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Cognitive and neuronal bases of expertise

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Thesis submitted to The University of Nottingham for the
degree of Doctor of Philosophy, August 2003

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Abstract

This thesis examines the cognitive and neural bases of expertise. In so doing, several psychological phenomena were investigated—imagery. memory and thinking—using different tasks, and a variety of techniques of data gathering, including standard behavioural experiments, questionnaires, eye-movement recording, and functional magnetic resonance imaging (fMRI).

Chess players participated in all the studies, and chess tasks were used. The data confirmed the versatility and power of chess as a task environment, since the results provided fruitful information for the understanding of different human cognitive processes.

The role of practice in this domain of expertise was examined. The strong view that extended deliberate practice is a necessary and sufficient condition for the acquisition of expert performance, did not receive support in this thesis. Alternatively, a less extreme position was adopted: extended practice is a necessary, but not a sufficient condition for the acquisition of expert performance.

A search for individual differences in factors unrelated to chess practice was carried out. The sources of these individual differences, as well as the cognitive abilities in which individual differences may exist, were considered. One of the sources—the age at which serious practice starts—was a good predictor of chess skill. Handedness, which is supposed to be determined by environmental factors in *utero*, slightly differentiated chess players from non-players, but no differences in this variable were found between strong and the weak players. Regarding the cognitive abilities, chess players performed slightly better than the non-chess players in a spatial task.

Individual differences were also considered within a single level of expertise—master level. Differences in forgetting rate in long-term memory and reaction time were observed for one of the masters. These results contributed to the improvement of an extant theory of expertise—template/CHREST [CHunks and REtrieval STructures] theory—by estimating values for some of its parameters based on the empirical data obtained, and by proposing the addition of a spatial short-term memory.

Acknowledgements

Expressing my gratitude in a few paragraphs is in no way enough. Probably, the best way of being thanked is to transmit the help received to other people. For the time being, I will (unsuccessfully) try to be fair by writing only a few words.

I am greatly indebted to Fernand Gobet for giving me the unique opportunity of being his PhD student. His supervision was not limited to the thesis—which he read very patiently—but he also spent his precious time in training my research skills. He also gave me all the support I needed to accomplish this endeavour, and shared with me his experience and knowledge in psychology.

I would also like to thank Amanda Parker who offered me the possibility to do fMRI research. She also read my thesis very patiently and gave me support during the three years of the doctorate. I am also thankful to Andrew Derrington, who, among other things, supported me in any application I had to submit and gave me advice for my academic career.

Ron Batchelor, Gareth Williams, Chris Vincent, Mark Buckley, Peter Lane, Kay Head, Ngoc Thai, and Merim Bilalic helped me in different types of technical aspects.

Lunchtime has been a moment for intellectual discussions with Javier Aguado Orea about, among other issues, the development of our research projects.

A special word should be dedicated to all the participants of the studies presented in this thesis, especially the masters. Without their disposition I would not have been able to produce this piece of work.

Finally, my family and friends have been very supportive, and I will thank them personally.

List of papers published or in press produced during the PhD period

Peer- reviewed

Campitelli, G., & Gobet, F. (in press). *The mind's eye* in blindfold chess. *European Journal of Cognitive Psychology.*

Campitelli, G., Gobet, F. & Parker, A. (2003). From questionnaires to fMRI in experts. A paradigm for the study of cognitive processes. Proceedings of the X *Psychology Research Meeting. Faculty of Psychology, University of Buenos Aires, Argentina.* (in Spanish)

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Book chapter

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CHAPTER 1

Introduction

Almost every human adult is an expert in several domains; for instance, recognition of human faces and speaking one's mother tongue. However, no-one would think to call everyone else 'an expert' just because they have mastered their own language. We generally refer to experts when speaking of a small percentage of individuals who are at the pinnacle of any domain that is considered socially important and that requires skills that go beyond the normal skills of the population. There are several domains in which society considers that there are experts: music, painting, sculpture, literature, science, sports, chess and others.

There are some questions about expertise that attract the attention of scientists. How is the expert performance acquired? Can anyone become an expert in any domain by spending thousands of hours of dedicated practice? Or, do those who excel in a domain have some innate 'talent'? Is the nervous system of experts different from that of non-experts? If it is, is that because it has changed as a consequence of practice or because it was different before becoming dedicated to the domain? Or, could the nervous system be in no way different, and the knowledge of the experts is what counts? This thesis is devoted to the study of expertise and will address some of these questions.

Why is it important to know about experts? Because the understanding of expertise has social, educational and psychological implications. From the social point of view, an example is that expert scientists contribute to the improvement of the quality of life of people by generating complex knowledge, which in turn, is applied to increase the life expectancy of the population (e.g., the discovery of penicillin). If one knew how expertise is acquired it would be possible to generate educational systems that favour its emergence. From the psychological standpoint, it is important to understand the circumstances under which experts surpass the normal limits of the cognitive system. If what differs between an expert and a novice is the software[1], the theoretical framework of cognitive psychology is safe; whereas if the difference is in the hardware, the whole theoretical framework of cognitive psychology might be jeopardized.

It is widely accepted that a fundamental study in the development of the scientific study of expertise was De Groot's (1946) study of chess players (e.g., Hoffman, Feltovich & Ford, 1997). Chase and Simon (1973) revived De Groot's study and proposed the 'chunking theory' from which two statements were quite influential in the wider domain of cognitive psychology. First, an expert does not have a different cognitive system from that of the lay person; what differs is the amount of knowledge. Second, this knowledge is acquired by thousands of hours of practice, and it requires at least 10 years of intensive dedication to reach the level of expert. Chase and Simon (1973) has been a widely cited article in cognitive psychology and has generated two lines of research. The first concerned the cognitive system of the experts and eventually led to the development of—among others—the 'template theory' (Gobet & Simon, 1996a), and the second had as its main purpose the demonstration that dedicated practice is a necessary <u>and sufficient</u> condition for the attainment of expert performance, a view that reached its summit in the 'deliberate practice' framework (Ericsson, Krampe & Tesch-Römer, 1993).

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[1] Software and hardware are two psychological terms introduced by the information processing account of psychology. The former refers to knowledge, representations, strategies, etc; which are assumed to be flexible. The latter refers to the more stable components of the cognitive system such as short-term memory, long-term memory (see Charness et al., 1996).

Neither of these two lines of research has proposed a general theory of expertise capable of irrefutably answering the questions presented above. This thesis explores both lines of research, and one of its aims was to gather data to contribute towards a general theory of expertise in which the two strands are combined. In so doing, chess was chosen as a task environment to carry out all the experiments. This is not a casual choice: as mentioned earlier, De Groot's (1946) study of chess players was a fundamental study that directly addressed the topic of expertise. Chase and Simon (1973) stated that chess is the drosophila of cognitive psychology, indicating that it is an excellent task environment to carry out experiments of psychological interest.

Continuing this idea I propose that a good research setting in psychology is one that allows researchers to study several relevant *psychological phenomena*, via different *tasks and techniques*, in order to generate or test *theories*, in the most *controllable* and *ecological* way possible. One of the purposes of this thesis is to show that chess has these characteristics. The advantages of using chess as a research setting were articulated in several articles (e.g., Simon & Gobet, 2000). Chess offers a good compromise between controllability and ecological validity. Nowadays, playing chess against a computer program or against a human opponent on the Internet is commonplace in players ranging from top-class to beginners. Furthermore, the study of chess openings with databases which display games on a computer screen is an unavoidable part of chess training. Thus, asking chess players to sit in front of a computer screen on which chess stimuli are presented, and asking them to give a response by clicking a computer mouse is a naturalistic task for them.

Another interesting feature of chess is that a very simple environment containing a white and black 8 x 8 board with 32 pieces (16 white and 16 black) of 6 different types—therefore a very controllable environment—could generate a vast number of positions (approximately 2^{143}, see De Groot & Gobet, 1996). Therefore, without losing experimental control it is possible to create many different experimental conditions (the classic example is the use of normal chess game positions and random positions). This flexibility also allows the researcher to design a variety of tasks (e.g., reconstruct a chess position, solve a chess problem, make a decision of a move to play, recognise previously seen positions, reproduce a sequence of moves). Once again, natural tasks can be used in a controlled environment.

A very important factor is that, during a chess game, a chess player has to perform numerous cognitive processes intensively, such as perception, imagery, encoding and retrieval of information, as well as thinking. Hence, the use of chess players as participants offers the possibility of investigating a variety of psychological phenomena.

A practical reason why chess is a favourable research setting is that there are numerous chess games in chess databases (the most important chess data base nowadays is Chess Base, which began to be commercialised in 1987) easily available for researchers in order to produce the stimuli. Finally, a further important factor is that chess players, ranging from top-class grandmasters to beginners, are ranked on an interval scale (Elo, 1978), which allows an easy assessment of the level of expertise of any player[2]. This is a very important tool

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[2] Arpad Elo developed a rating scale in 1978, and since then the World Chess Federation (FIDE) has used it to rate chess players. The scale is exclusively based on games played in tournaments that fulfil FIDE's requisites. Almost all national federations have also their own rating with the same or similar system developed by Elo. The scale has a normal distribution and a standard deviation of

inasmuch as determining the level of expertise within a domain is more difficult than one could expect. In some domains (e.g., medicine), the years of experience within a domain, or the position held, are taken as parameters to differentiate experts from novices. This measure may be correct; however, the profit that different people take from their experience in a domain is not constant, and some newcomers might have an equal or better level than more experienced individuals. ELO rating scale avoids this kind of problem, because it measures performance directly. In addition, expertise can be assessed categorically (i.e., experts vs. novices, as in most of the other domains) and parametrically (i.e., expertise can be measured along a continuum).

In summary, understanding expertise has social, educational and psychological implications. A general theory of expertise that fully explains the phenomenon has not yet been developed, and would be valuable. Two lines of research have explored expertise. One investigated the characteristics of the cognitive system, and the other focused on the role of practice. This thesis aims to contribute towards a theory of expertise, combining these two strands of research. For this purpose, chess has been chosen as a task environment, for it provides the conditions for investigating several psychological phenomena related to expertise.

In the next section I will state explicitly the purposes and theses of this piece of work. Then, I will give details of how this work is organised.

