70 mins

Appendix 2: Qualitative Evidence of Heuristics Use During Route Planning by Expert and Novice Orienteers

Subject	Quote	Start-first, work-forward heuristic		Control-first, work-backwards heuristic	
		Start-first	Work-forward	Control -first	Work-backward
Experts					
1	I mainly focus on the control first . . . [and] then look for the best line into the control and I work my way back from that.	No	No	Yes	Yes
2	I tend to look at the end of the leg and work my way back for the best line into the control.	No	No	Yes	Yes
3	I . . . look at . . . the actual control site first and plan backwards from that.	No	No	Yes	Yes
4	I start from the control, try and find an attack point . . . near the control . . . and work back from there trying to find out how to get to there.	No	No	Yes	Yes
5	First thing . . . is . . . looking for a route into the control . . . then you ve got to look into the route into the control and . . . you iterate that back until you re happy with the route.	No	No	Yes	Yes
6	Try and start by working back from the control . . . to where you re coming from so you can identify an attack point.	No	No	Yes	Yes
7	Check for the control first . . . how to get in, and for an attack point really.	No	No	Yes	Yes
8	First of all you . . . pick out whether the control is actually tricky . . . and that s going to determine your route then. If you think there s only one line that you re going to get the control on then that determines the route.	No	No	Yes	No

Subject	Quote	Start-first, work-forward heuristic		Control-first, work-backwards heuristic	
		Start-first	Work-forward	Control -first	Work-backward
9	Basically I look at big features near the control to . . . attack the control with.	No	No	Yes	No
10	Initially . . . I would look at the control but I think it s very basic . . . you find out where it is and then it s a matter of how do I get to there?	No	No	Yes	No
11	I look at the control first and look for an attack point and then I look at the best route to get to that attack point.	No	No	Yes	No
12	Look at the circle, pick an attack point and then work backwards a little bit but then sort of work forwards as well.	No	No	Yes	No
13	I tend to glance at the control . . . just see roughly if it s a complex area . . . not taking much detail . . . then look from the start or work from where I am forwards as I m moving.	No	Yes	Yes	No
14	[I] look for obvious features near the control . . . then try to work out which way I m going out from the start, just like linking together whatever s in the middle and a nice attack point at the end.	No	No	Yes	No
15	So on this particular leg I had a look where the control was and then anything that quickly came out of the map.	No	No	Yes	No
16	[I] plan my route . . . depending on how . . . I was going to attack the control . . . I want to see where I m going [i.e., the control] first and see that area around the control.	No	No	Yes	No
17	I d start off, I d look at the control [that I m at], look at the way out . . . [then] look at the whole leg, the middle section of it . . . to get a general idea of what route to take.	Yes	Yes	No	No

Subject	Quote	Start-first, work-forward heuristic		Control-first, work-backwards heuristic	
		Start-first	Work-forward	Control -first	Work-backward
18	Look at the general shape of the terrain that you re going to occur on the leg . . . After that then I d be looking at . . . the control.	No	Yes	No	No
19	I d do that first of all, see if there s any obvious route that is easy to get to [and] that would use a path or some sort of feature that you can run along . . . then [I would] look for some attack point that you can attack the control from [and then] go for that.	No	Yes	No	No
20	This participant provided no evidence of either heuristic				
Novices					
1	I would look at the whole length from the start to the finish	Yes	Yes	No	No
2	A good look at how to get out from the start using any . . . features that I could . . . just follow those up the page really	Yes	Yes	No	No
3	Well basically I want to look at the start where I m going to straight away then, rather than look on the route . . . as I home in to the banner [control] . . . I ll be looking for an attack point	Yes	Yes	No	No
4	I d have a good look at how to get started, where my first little goal will be . . . and when I got there I d . . . find another point . . . and I d . . . get further along and find the end like that.	Yes	Yes	No	No

Subject	Quote	Start-first, work-forward heuristic		Control-first, work-backwards heuristic	
		Start-first	Work-forward	Control -first	Work-backward
5	. . . I . . . plan to get to the control as straight as I can . . . [and] just any stuff worth using to find your way from the start to the finish . . . there might be . . . a river a few metres up from the start, then a house a bit further then . . . the next thing might be like a hill. . . . You just get yourself some markers . . . to show you the way so you know your plan s going . . . to get you there [the control]	No	Yes	No	No
6	I want to look for a good route to the control flag . . . look for a line running from the start to the control	No	Yes	No	No
7	I d be looking for like stepping stones to lead me there and make my job easy . . . I would be looking for long features that might help me to follow even if that meant wandering off from a more straight line	No	Yes	No	No
8	You d plan A to B via C, D, E for example	No	Yes	No	No
9	I think I look at where I m going to try and get to and where I am at when I start . . . and then plan a way to get to the control that s the easiest . . . a direct route	No	Yes	Yes	No
10-20	These participants provided no evidence of either heuristic				