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200 points. The best player has around 2800 points and the weakest player has 1800 (last year the cut-off threshold was 2000, and five years ago it was 2200). In the psychology literature, players between 1600 and 1800 points are called 'class B players', players between 1800 and 2000 points are considered 'class A players', players between 2000 and 2200 are labelled 'experts', players with more than 2200 are considered masters. The World Chess Federation awards players with titles according to their level; players with more than 2300 are called 'FIDE masters', most of the players with more than 2400 are international masters and most of the players with more than 2500 are grandmasters.

1.1. Purposes and theses

One of the purposes of this thesis is to gather data in order to contribute towards a general theory of expertise. Except for chapter 9, all the experimental chapters focused on different psychological phenomena related to expertise. Providing a definite theory of expertise is beyond the scope of this work; instead, the data gathered are used in order to suggest improvements to an extant theory—the template/CHREST [CHunks and REtrieval STructures] theory (Gobet & Simon, 1996a; see next chapter, section 2.1.2).

The second purpose is to gather data in order to support three specific theses, which are stated below.

First thesis: Chess is a versatile and powerful task environment to study expertise and psychological phenomena related to expertise.

Second thesis: Extended practice is a necessary, but not sufficient, condition to achieve expert performance in chess.

Third thesis: There are individual differences in factors not-related to extended practice within chess that account for part of the differences in chess rating.

In order to deal with the first thesis, chess experiments were carried out in a range of tasks, using a variety of techniques, and various psychological phenomena were investigated. Regarding the tasks, a questionnaire was administered to a large number of chess players of different levels (see chapter 4); in chapter 5, the task used was blindfold chess;[3] in chapter 6, a questionnaire of similar characteristics to the one in chapter 4 was used; in chapter 7, numerous immediate and delayed

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[3] Blindfold chess is a variant of chess in which at least one or the players do not use the chessboard; instead (s)he communicates her/his move out loud and receives the move of the opponent by the same procedure.

memory recall tasks were performed. In chapter 8, a number of problem-solving tasks were carried out. In chapter 9, a delayed recall task was performed, and the participants carried out two similar delayed response recognition tasks.

The techniques used to record data also varied in nature; questionnaires were used in chapter 4 and 6; standard behavioural measures were obtained in chapters 5, 7, 8, 9 and 10; eye-movement recordings and think-aloud protocols were obtained in chapter 8; finally, in chapters 9 and 10 functional magnetic resonance imaging (fMRI) was carried out (see methods section in chapter 3, section 3.1).

A range of psychological phenomena was covered by this work. Chapters 4 to 8 investigated expertise from different perspectives. Chapters 4 and 6 investigated the role of deliberate practice in the acquisition of expert performance, chapter 5 researched the subject of expert imagery, chapter 7 dealt with the topic of expert memory, and chapter 8 with expert thinking. Chapter 9 enquired into neural aspects of autobiographical memory, and chapter 10 was devoted to the influence of expert knowledge upon working memory tasks in brain activation.

The second thesis expresses the idea that extended practice is a necessary but not sufficient condition to achieve expert performance. Chapters 4 and 6 addressed this issue via a correlational study, in which a large sample of chess players reported the amount of time studying and playing chess.

Since extended practice cannot account for all the variance in chess rating, the third thesis argues in favour of individual differences unrelated to practice. This subject was addressed in chapters 6, 7 and 8, where 6 participants (two strong chess masters, two intermediate players and two non-players) took part in several tasks. Using a small number of participants in numerous tasks—following the framework of Gobet and Ritter (2000)—allowed me to detect some individual differences that otherwise would have remain unnoticed. In anticipation, some individual differences in non-domain specific factors were observed; however, prudence should be observed before making strong claims. In chapter 11, I will suggest some candidate factors to be further investigated.

The rest of the thesis is organised as follows. The next chapter (chapter 2) presents a literature review of all the topics treated in the experimental chapters. Chapter 3 deals with the methodological issues of the thesis, and the technique of fMRI will be explained in detail. Chapters 4 to 10 are empirical and an overview of them has been already given. Finally, chapter 11 has three sections. The first summarises the results, the second proposes improvements to the template/CHREST theories and the last evaluates the purposes and theses stated in this chapter.

CHAPTER 2

Theoretical and empirical review of expertise

In chapter 1, it was stated that one of the goals of this thesis is to provide data towards a general theory of expertise. Fortunately, I am not alone in this endeavour; indeed, a vast amount of work has been done before with the same aim. In section 2.1, a brief review of theories of expertise, as well as the reasons why one of the theories—template/CHREST—was chosen as a guide, is presented. In section 2.2, one of the strands of research within expertise is explored (i.e., the acquisition of expertise), emphasising the 'innate talent vs. deliberate practice' debate. Section 2.3 moves to the characterisation of the cognitive system of the expert. The analysis will be carried out at two levels: the functional level (sub-section 2.3.1) and the brain level (sub-section 2.3.2). The first of these sub-sections will review studies into expert imagery, expert memory and expert thinking. The second sub-section will be devoted to brain imaging studies.

2.1. Theoretical framework

Several theories of expertise have been put forward and a number of reviews have appeared elsewhere (e.g. Gobet, 1998a; Holding, 1985, Saariluoma, 1995). Here, I will only highlight the most important aspects of the theories. As indicated earlier, there are two main strands of research into expertise. The first strand of research investigates how the expert levels are acquired (e.g., Ericsson et al., 1993; Howe, Davidson & Sloboda, 1998). This line of research will be extensively discussed in section 2.2 when the 'innate talent vs. deliberate practice' debate will be presented. The second, enquires into the cognitive processes of the experts (e.g., Chase & Simon, 1973; Gobet & Simon, 1996a; Holding, 1985; Saariluoma, 1990). In the next sub-section (2.1.1), a number of these theories will be summarised, and the following sub-section (2.1.2) will concentrate on the template/CHREST theory. The latter will be explained in more detail, for it is the one that I chose to guide my empirical studies.

2.1.1. Theories of expertise

The following theories will be briefly summarised: chunking theory (Chase & Simon, 1973), SEEK (SEarch, Evaluation and Knowledge) theory (Holding, 1985), long-term working memory theory (Ericsson & Kintsch, 1995), apperception-restructuring theory (Saariluoma, 1992), and constraint attunement hypothesis (Vicente & Wang, 1998). The next section will be devoted to the template/CHREST theory (Gobet & Simon, 1996a).

Chunking theory (Chase & Simon, 1973).

This is the best detailed theory of this section, allowing for clear predictions to test its accuracy. This is an important issue, because many psychological theories are ill-defined, and in turn unfalsifiable (see Popper, 1959, for the importance of falsifiability of scientific theories). Indeed, the chunking theory was falsified and modified (see next section, 2.1.2).

This theory explained the differences in chess skill by the amount of familiar chunks stored in long-term memory. The cognitive system of the chess master has the same limits of capacity as the normal cognitive system. The chunks are familiar configuration of 3 or 4 chess pieces stored in long-term memory by practice. These patterns allow chess players to recognise positions rapidly and automatically generate moves.

This theory was implemented in a computer model (EPAM) which contained a long-term memory, a short-term memory and a 'mind's eye'. All the systems had the characteristics of the normal cognitive system (e.g., the short-term memory capacity was limited to 7 chunks (Miller, 1956), storing a chunk into long-term memory needed 8 seconds (this estimation takes into account the verbal learning studies; see Jung, 1968)).

The theory accounted for the available data quite well; however new data put the theory into question (see the memory section for details, section 2.3.1.2) and some alternative theories were proposed. One of them, SEEK, will be explained next.

SEEK theory (Holding, 1985).

Holding denied the pattern recognition explanation of the chunking theory, and proposed that thinking ahead, evaluation and knowledge are the main factors that explain expertise in chess. Masters play better than novices because they search deeper and faster, and they evaluate better using their knowledge. Unlike the chunking theory, Holding proposed the idea that verbal knowledge, instead of visuo-spatial patterns, are fundamental in chess expertise.

Holding has the merit of pointing out some shortcomings of the chunking theory and giving emphasis on the search processes of the chess players. SEEK has been well considered, for it seemed to solve the problems of the chunking theory. However, it is very difficult to derive predictions from the theory without ad-hoc assumptions because the theory has not been formalised. Moreover, Gobet (1998a) showed that it does not account for the available data.

Apperception-restructuring theory (Saariluoma, 1992).

Based on the fact that human thinking is highly selective and that experts are capable of segregating the relevant from the irrelevant, Saariluoma revived the concept of apperception (Kant, 1781; Leibniz, 1704). Apperception refers to conceptual perception or construction of semantic representations (Saariluoma, 1995). He argues that while thinking, chess players construct mental spaces via apperception, and also that shifts between mental spaces are carried out by restructuring (using a term of Gestalt psychology; Duncker, 1945).

The apperception-restructuring theory has the value of trying to reconcile the chunking and SEEK theories. Also, it paid attention to a typical phenomenon in problem-solving situations (i.e., functional fixation), and tried to explain a feature of expert thinking—selectivity in search. The disadvantage of the theory is that it has not been formalised yet, and it is difficult to derive predictions in order to falsify the theory.

Long-term working memory (Ericsson & Kintsch, 1995).

This theory emerged to account for all the data available in the psychology of expertise. In the field of chess, it proposes the point that masters use a retrieval structure representing the chessboard, which allows them to encode chess pieces forming a hierarchical organisation, and having rapid access to long-term memory. It also proposed that chess players encode information by elaborating long-term memory schemas. The theory has the advantage of putting together empirical data of a variety of fields of expertise, including language. Therefore, it is not only a theory of expertise but also a general theory of memory.

Once again, although quite popular, this theory is vaguely defined, not formalised, and ad-hoc assumptions must be made in order to derive predictions. Gobet (1998a) considered two versions of the theory in order to compare its explanatory power to that of chunking, SEEK and template theory, and the theory does not explain all the available data in chess in any of the two versions.

Constraint attunement hypothesis (Vicente & Wang, 1998).

This theory was proposed as an ecological theory of expert memory. In fact this is not a theory of the cognitive system; Vicente and Wang proposed that it is more important initially to have a product theory (i.e., a theory of the production of an expert) than a process theory (i.e., a theory of the cognitive processes of an expert). The reason why it is included in this group is because it is closely related to the theories explained above (indeed several arguments between the theories were published; see Simon & Gobet, 2000).

The constraint attunement hypothesis proposes that one of the hallmarks of expertise is the attunement to goal-relevant constraints. For instance, the fact that chess masters search selectively could be the consequence of having educated their attention to focus on relevant moves. When no goal-relevant constraints are present in the environment then expertise does not emerge (for instance, in random chess positions). The more goal-relevant constraints in the environment the higher the differences between the experts and novices.

Another example is a study in recognition memory for X-rays (Myles-Worsley et al., 1988). In this study expert radiologists performed better than novices when recognising abnormal X-rays and they performed worse than novices when recognising normal X-rays. Vicente and Wang (1998) proposed that this result could be explained by the fact that the relevant goal of expert radiologists is to identify abnormalities; when the relevant goal is absent the expertise effect does not arise.

Simon and Gobet (2000) argued that process theories do not need to wait for product theories to be completed, and that theories should be clearly defined in order to be tested and, if necessary, falsified. Once again, the lack of formalisation and vagueness are some of the shortcomings of the theory.

2.1.2. Template/CHREST (Gobet & Simon, 1996)

The brief review of theories of expertise presented above has shown a common pattern: vagueness, lack of formalisation, and difficulty in deriving predictions that could falsify the theory. The only exception is the chunking theory. A good example of how scientific knowledge should develop is the change from the chunking theory (Chase & Simon, 1973) to the template theory (Gobet & Simon, 1996a). Every theory should be formulated in a way that clear predictions could be derived from it; if these predictions are empirically tested and they fail to pass the test, the theory must be changed (Popper, 1959). The reasons for the change are explained in the expert memory section (see sub-section 2.3.1.2). Here, I will focus on the explanation of the theory. First, I will briefly explain the CHREST model and its advantages, and then I will point out some disadvantages that this thesis aims to improve.

Like the chunking theory, the template theory suggests that chess players store in long-term memory familiar patterns of chess configurations, and that these patterns elicit moves. When a chess position is seen, the patterns in long-term memory are automatically accessed, and a move is generated. The difference with the chunking theory is that chunks that are visited several times, evolve into more complex structures called templates. These differ from the retrieval structures of the long-term working memory theory in that the retrieval structures are explicitly acquired, whereas the templates are implicitly acquired throughout the practice of chess. The templates contain a core with approximately 12 pieces, and slots in which additional information could be added. This information may be other chunks, moves, or more abstract knowledge such as the name of the opening, strategies and plans.

Parts of the template theory were implemented in a computational model called CHREST. Except from the templates, the rest of the model contains the same characteristics as the chunking theory: a short-term memory, a long-term memory with a discrimination network and a mind's eye. The short-term memory is an array in which pointers of the chunks accessed are placed. (its capacity limit has changed from 7 in the chunking theory to 4 chunks in CHREST, based on Zhang and Simon's (1985) estimation). The mind's eye is a transient visual storage in which information from the retina or from memory could be placed.

CHREST not only aims to explain how the cognitive system of the expert works, but also, how expertise is acquired. By two processes—discrimination and familiarisation—the model is capable of learning the information fed into it (for a detailed explanation of these processes see De Groot & Gobet, 1996). These processes and others have estimated time parameters (for instance, it takes 8 seconds to discriminate, 2 seconds to familiarise, 250 milliseconds to fill in a template slot; see chapter 11, table 11.1 for a complete description of the parameters)

Like the chunking theory, the difference between an expert and a novice is explained by a differential amount of information that is stored in long-term memory. CHREST could be fed with chess positions, and it will create chunks, and eventually templates, throughout the discrimination network. The more positions fed into the model, the larger the discrimination network and the larger the templates and chunks available.

The model can simulate the most studied paradigm up to that point: the reconstruction of a position that had been seen for a brief period of time. Another appealing feature of the model is that it simulates eye-movements during the reconstruction task. When presented with a chess stimulus, the model fixates on a part of the board, extracts information, accesses a chunk or template that matches the information, and places a pointer to it in the short-term memory. When familiar positions are presented, the model accesses the chunks or templates that correspond to the positions presented, and the performance is high (in fact, the higher the network, the higher the performance). However, when a random position is presented, the model only recognises the familiar chunks that by chance are present in the stimulus, therefore the performance is lower.

One of the criticisms of chunking theory was that it did not take into account the search aspect of the thinking behaviour of chess players (see SEEK theory). Gobet and Simon (1998) explained that "pattern recognition makes search possible". Pattern recognition procedures that elicit moves when they are accessed, apply not only to the stimulus presented but also to recursively over the new positions that are updated in the mind's eye when a move is triggered by the chunk/template accessed.

There are several advantages in template/CHREST. First, it is a formal theory from which clear predictions can be derived and empirically tested, and if necessary, falsified. Second, it provides mechanisms not only of how the cognitive system of the expert works, but also of how the level of expertise is acquired. Third, it accounts for a wide range of data, including eye-movement measures (see De Groot & Gobet, 1996). Fourth, it takes into account the role of high-level knowledge that is part of the templates.

There are shortcomings, some of which this thesis will try to help to correct. First, so far, within chess the computational model is only prepared to simulate the reconstruction task (although a model of the CHREST family—CHUMP [CHUnking of Moves and Patterns]—simulates the generation of moves by pattern recognition). In chapter 11, it is proposed how some other tasks can be easily simulated without changes in the model. Second, high level knowledge is part of the template theory but is still not fully implemented in the computational model. The data provided by the think-aloud protocols analysis (see chapter 8) could be taken as the content of this knowledge. Third, some of the parameters estimated are based on empirical data, but the number of nodes in the long-term memory network is estimated in order to roughly fit the performance of the humans in the task (see Gobet & Simon, 2000). An estimation of some of the parameters based on the data of this thesis is presented in chapter 11. Fourth, the search behaviour is part of the template theory but is still not implemented in CHREST. As an intermediate solution, Gobet (1997) calculated the depth of search and total number of moves generated in a problem-solving situation as a function of the number of nodes of the long-term memory network. In so doing, Gobet estimated the number of moves generated by templates, chunks and heuristics. An evaluation of this estimation is carried out in chapter 8.

It is worth noting that these improvements could be proposed only because of the clarity and formalisation of the theory. The other theories reviewed earlier would not have allowed me to carry out this work.

Now that the theories of expertise have been discussed and that I have shown the one that I chose as a guide for my experiments, the review becomes somewhat more empirical. The next section (2.2) will deal with the strand of research devoted to the acquisition of expertise, and the following section (2.3) will focus on the characteristics of the expert cognitive system.

2.2. Acquisition of expertise

There is a consensus that individual differences in performance exist in most, if not all, domains of expertise. The debate arises when researchers try to explain the source of these individual differences: some authors, continuing the tradition established by Galton (1869), propose that innate talent accounts for most individual differences, while others argue that these differences are better explained by the extended period of intense practice that most experts have to go through. Support for innate talent theories is offered by the study of precocious attainments such as those of Mozart (music), Ramanujan Srinivasa (mathematics), and more recently, Bobby Fischer (chess).

First, the debate on general expertise is presented and then the application of this debate to chess expertise will be discussed. Geschwind and Galaburda (1985) proposed an influential neuropsychological theory describing the relationship between brain development and cognitive abilities. Great exposure or high sensitivity to intrauterine testosterone in the developing male foetus would lead to a less developed left hemisphere and, as a consequence, a more developed right hemisphere than in the general population. This would result in a higher probability of being non-right-handed and being gifted in visuo-spatial abilities, and as a consequence, in domains such as mathematics, music, and chess.

At the other extreme of the talent/practice continuum, one finds the framework of deliberate practice, which was developed by Ericsson et al. (1993), influenced by Simon and Chase's (1973) earlier work on chess expertise. The main assumption is that the differences observed in performance in a number of domains (including sports) are due to differences in the amount of deliberate practice. Deliberate practice consists of activities deliberately designed to improve performance (playing and teaching are excluded from this category), which are typically effortful and not enjoyable. Moreover, these activities cannot be extended throughout long periods and must therefore be limited to a few hours a day (around 4), because of risks of burnout. High attainments are possible only if there is strong family support and a favourable environment and after 10 years of deliberate practice. Ericsson et al. (1993) reported results from music expertise, showing that the more skilled engaged more in deliberate practice. The same pattern was found in karate (Hodge & Deakin, 1998), soccer and hockey (Helsen et al., 1998), as well as skating and wrestling (Starkes et al., 1996).

Ericsson et al. do not rule out the participation of inherited factors, but they limit their role to motivation and general activity levels, explicitly excluding cognitive abilities. Evidence supporting the role of deliberate practice and questioning the role of talent includes a series of longitudinal experiments in the digit-memory span task. The results show that, with sufficient practice, average college students could achieve higher levels than those attained by individuals previously thought to have inherited skills (Chase & Ericsson, 1981). Proponents of the essential role of practice adduce several arguments against the innate talent theory: this theory is mainly supported by anecdotal studies, and based on common sense, and there are no scientific tests for the theory (Howe et al., 1998; Ericsson & Charness, 1994; Ericsson et al., 1993).

Charness et al. (1996) outlined a general framework of skill acquisition and expertise, where five factors support the acquisition of skill: (a) external social environment, (b) internal motivation and personality, (c) external information, (d) practice, and (e) cognitive system (software and hardware). Charness et al. consider that the cognitive system (both the software and the hardware) changes as a consequence of practice in the domain of expertise.

Innate talent in chess.

Based upon Geschwind and Galaburda's (1985) theory, Cranberg and Albert (1988) speculate that the primary neurological components of chess skill are located in the right hemisphere, and that chess skill develops more in males and non-right-handers than in females and right-handers, respectively. They argue that individuals with enhanced right-hemisphere development might have an advantage at chess. Cranberg and Albert's (1988) reasoning runs as follows: chess is a visuo-spatial task, visuo-spatial tasks are performed by the right hemisphere, non-right-handed individuals have the right hemisphere more developed, so the non-right-handers should be more represented in the chess population.

There is an extensive literature showing that visuo-spatial tasks are mainly performed by the right hemisphere (e.g., Kogure, 2001; Stiles-Davis, 1988; Witelson & Swalow, 1988). There is also a documented link between visuo-spatial abilities and chess. Robbins et al. (1996) and Saariluoma (1991) showed that when chess players were presented with a visuo-spatial secondary task, their performance in a chess task decreased, but when the secondary task was verbal, the performance remained unchanged.

Sending an informal questionnaire to 396 US chess players, Cranberg and Albert (1988) collected data on handedness to test another prediction of Geschwind and Galaburda (1985)—that there should be proportionally more non-right-handers in the chess population than in the general population. They found that there were 18% of non-right-handers in the chess population, which is significantly different from the rate in the general population (10 to 13.5%; Bryden, 1982; Geschwind, 1983). However, they could not find differences between a group of high-level players and a group of low-level players.

Deliberate practice in chess.

In their seminal study of perception in chess, Simon and Chase (1973) pointed out that a decade of intense preoccupation with the game is necessary in order to reach grandmaster level. They also estimated that a master has spent roughly from 10,000 to 50,000 hours playing or studying chess, and that a class A player has spent from 1,000 to 5,000 hours. As we have seen, Ericsson et al. (1993) have taken these results to their extreme by stating that levels of performance are not limited by putative innate factors, but that they can be further increased by deliberate efforts.

Indeed, the supporters of deliberate practice (e.g., Ericsson et al., 1993; Ericsson & Charness, 1994; Howe et al., 1998) reject the existence of innate cognitive talent in expert performance, arguing that there is no evidence for inherited abilities and that expert performance is directly related to the amount of deliberate practice. Charness et al. (1996) tested this theory in the field of chess by asking players to report the number of hours spent both studying chess alone and playing or analysing games with others. They proposed that the number of hours of study alone, rather than the number of hours of studying and practising with others, best measures the concept of deliberate practice. The results showed a strong correlation between chess skill—measured by the Elo rating—and the number of hours spent studying alone. They also found a strong but less important correlation between chess skill and the number of hours spent studying or practising with others.

Biographies of world chess champions and other strong grandmasters (e.g., Botvinnik, 2000; Brady, 1973; Forbes, 1992) show that intense dedication to chess is needed to attain high levels of performance. Krogius (1976) presents data showing that former world champion Bobby Fischer—the case mostly discussed by the proponents of the innate talent hypothesis—is almost within the bounds of the 10-year practice rule. Fischer attained his first grandmaster result after 9 years of starting playing chess. Even Judith Polgar, grandmaster at 15 years and 5 months, started intensive practice at 4 (Forbes, 1992). However, there are a number of recent cases that do not seem to respect the 10-year rule. World champion Ruslan Ponomariov attained the grandmaster title at the age of 14 years and 17 days, and Peter Leko (top 5 in the world) at 14 years and 5 months. In interviews, both of them reported starting playing chess at the age of 7. Also, Ponomariov attained 2550 Elo points (considered grandmaster level) at the age of 12 years and 8 months and Leko at the age of 13 years and 9 months. More recently, the record of the youngest grandmaster has been broken three times: Teimur Radjavob, Bu Xiangzhi, and Sergey Karjakin achieved the grandmaster title at the age of 14 years, 14 days; 13 years, 10 months, 3 days; and 12 years, 7 months respectively. Hence, although there is substantial evidence supporting the deliberate practice framework, it may be the case that inter-individual variability has been underestimated.

My standpoint is that extended practice is a necessary condition to acquire expert performance. However, it is not a sufficient condition—the position of the deliberate practice framework—and there are other factors not related to the practice within the domain of expertise that influence the acquisition of expert performance. I propose four sources of individual differences, although I do not rule out others. The first one is interaction with the environment made without any purpose of acquiring expert performance. One example of this, in the case of chess, is rich visuo-spatial stimulation in early years. The brain is quite flexible in early years (see for example, Eliot, 1999), and the interaction with the environment shapes its development. If, for any reason, a child is exposed to a rich visuo-spatial environment, (s)he might have an advantage in chess.

The second source is also environmental, but is during pregnancy. Basically, Geschwind and Galaburda's (1985) proposal; as explained above, great exposure or high sensitivity to intrauterine testosterone in the developing foetus, causes a more developed right hemisphere, and as a consequence, the probabilities of being non-right handed and having an advantage in visuo-spatial abilities over the general population increase.

The third source of individual differences is genetic. So far, there is no possibility of measuring this source of individual differences in cognitive abilities directly and it was only estimated by the heritability paradigm. However, the accelerated progress of genetic studies will open doors to measure directly genetic influences in expertise (see Grigorenko, 2000).

The fourth source of individual differences is related to the age at which the serious practice starts. Elo (1978, p. 100) presented data supporting the hypothesis that early introduction to the game of chess and to organised competition is important to achieve master level. All the masters (n=60) reported that they had learned the rules of chess before 17 years of age (range: 5 to 16; mean: 9.6). Moreover, they began organised competition before 19 years of age (range: 10 to 18; mean: 14.8). A possible explanation for this is related to the flexibility of the brain in childhood (e.g., Eliot, 1999). Starting to play chess seriously at early ages would allow the formation of appropriate domain-specific neuronal networks before the brain becomes more rigid.

Chapter 4 addresses this debate experimentally, by submitting a questionnaire similar to that of Charness et al. (1996) to a group of chess players of different levels. Furthermore, the Edinburgh Handedness Inventory was used to investigate more formally an issue that was the interest of Cranberg and Albert (1988).

2.3. Cognitive system

As acknowledged in sub-section 2.1.1, Chase and Simon (1973) proposed that the cognitive system of experts has the same limits as the normal cognitive system (e.g., limited short-term memory capacity). What differentiates an expert from a novice is the amount of knowledge stored in long-term memory. Chi, Glaser and Rees (1982) suggested that not only the amount of knowledge matters but also its organisation is important. At the opposite end, Jensen (1972) suggests that the intelligence of a person is explained by a faster cognitive processor. Charness et al. (1996) proposed that the 'hardware' (i.e., the more stable structures) of the cognitive system can be modified by practice.

My view is that amount of knowledge and its organisation are fundamental and that extended practice is the most important cause of its acquisition. However, similar amounts of practice could lead to different levels of expertise and that may be because the stable components of the cognitive system are different. Practice could do a lot in order to acquire knowledge, but very little to modify the hardware. The flexibility of the brain (i.e., hardware) decreases with age, being very flexible in childhood, less in adolescence and even less in adulthood (see Eliot, 1999). Therefore, it is more likely that changes in hardware happen at early ages than in adulthood. In chapter 11, I will propose different parameters for the cognitive system of players. Interestingly, the differences in aggregate data between players of different levels in parameters of the cognitive system may be not very large; on the other hand, individual differences within the same level of expertise were found and were analysed.

From chapter 5 to chapter 10, this thesis investigates three features of the cognitive system in experts: imagery, memory and thinking. In this section, studies that tried to elucidate the functioning of the cognitive system of experts are reviewed. In so doing, two different levels of explanation of psychological phenomena are considered: the functional level (subsection 2.3.1) and the brain level (2.3.2). In order to link this review to the experiments carried out in this thesis, in some cases it was necessary to provide a brief review of general aspects of cognitive processing.

2.3.1. Functional level

Three cognitive processes will be examined: imagery (2.3.1.1), memory (2.3.1.2) and thinking (2.3.1.3).

2.3.1.1. Expert imagery

Mental imagery, and in particular visual mental imagery, has been the subject of intensive research in psychology. For instance, interest in mental imagery has risen since the classical studies on rotation and scanning of mental images by Cooper and Shepard (1975). Mental imagery was also a topic of a sharp debate in cognitive psychology about whether imagery is made possible by propositions or by analogous mental images. Pylyshyn (e.g. Pylyshyn, 1973)—supporting the propositional view— and Kosslyn (e.g., Kosslyn & Pomerantz, 1977)—leading the analogous position—were the main contenders (see Kosslyn, 1994 for a complete history of the debate). Recently, experimental and theoretical research has been backed up by brain-imaging techniques, which have helped develop hypotheses about the brain areas involved in manipulating mental images (for a review, see Kosslyn, 1994).

Regarding expert imagery, as pointed out by Saariluoma (1991), little research has been done outside the chess field. Although some studies gave indirect clues about the existence of expert imagery (e.g., architects, Akin, 1980; electronic engineers, Egan & Schwartz, 1979; mathematics, Hayes, 1973; mental abacus operation, Hatano et al., 1977), none of those studies directly focused on expert imagery. On the other hand, blindfold chess has been instrumental in providing preliminary conceptualisations of this phenomenon. The following section tackles this issue.

Blindfold chess

The focus of research using blindfold chess has been to understand how chess masters can use mental imagery to maintain a representation of the positions generated during look-ahead search. Blindfold chess, where players play without seeing the board, has been especially informative on the cognitive processes and representations used by chess players to manipulate mental images (see Saariluoma, 1995, for a review).

Blindfold chess seems to require remarkable cognitive capabilities; hence, this style of play has attracted the interest of a number of psychologists, starting with Alfred Binet (1893/1966), who asked well-known chess players to fill in a questionnaire about the characteristics of their representations while playing blindfold chess. He found that skilled players do not encode the physical properties of the pieces and board, such as the colour or style of pieces, preferring an abstract type of representation. In an introspective account of the way he played simultaneous blindfold chess, grandmaster and psychoanalyst Reuben Fine (1965) emphasized the role of hierarchical, spatio-temporal Gestalt formations, which allow the player to sort out the relevant from the irrelevant aspects of the position. He also noted the possible interference between similar games, and the use of key statements summarizing the positions as a whole. Finally, he stated that the use of a blank chess board was more of a hindrance than a help for him, although other players, such as George Koltanowski, who held the world record for the number of simultaneous blindfold games, found this external help useful.

Pertti Saariluoma, in a series of ingenious experiments, systematically explored the psychology of blindfold chess. In these experiments, one or several games were presented aurally or visually, with or without the presence of interfering tasks. With auditory presentation, the games were dictated using the algebraic chess notation, well-known to chess players (e.g., 1.e2-e4 c7-c5; 2. Ng1-f3 d7-d6; etc.). With visual presentation, only the current move was presented on a computer screen. Saariluoma (1991) uncovered several important issues. First, blindfold chess relies mainly on visuo-spatial working memory, and makes little use of verbal working memory. Second, differences in LTM knowledge, rather than differences in imagery ability per se, are responsible for skill differences.

Third, in a task where games are dictated, masters show an almost perfect memory when the moves are taken from an actual game or when the moves are random, but legal, while performance drops drastically when the games consist of (possibly) illegal moves. Saariluoma took this result as strong evidence for the role of chunking (Chase & Simon, 1973) in blindfold chess. Fourth, visuo-spatial working memory is essential in early stages of encoding, but not in later processing. According to Saariluoma (1991), this is because the positions are later stored in LTM and thus insensitive to tasks interfering with working memory.

Continuing this line of research, Saariluoma and Kalakoski (1997) uncovered additional phenomena. First, replacing chess pieces with dots had little effect on the memory performance for both masters and medium-class players—a result that supports Binet's (1893) conclusion of abstract representation in blindfold chess. Thus, when following a game blindfold, the critical information is that related to the location of the piece being moved, and not information about colour or size. Second, transposing the two halves of the board leads to a strong impairment, which, according to Saariluoma and Kalakoski, is due to the time needed to build a mapping between the perceived patterns and the chunks stored in LTM. Third, they found no difference between an auditory and a visual presentation mode. Finally, given more time, less skilled players increase their performance, although they still perform less well than highly skilled chess players.

In a final set of experiments, Saariluoma and Kalakoski (1998) scrutinized players' problem-solving ability after a position had been dictated blindfold. They found that, in a recognition task, players show better memory with functionally relevant pieces than with functionally irrelevant pieces; this effect disappears when players' attention is directed towards superficial features (counting the number of white and black pieces) instead of semantically important features (searching for white's best move). Moreover, in a problem-solving task, players obtained better results when a tactical combination is possible in a game rather than in a random position. Finally, although there was no performance difference between visuo-spatial vs. auditory presentation of the moves, a visuo-spatial interfering task (Brook's letter task) negatively affected problem solving.

In chapter 5 of this thesis, two experiments with blindfold chess are presented. Both experiments were devoted to the interference produced by irrelevant contextual information over the image that players had to bear in mind.

2.3.1.2. Expert memory

As discussed in the previous sub-section, chess players are capable of some memory feats, such as playing several blindfold games at the same time. Taking this into account, it was natural to think that chess players may have a higher memory capacity than the general population. In the following sections, an examination of studies of memory in chess players is presented. Briefly, all the studies agree on one point: chess-players' general memory is normal, their memory feats are restricted to their domain of expertise.

The review of expert memory will be divided into three sub-sections. The first two sub-sections (2.3.1.2.1 and 2.3.1.2.2) succinctly review the relation between general memory and memory in experts; 2.3.1.2.1 is devoted to immediate recall tasks and 2.3.1.2.2 to delayed recall tasks. The last section (2.3.1.2.3) directly addresses memory studies in chess.

2.3.1.2.1 Immediate recall

The memory span task was first used by Jacobs (1887) who presented sequences of items to students. They had to remember and say the list in the correct order. Then, the number of items in the sequence increased until the students failed to produce the correct sequence. Miller (1956) showed that the immediate memory span in random letters is 6. When the items in a list can be meaningfully grouped into 'chunks' the span counted in number of items increases. However, the number of chunks remains constant in about 6 (see Baddeley, 1990 for a more complete review). Later, it was found that long-term memory was involved in this task, and that a better estimate of short-term memory capacity is 4 (see Cowan, 2000). The digit memory span task was used to train college students to increase their span. Ericsson and Chase (1981) showed that the memory span could be immensely increased by using long-term memory retrieval structures. The same individuals who by training attained a digit span of around 100, possessed a normal span for letters, suggesting that expertise could be acquired by extended practice without the need a 'talented' cognitive system.

Chi (1978) examined the influence of knowledge for memory span. She submitted children chess players and adult non-players to a digit-span task and to a reconstruction of a chess position (see subsection 2.3.1.2.3). The former performed better than the latter in the reconstruction of chess positions (9.3 pieces to 5.9 pieces); however, the children's memory span for digits was smaller than that of adults (6.1 digits to 7.8 digits). Schneider et al. (1993) replicated this finding, reaching similar figures: young chess players reconstructed 8.8 pieces correctly against 4.6 pieces in the non-player adults, and 5.8 and 7.6 were the digit spans, respectively. These results show that the skill effect in the chess memory task is not due to an increased memory capacity, but to the knowledge base stored in long-term memory.

In chapter 7 (sub-section 7.2.2), a number of memory span tasks was carried out in order to compare the performance of chess players in a general memory task to that of domain-specific memory tasks.

2.3.1.2.2 Delayed recall

In the previous sub-section, the retrieval phase of the memory tasks occurred straight after the encoding phase. In this sub-section, the retrieval phase is performed at least 30 minutes after the presentation (and, sometimes, weeks later) of the to-be-remembered stimuli. Typically, the studies aimed at testing the limits of the cognitive system in storing information when enough time is given to its encoding.

Standing (1973) assessed the capacity of the cognitive system to store information by presenting 10,000 pictures. The performance of participants was above 80% for 10,000 pictures and above 90% up to 1,000 pictures when the recognition phase was performed two days later. These results led to the conclusion that long-term memory for visual stimuli is unlimited. Moreover, this study also uncovered that participants performed better for pictures than for words. Franken & Rowland (1979) tested their volunteers a week after the encoding showing a clear decrease in performance, demonstrating a remarkable decay of the information in long term memory over time.

In chess, there were two studies aiming at testing the limits of the cognitive system in storing information: Cooke et al. (1993), and Gobet and Simon (1996a). In both studies the participants were presented with a series of positions that they had to remember. All the studies found that players increased the number of pieces recalled as a function of the number of positions presented, and that the percentage correct diminished. In Cooke et al. (1993), the best participant managed to reconstruct 50% with 9 positions, summing a total of 120 pieces. In Gobet and Simon (1996a) the master group of the second experiment performed at 50% with 4 boards (i.e., 80 pieces). In the same article an international master was trained with mnemonics, and after 150 trials he reconstructed 178 pieces correctly (above 60% correct).

The long-term retention of visual information was tested in this thesis by presenting 250 pictures. Additionally, in a different session, participants were given the same test but with chess positions. The comparison of the individual scores between the two conditions led to intriguing findings (see chapter 7, sub-section 7.1.1).

2.3.1.2.3. Expert memory in chess

The previous sub-section dealt with the link between general memory experiments and expert memory experiments, whereas the present sub-section focuses on chess. Three types of tasks are reviewed: reconstruction of normal game and random positions, recognition experiments and memory for move sequences. All these tasks were used in chapter 7; hence a review of them is appropriate.

Reconstruction of game and random positions

The reconstruction task is the 'classic' task in chess expertise. In this sub-section the highlights are given; for more exhaustive reviews of this topic see Holding (1985), Saariluoma (1995), Gobet (1998a), and Gobet et al. (in press).

Djakow, Petrowski & Rudik (1927) designed an experiment that became a classic in chess psychology research. The best players in the world at that time were presented during 60 seconds with a chessboard resembling a chess position. After this presentation, the players had to reconstruct the position on an empty chessboard. They found differences between the performance of the grandmasters and that of non-chess players. DeGroot (1946/1978) followed Djakow et al.'s technique, but instead of presenting the position for 60 seconds, he diminished the time of presentation to a range varying from 2 to 15 seconds. De Groot had also access to the strongest grandmasters (something incredibly expensive nowadays) who performed almost perfectly. A group of intermediate level players performed below 50 per cent (later, Chase & Simon, 1973; Gobet & Jackson, 2001, found that a non-chess player cannot remember more than 4 pieces (12 to 15%)). This pattern of results was replicated in several studies (see Gobet & Simon, 1996b). Chase & Simon (1973) asked the players to reconstruct not only a chess position but also a position in which the chess pieces were randomly distributed throughout the board. Strikingly, their chess master hugely decreased his performance and showed only a small difference in comparison to weaker players. This result showed the domain-specificity of the chess players' expertise. Another 'control' task used was the reconstruction of a position of 3 dimensional shapes displayed on an irregular board (see Schneider et al., 1993). In this case, no skill effect was found in the immediate recall task (in chapter 7, sub-section 7.2.1, a similar task was introduced).

Chase and Simon (1973) explained the results in terms of the 'chunking theory' (see sub-section 2.1.1). They were interested in the analysis of the size and number of groups of pieces that the players used in order to reconstruct the positions. The pieces placed on the chessboard within a time window of 2 seconds were considered part of the same piece of information, i.e., 'chunk', and the ones that were placed with a gap of more than 2 seconds were considered belonging to different chunks. The number of pieces reconstructed within the 2 seconds time window was 3 or 4. The chunking theory was implemented in a computer model of the EPAM family. One of the critical assumptions of the model was that the information for the memory task was stored in short-term memory (7 chunks of information (see Miller, 1956) times 4 pieces equals 28 pieces which is close to the highest number of pieces that could be present in a chess position (32 pieces)).

Charness (1976) introduced an interference task (i.e., counting backwards) during 30 seconds between the presentation of the position and its reconstruction. He found that, unlike with verbal material, players' performance diminished very little. This result supported the involvement of long-term memory storages in the reconstruction task. In the same direction, Frey and Adesman (1976) presented chess players with 2 positions to remember instead of one. The performance of the second position was fairly high, creating difficulties for the chunking theory, since the number of chunks needed to be stored in short-term memory were more than the known limit of 7+/-2. Moreover, Cooke et al. (1993) and Gobet and Simon (1996a) presented the participants with up to 9 positions. Although the percentage of correctly placed pieces diminished, the number of pieces accurately placed increased. Therefore, the chunking theory needed a revision.

Gobet and Simon (1996a) accounted for those results by revising the chunking theory and turning it into the 'template theory' which was also implemented in a computer model (see sub-section 2.1.2).

In chapter 7 (section 7.2.1) of this thesis, the reconstruction task is presented with normal game positions, random positions, and a new version—'shapes'—. The performance in this task was compared to that of general memory span measures. To anticipate, the typical results of the literature were replicated: high skill effect in the reconstruction of normal game positions, small effect in random positions, null effect in a 'shape' condition, and no effect in general digit and letter span. However, a tendency towards differences in spatial span was found.

Recognition tasks

Goldin (1978, 1979) carried out a series of recognition experiments and found skill effects in this type of task, as well. Following Craik and Lockhart's (1972) levels of processing framework, Goldin (1978) presented the participants (range, from class B to experts) with 24 positions. The participants performed either a deep task (by finding the best move) or a shallow task (by counting the number of pieces on black squares) for between 42 to 60 seconds. After 10 minutes of an interpolation task, the players went through a forced-choice recognition session (the target and two distractors were presented in each of the 24 trials). They performed at 67% for the move task and 55% for the count task (chance = 33.33%). In a second experiment, class A players in a similar task, performed at 87% for an evaluation condition (deep level of processing) and 71% and 84% for two shallow tasks. Class D players performed at 71%, 71% and 54% respectively; and non-players at 75%, 58% and 50% (chance = 50%).

In Goldin's (1979) experiment 1, the participants were presented with 21 game positions during 90 seconds, and they had to think out loud and decide which side had the advantage. After this session they went through a 15-minutes session of interpolated activity and then they went through an incidental forced-choice task. Across participants, 87% of the responses correctly recognized the stimuli seen in the presentation session. Moreover, there was a skill effect. In a second experiment, class A and class B level players were presented with 80 game and 80 random positions. The time of presentation was self-paced, and its average was around 50 seconds per position. In a subsequent forced-choice tasks, class A players performed at 95% and class D players at 72%.

In chapter 7 (section 7.1.1), a recognition task was used with chess positions and pictures; however, there the number of items was much higher (i.e., 250) and the presentation time much lower (i.e., 5 seconds).

Memory for chess game sequences of moves

The study and memorisation of opening-moves sequences is an important aspect of chess training. Monographs, books and encyclopaedias are devoted to increasingly specialised sub-variations of openings. This material can be found both in paper and electronic format. However, the chess psychology literature has paid little attention to this facet of chess preparation. For instance, Chase and

Simon (1973), Saariluoma (1991), and Campitelli (1999) showed move sequences, but with different goals.

Chase and Simon (1973) found that there is a skill effect for the recall of move sequences, both with normal games and with random games. This is not in agreement with the lack of skill effect in the reconstruction of random positions. The researchers explained the results in terms of the long time of presentation (2 minutes). This is enough time to recognise information and to store the outcome in long-term memory. Additionally, Gobet and Simon (2000) showed a skill effect in random positions, when the time of presentation has increased to 1 minute.

Saariluoma (1991) and Saariluoma and Kalakoski (1997) showed sequences of moves in a blindfold way. Those data have already been reviewed in section 2.3.1. Suffice it to say that skill effect was found for real and random games; however, no effect (and really bad performance; below 20%) was found in random illegal games. Campitelli (1999) showed a sequence of opening-moves, but he tested memory for the position and not the sequence.

In chapter 7 (section 7.3), memory for move sequences was tested in three conditions: move sequences of a chess game, of a draughts game and of a GO-like game. To anticipate, a skill effect was found for memory of move sequences, and interestingly, it was higher for the least chess-related tasks—GO.

2.3.1.3. Expert thinking

Expertise in science and chess are strongly related to expert thinking. The tradition of studying thinking by problem-solving situations started with the behaviouristic and Gestalt schools at the beginning of last century. Behaviourism and Gestalt psychology studied problem solving behaviour from different approaches. Thorndike (1911)—main contender of behaviourism—studied problem solving with cats and developed a series of rules of learning from his studies. Gestalt psychology, strongly opposed to behaviourism, was more interested in internal aspects of problem solving (e.g., Kohler (1917/1957) studying monkeys; Duncker (1945) in humans). They proposed concepts like restructuration and functional fixation; however, the features of the internal processes were not defined. Selz (1924) proposed a model of thought processes. He suggested that thinking processes are determined by the "intelectual personality" of the person, her/his subjective perception of the features of the problem, and her/his motivation to perform the task. De Groot (1946) took Selz as his mentor, and realised a think aloud protocol analysis of chess grandmasters. Newell and Simon (1972) gave the first analysis of thinking processes in terms of information processing, using think-aloud protocols of participants solving chess problems and other types of problems. The relation of the last two studies with chess is apparent. Now, the direct analysis of thinking in chess is to be carried out.

Expert thinking in chess

A review of this topic can be found in Holding (1985) and Gobet et al. (in press). DeGroot (1946/1978) investigated the think aloud protocols of players ranging from very strong grandmasters (some of them world champions), to class level players. He analysed in depth the qualitative factors of the results and gave less importance to the quantitative aspects. Gobet et al. (in press) provide a review of both factors, giving the same importance as De Groot. In this thesis more importance is given to the quantitative components of problem solving; consequently, only the latter are reviewed in this section.

De Groot's participants were presented with a chess position displayed on a chessboard. The experimenter asked the subjects to analyse the position, communicating their thoughts out loud until they decided which move they would play if they were playing a game. The most important finding was that, although grandmasters prevailed over the experts in terms of the quality of moves chosen, no differences were found in the macro-structure of the protocols. That is, number of moves visited, depth of search, and speed of search (number of moves per minute)—among other variables—remained constant across the different levels of players.

Wagner and Scurrah (1971), Newell and Simon (1972), and Holding (1985) carried out the same reconstruction task used by De Groot's (1946/1978) with only one player (the first two employed one of the positions used by DeGroot). Accordingly, they were not interested in the comparison between masters and weaker players, but they analysed the protocols in order to put forward theories of information processing.

Charness (1981) submitted a number of players of varying levels of skill, ranging from class D to class A, to the same task as DeGroot's (1946/1978) in four different positions. Once again, Charness found that the quality of moves was a function of chess skill. Unlike DeGroot, he did find a slight but a significant difference in depth of search in terms of chess skill (1.5 plies depth increase per standard deviation increment in rating). Moreover, total moves analysed, number of episodes and number of branches differed in terms of skill, the better the players the higher the figures.

Finally, Gobet (1998b) reused De Groot's popular position A (as Wagner & Scurrah, 1971 and Newell & Simon, 1972). In this case a number of players of different levels (ranging from international masters to class B players) went through the same procedure. Once again, quality of moves varied across skill levels. Unlike De Groot (1946/1978) and in agreement with Charness (1981), mean depth of search varied across levels of expertise; however, the difference was rather low (i.e., 0.6 plies per standard deviation in chess rating).

It is worth noting that De Groot (1946/1978) took notes of the think aloud protocols of the players, whereas in all the other studies, tape recorders were used in order to obtain the data. This difference may be the cause of the lesser absolute number of nodes, branches, episodes, etc in De Groot's study in comparison with all the other studies.

In a different approach, Calderwood, Klein and Crandall (1988) and Gobet and Simon (1996c) investigated the role of reflection time at the skill level. They showed that when thinking time is reduced, the skill level of masters (including the world champion) decreases only slightly. The researchers suggested that this is evidence in favour of the strong influence of pattern recognition processes. Charness et al. (2001) showed that experts were faster at solving a simple chess problem. They also measured eye movements and found that experts performed less eye fixations than the intermediate players.

In chapter 8 several of these issues are tackled. By using thinking-aloud protocols, depth of search, speed of search and quantity of information generated were the variables investigated. The results are not in agreement with the literature just reviewed; in short, all the variables were found linearly related to chess rating (see section 8.3). Regarding short reflection times, a 10 seconds problem-solving task was used. There was a skill effect, and the differences were not explained by differences in a simple reaction time. However, within the master level, a relation between simple reaction times and performance in a quick problem solving task may exist.

2.3.2. Brain level

In this sub-section two research fields will be reviewed. They correspond to the experiments presented in chapters 9 and 10. One of this work's theses is that chess is a versatile and powerful task environment to investigate psychological phenomena. The emergence of brain imaging techniques opens a new area of research, and there are only a handful of brain imaging studies in chess. Indeed, when this study began, there was not any functional magnetic resonance imaging (fMRI) study in chess published. In fact, the experiments presented in chapter 10 are the first ones comparing experts and novices using fMRI. Thus, one of the reasons of these experiments was to extend the use of chess as a research task using a new technique.

Chapter 10 focused on comparisons between chess players and non-players in memory tasks. A review of studies with experts, chess players and practice studies is presented in the next sub-section (2.3.2.1). Chapter 9 has a different rationale than the other experimental chapters. Instead of emphasising the difference between different levels of expertise, chess was used as a tool to study autobiographical memory. A review of this topic is presented in sub-section 2.3.2.2.

2.3.2.1. Brain imaging of expertise

In this sub-section, a review is carried out of brain imaging studies in expertise (section 2.3.2.1.1) and practice (2.3.2.1.2). Within the first section, studies with chess players and other experts are considered. In the case of chess, not only the high-spatial resolution brain imaging studies are examined, but also studies with patients and EEGs are taken into account. This review is an introduction to the two fMRI studies with chess players presented in chapter 9.

2.3.2.1.1. Brain imaging in expertise.

Chess players

EEGs and brain lesions.

Cranberg and Albert (1988) reviewed a series of EEG (electroencephalogram) studies with chess players and brain lesions. For example, Malkin (1982) recorded EEGs of strong grandmasters - including a world champion - prior to their games, showing completely normal patterns. In another study, Cranberg and Albert presented data of a chess master playing a blindfold game showing higher frequencies (beta range) in the right hemisphere in comparison with those of the left hemisphere (alpha range) when the position was quiet. However, when the master had to analyse a number of variations and he reported use of a sub-vocalisation strategy (e.g. " if he goes there, I reply like this, and then he...") the pattern of the left hemisphere resembled that of the right one. However, another chess player in the same situation did not show differences between hemispheres. In the same book chapter, Cranberg and Albert presented data of players that suffered brain lesions. They tried to test their theory of right hemisphere specialisation in chess playing. Their data suggest that relatively large lesions in the left-hemisphere did not impair chess skill. Nonetheless, these data should be considered cautiously inasmuch as no extended right hemisphere lesion was reported, and the assessment of the chess skill was not very accurate.

In a more recent study, Volke et al. (2002) performed an EEG study with chess experts and novices, carrying out simple tasks with chess stimuli. In the more complex tasks (i.e. check detection, check mate judgement, and mating in one) the experts showed a more posterior pattern of brain activity, whereas the novices showed a higher activation in frontal areas. Moreover, chess players displayed a greater coherence on their EEG signals.

Brain imaging (high spatial resolution).

Only four brain imaging studies have been carried out with chess players until now. Additionally, an fMRI study with GO players is included in this section. A number of techniques were used in the studies (SPECT, PET, gamma bursts, and fMRI). Nichelli et al. (1994) pioneered in this field conducting a PET study with ten chess players (the level of the players is only vaguely reported). They applied the hierarchy cognitive subtraction method, in which they used four conditions (black and white discrimination, spatial discrimination, rule retrieval and checkmate judgement). They found bilateral activations in medial and lateral posterior parietal and superior occipital cortices (Brodmann areas 7 and 19) in two of their subtractions. When retrieval of rules was required, they found activations in the inferior, lateral and medial parts of the left temporal lobe including the hippocampus.

Onofrj et al (1995) carried out a SPECT study with 5 players (1 master, 2 experts and 2 Class A level players). The participants had to solve a problem blindfold (i.e. they first saw a chess position in which there was a winning combination and then they searched for the winning combination without looking at the position). They found activation in non-dominant dorsal frontal and middle temporal lobes in all of the players.

Amizdic et al. (2001) conducted a gamma-bursts study with 20 chess players. The range was from Class B players to grandmasters. The tasks consisted in playing a chess game against a computer, and the subjects were scanned 5 seconds after the computer made its move. They found a pronounced activity in medial temporal structures (i.e. perirhinal, entorhinal cortex and hippocampus) in amateur players –but not in masters- relative to the activation in parietal and frontal areas.

Atherton et al. (2003) carried out an fMRI study with novice chess players. The participants performed two conditions: 'game', in which a normal chess position was presented, and 'random', in which the pieces of a chess position were randomly distributed throughout the board and were also transposed to the edges of the squares. In the game condition, the task consisted in determining the next best move for white, and in the random condition, the players were asked to search and identify the pieces that were previously marked with a low contrast embedded five-pointed star. Also, there was a resting session in which an empty board was presented and participants looked at the centre of it. In the game > random contrast, a large area was bilaterally activated, including Brodmann areas (BA) 7, 19, 39 and

40 in posterior parietal areas, superior occipital gyrus, supramarginal gyrus and inferior parietal lobe. Furthermore, some frontal areas (BA 6, 8 and 9) were active in the left hemisphere.

Chen et al. (2003) present a GO fMRI study that was a twin of Atherton et al.'s (2003) study. Chen et al. carried out exactly the same design as Atherton et al., using GO stimuli and GO players rather than chess stimuli and players. Although the players were considered amateur, all of them possessed GO rating, giving the hint that their level was greater than that of the chess players. The pattern of results was similar to Atherton et al.'s. A posterior area in parieto-occipital regions was bilaterally activated (BA 7, 40, 19) and also a number of frontal areas (BA 9, 6, 4) and the somato-sensory cortex (BA 1, 2, 3). In addition, a posterior temporal area (BA 37) was activated.

Summing up, three of the studies used a problem solving task (Onofrj et al., 1995; Atherton et al., 2003; Chen et al., 2003). In one, participants played a chess game (Amizdic et al., 2001) and a series of simple tasks was carried out in Nichelli et al. (1994). Four out of 5 showed brain activity in posterior parietal regions, and four out of five found brain activity in a number of frontal regions. Unfortunately, the quality of the reports is not good; in some cases the level of the player is rather low (Nichelli et al., Atherton et al), other reports are very concise and some important details are missing (Nichelli et al, Amizdic et al.). For that reason, no strong conclusions could be drawn from this set of data. However, there was agreement in 80% of the studies in that chess playing or problem solving recruits a number of frontal and posterior parietal areas. It is well known that these areas are engaged in working memory processes (e.g. Goldman Rakic, 1998; Fuster, 1998; Duncan & Owen, 2000).

The prediction of Cranberg and Albert (1988) regarding the predominant involvement of the right hemisphere over the left hemisphere in chess was not supported by more powerful techniques.

Regarding experts vs novices contrasts, only two articles carried out such comparisons (Amizdic et al., and Volke et al.). Volke et al. (2002) uncovered that chess experts recruit more posterior areas of the brain, and they show more coherence in their EEG signal. Unfortunately, Amizdic et al. (2001) grouped together frontal and parietal activations, consequently it is not possible to compare the studies in that sense. Nonetheless, Amizdic et al. found a different pattern of brain activity in experts and novices; in short, the former recruited more frontal and parietal than temporal areas, and the latter displayed an equally distributed pattern of activation.

There are two lessons we can learn from this review of brain imaging studies with chess players: first, frontal and parietal areas are needed in order to solve chess problems and in order to play chess; second, the pattern of brain activity of chess experts differ from that of the novices. As we will see in chapter 10, these two findings were corroborated by the fMRI studies of the present thesis.

Other experts

Pesenti et al. (2001) compared a mental calculation expert to normal participants in mental calculations. They used calculations that could be retrieved from long-term memory as a baseline task, and they subtracted its activations from those of mental calculations that could not be retrieved from memory. They found activations that the expert and the normal subjects shared across the whole brain.

Moreover, they found areas activated only in the expert: left paracentral lobule, right middle occipito-temporal junction, right medial frontal gyrus, right anterior cingulate gyrus. The authors concluded that the acceleration of existing processes does not explain the results. Instead, expertise requires new processes relying on different brain areas. These new processes are shifting from strictly short-term, effort requiring storage strategies to highly efficient episodic memory encoding and retrieval strategies, application of automated resolution algorithms, and careful monitoring and control of these algorithmic resolution (see Chase & Ericsson, 1981; Pesenti et al, 1999).

Isabel Gauthier and her group realised a number of brain imaging studies with experts. Their interest in expertise comes from a controversy in the face-recognition field of research. Kanwisher et al (1998) and many other studies showed that there is an area in the fusiform gyrus (temporal lobe) which selectively activates when the participants recognise faces. This finding is quite robust, and was also found in monkeys (e.g. Heywood & Cowey, 1992). The natural explanation that different parts of the brain are specialised in the processing of different kinds of stimuli was challenged by Gauthier who follows Tanaka's (1993) ideas. Gauthier et al. (1999) suggest that the activation of the fusiform 'face' area is not specific to faces, but this develops with expertise. Since humans are experts at recognising human faces at the individual level, the activation in the fusiform 'face' area while humans recognise faces, is caused by the human capacity to differentiate faces at the individual level. Following this idea, this group submitted experts to brain imaging scans looking only at the fusiform gyrus.

Gauthier et al (2000) studied bird and car experts in memory tasks. They found more activation in the "fusiform face area" in car experts when they were presented with cars and in bird experts when they were shown bird stimuli. Gauthier et al. (1999) and Tarr and Gauthier (2000) trained subjects in recognising novel objects, which they called 'greebles'. They found increased activity in the fusiform gyrus when the participants were experts in recognising 'greebles' at the individual level. It is worth noting that the increase in brain activity occurs when the recognition is at the subordinate level. For instance, an expert can recognise a robin more categorically as a living object (superordinate level) or as a bird (ordinate level) or at a more individual level as a robin (subordinate level). Gauthier et al. (2000) investigated changes in brain activation of the fusiform 'face' area with participants that were trained in recognising novel objects called 'greebles'. The results followed the same pattern: experts showed increased activity in the fusiform face area when recognising greebles at a subordinate level.

Finally, Krings et al (2000) studied 4 piano players in a complex motor task. They compared them to 4 normal volunteers, focusing on 4 areas of the brain known to be activated in motor tasks: primary sensori-motor cortex, supplementary motor area, superior parietal areas, and premotor areas. They found a reduction in the activation in all the areas in the piano players. The researchers concluded that, due to long-term motor practice, manual dexterity increased in piano players; therefore, for the same movements, fewer neurons have to be activated.

2.3.2.1.2. Brain imaging related to practice

The rationale of this field is simple. First, volunteers go through a scanning section performing a task for which they are naïve. After this, they are trained in this task, and finally, they are scanned again. The pattern of activations obtained after training are compared to that of before training in order to know the effect of training over brain activity. Alternatively, volunteers go through training while they are scanned, and the comparison takes place between the first scans and the last ones; sometimes, there could be parametrical analysis of time and brain activity changes. An example of this kind of studies is the one explained above, that is, training 'greeble' experts. Those studies were included in the previous section because participants acquired expertise level for the authors. Nonetheless, they could also be part of the present section.

Van Horn et al. (1998) asked participants to find the correct pathway through a maze while they were being scanned. In order to do this, they had to try and err at the beginning and learn with the feedback provided. In the first scans, participants showed a frontal lobe pattern of activations with less activity in posterior areas. In the last scans –when the subjects were performing the task almost perfectly- the activation in the frontal lobes almost disappeared and a pattern of posterior areas emerged. Particularly noteworthy is the activation in bilateral precunei and posterior cingulate.

Kassubek et al. (2001) scanned subjects before and after training of a mirror reading task. They measured the activations obtained during mirror reading as well as those of a normal reading task. Brodmann areas 6 (frontal eye field and supplementary eye field), 7 (superior parietal lobule including right precuneus) and 40 (inferior parietal lobule) showed greater activation in the mirror reading task in comparison with that of the normal reading task before training. After training, there was a reduction in activation in areas 6 and 7, but not in 40, in the mirror reading task in comparison to normal reading. The authors proposed that the reduction in BA6 was due to a decrease in the effort and precision of gaze fixation and saccadic scanning. Moreover, the reduction in BA7 suggested an increase in the efficiency of specialised mental transformation processes, which led to a reduction in the effort and time required to decode mirror-reversed letters and to hold them in visuospatial working memory.

Berman et al. (1995) scanned volunteers before and after training of the Wisconsin card sorting test. The pattern of activations included areas in the frontal, parietal, temporal and occipital lobes. Somehow surprisingly, the pattern did not change after training.

Jansma et al. (2001) submitted participants to the Sternberg's item recognition paradigm in which a target set of consonants is followed by individual consonants presented sequentially. The task consisted of deciding whether the current consonant belonged to the target set or not. There were two conditions of interest. In the trained condition, the subjects were presented with the same target set during the whole experimental session within the scanner. The participants had previously gone through a period of practice with the same target set. In the novel condition the subjects were presented with a new target set. Jansma et al. compared the brain activity of the trained condition with that of the novel condition. They found a reduction of brain activity in bilateral dorsolateral prefrontal cortex, right frontal pole and right superior parietal cortex; all those areas had been previously selected by the researchers because they are thought to be 'working-memory areas'.

Weissman et al. (2002) trained participants to direct their attention to either local or global aspects of the stimuli. When the practice coincided with the task the participants had to perform, there was a reduction of neural activity in left inferior parietal lobe, whereas when the practice led to a conflict between the previously practised and the current task there was an increase of brain activity in medial frontal regions. Weissman et al.'s explanation of the results is that practice strengthens schemas.

Petersson et al. (1999) scanned participants in novel and a pre-learned recall tasks. The subjects had to recall either a well-learned design or a novel one. They found practised related decrease of neural activity in prefrontal, anterior cingulate, posterior parietal and medial temporal regions. Petersson et al. explain the results in terms of automaticity. Practice causes a decrease of dependence on attentional and working memory processes. They also found an increase in superior temporal and supramarginal gyrus and in the right mid-occipito-temporal region in well learned designs. The researchers believe that the superior temporal and supramarginal gyrus activation is due to a lower degree of attentional suppression of task irrelevant components, whereas the increase in right mid-occipito-temporal areas may be related to more fully developed representations of the design.

2.3.2.2. Autobiographical memory

As specified earlier, in chapter 9 the emphasis was not on expertise but on using chess as a task environment in order to elucidate a psychological phenomenon. There are several problems to carry out brain imaging studies in the field of autobiographical memory. Chapter 9 shows a methodology to deal with these problems. In this review, chapter theoretical views and empirical studies of autobiographical memory will be considered.

Research into autobiographical memory started with Galton (1883) who developed a technique that is still broadly used. This entails presenting a participant with a cue word, and asking her/him for the retrieval of some personal memory related to the cue word. This technique was used in one of the brain imaging studies reviewed in this section (Conway et al., 1999). More structured techniques were developed such as the autobiographical memory schedule (Kopelman, Wilson & Badeley, 1989) and single case studies (e.g., Linton, 1975; Wagenaar, 1986). Extensive reviews can be found in Baddeley (1990) and Conway and Pleydel-Pearce (2000).

Autobiographical memory is a topic investigated in several sub-fields of psychology such as cognitive psychology (e.g. Conway, 1990), personality (Mikulincer, 1998), developmental psychology (Howe & Courage, 1997), and neuropsychology (Conway & Gthenaki, 2000). Conway and Pleydell-Pearce (2000) presented a model of autobiographical memory that encompasses the knowledge obtained in different fields of research. They proposed that autobiographical memories are transitory mental constructions within a self-memory system (SMS). The SMS is composed of two structures: a knowledge base and a working self. The system only works when the two structures are linked and both structures can also work independently.

Conway and Pleydell-Pearce propose that the knowledge base is hierarchically organised according to three types of information: lifetime periods, general events, and event-specific knowledge (ESK). For instance, in the memory: " *When I was twenty years old I was studying philosophy at Cambridge. I can perfectly remember Professor X lectures. One day, he came with a pink jacket...*" the expression "when I was twenty years old" gives information of the lifetime period, "Professor X lectures" indicates a general event within the lifetime period, and "pink jacket" is an ESK of the general event. The last one is information of the perceptual characteristics of the memory (in this case visual, but information of any sense could be encoded). Conversely, lifetime period and general event information are more abstract and they are not related to the type of sensory information encoded during the acquisition of the memory.

The other component of the SMS is the working self. Conway and Pleydell-Pearce introduced this term, explicitly linking it to the working memory concept developed by Baddeley (1986). Its function is to coordinate and to modulate computationally separate systems. The working self has a goal structure that restrain cognition and behaviour and that have a critical role in encoding and retrieving autobiographical memories into and from the knowledge base.

An autobiographical memory could be retrieved in two ways: generative retrieval and direct retrieval. In generative retrieval, the working self accomplishes a vital role. The generative retrieval concept was derived from Norman and Bobrow (1979) and consists of a number of stages. First, the elaboration of a cue with which to begin the searching for a memory and the simultaneous establishment of verification criteria, which form the retrieval model (working self goal). Second, the memory description (i.e., the cue) triggers the activation of nodes of the autobiographical knowledge base. These nodes become automatically available to control processes and are constantly evaluated in terms of the verification criteria. When the evaluation is satisfactory (i.e., is compatible with working self goals), a stable pattern is formed in the knowledge base, and the searching ceases. Conversely, in direct retrieval no cue elaboration or search phases occur. This type of retrieval occurs when a an ESK existent in the autobiographical knowledge base is directly presented to the rememberer. Therefore, the working-self does not play an important role in this type of retrieval.

Another important theoretical conceptualisation was put forward by Maguire and Mummery (1999) who proposed that in the classification of memories into impersonal facts—semantic memory—and personal events with specific temporal context—episodic memory— (Tulving, 1983) the temporal context and the personal relevance of the memories are two factors that are unconfounded. Therefore, Maguire and Mummery proposed four types of memories: general knowledge (no personal-relevant, no temporal context), autobiographical facts (personal relevant, no temporal context), public events (no personal relevant, temporal context), and autobiographical events (personal relevant and temporal context) in order to unconfound the two factors: personal relevance, and temporal context.

Conway and Pleydell-Pearce (2000) give some information about the brain locations of the SMS. They propose that the goals of the working self are located in the frontal and anterior temporal regions (specifically, in the left hemisphere), the retrieval model is formed in the right frontal lobe, and the autobiographical knowledge base is situated in posterior networks (primarily in the right hemisphere). The abstract lifetime period knowledge is stored in the right frontal lobe, knowledge of general events in the temporal lobes and ESK in occipito-parietal networks. Additionally, they suggest that when a memory is generated, its maintenance in awareness requires the activation of right frontal, posterior temporal and occipital sites.

2.3.2.2.1 Brain imaging studies in autobiographical memory.

Although autobiographical memory has been extensively studied in many domains of psychology, only a handful of brain imaging studies have been carried out. Fink et al. (1996) carried out a PET study with three conditions: 'Personal', 'impersonal' and 'control'. In the first conditions, participants were aurally presented with a sentence related to an event of their own lives and they were instructed to imagine what happened to themselves in the described situation. The information of the life events was obtained in a semi-standarised interview carried out weeks before the scanner. In the interview questions about childhood, adolescence and early adulthood were asked. The impersonal sentences referred to a person the participants had met 1 hour before the scanner, where they had to imagine what happened next to that person. In the control condition, the subjects remained with their eyes closed. As expected, the impersonal > control contrast showed bilateral activation of temporal areas related to speech processing. The personal > impersonal contrast displayed a right lateralised pattern of activations in medial and lateral aspects of the temporal lobe (including, hippocampal, parahippocampal, and amygdaloid regions), anterior insula, posterior cingulate, temporo-parietal junction and prefrontal cortex.

Conway et al. (1999) undertook a PET study containing an autobiographical memory condition and a paired-associate recall task as control. For the first condition participants were trained to recall an event of their own lives after the visual presentation of a word before the scanning session. During the scanning session, they were presented with those words and they were asked to report as much detail as possible of the episode. Participants were also requested to respond with a word that in the future would allow them to retrieve the situation that they remembered during the scanning session. The age of the memories was also manipulated. The participants were asked to generate less than 12 months' old memories in the recent condition and memories before they were 15 years old in the remote condition (the average age of the participants was 31). In the control task, the participants learnt a list of word pairs before the scanning session, and during the experiment, they were presented with a word of the list and they were asked to provide the word corresponding to the same pair. Unlike the Fink et al. (1996) study, Conway et al. (1999) found a left hemisphere pattern of activations when they subtracted the activation of the control task from that of the autobiographical memory condition. They found activation on frontal areas BA 45, BA 47, BA6 and BA9, as well as in the parieto-occipito-temporal junction (BA 39). When they compared recent memories with remote memories no effect was found in either direction.

Conway et al. (2001) performed a slow cortical potential study of autobiographical memory similar to the one reported above. The high temporal resolution of this technique allowed the researchers to investigate the timing of the formation of the memories. They found that the generation of an autobiographical memory starts on the left frontal lobe and afterwards the activation was apparent in posterior temporal and occipital areas, mainly in the right hemisphere.

Maguire and Mummery (1999) performed a PET study. They manipulated the temporal context and the personal relevance of the memories as explained above. An interview before the experiment was carried out and information of the participants' lives were obtained in order to generate statements of those four types of memories that ranged from 2 weeks to 20 years of age. The task consisted of a truth judgement of the statements. When all the tasks were compared to a control task in which the participants listened to a disorganised sentence - like Conway et al. (1999) - Maguire and Mummery found a left hemisphere pattern of activations. This pattern included medial pre-frontal areas (BA 10), anterior lateral middle temporal gyrus (BA 21), temporal pole (BA 38), hippocampus and parahippocampal gyrus (BA 28/36), posterior cingulate (BA 31) and occipito-temporo-parietal junction (BA 39). In the contrast personal relevant memories > no-personal relevant memories the following areas were activated: frontal cortex (BA 10), the temporal pole (BA 38), and the occipito-temporo-parietal junction (BA 39).

Age of autobiographical memories

Niki and Luo (2002) followed Conway et al.'s (1999) investigation of the age of autobiographical memories in an fMRI study. One or two days previous to the scanning session, the participants provided a list of places that they visited 7 years before the experiment and other places that they visited 2 years or less previous to the scanning session with landmarks present in the place. Within the scanner, the participants were presented with either the name of the place, or landmarks present in the place and they were required to recall the experience of visiting the place. The main interest of the researchers was to assess the differential role of the medial temporal lobes in remote and recent memories. They found more activation in this area for recent memories, but also many other areas were activated, specially the left medial occipital gyrus (lingual gyrus, BA 18). In the opposite contrast (i.e., remote > recent memories), the major area was the left frontal lobe (local maxima at BA 10). This finding contrasts with Stark and Squire (2000) study, in which no differences were found in the medial temporal lobe between recent and remote memories (although, no autobiographical memories were used). However, in the last study shorter time windows were used (1 week, 1 day and 1 half hour before the scanning session).

Maguire et al. (2001) did not find differential activity in the hippocampus, but they found a parametric increase activity in the right ventro-lateral prefrontal cortex for recent memories. In this study, the memories were collected in an interview and ranged from 20 years' old memories to two weeks of age memories. Finally, as stated above, Conway et al. (1999) did not find differences in brain activity between remote and recent memories.

The study carried out in this thesis (see chapter 9) used two chess masters as participants. This study involves a new methodology in studying autobiographical memory which does not require a previous interview, and the experimenter has great control over the generation of memories. Furthermore, the ecological validity of the autobiographical memory field is in no way lost.

2.4. Summary

The extensive review of literature presented in this chapter is a necessary basis for the experimental chapters. How does this review leave the three theses stated in the introduction? Regarding the versatility and power of chess, the review shows that chess is a flexible tool that offers the possibility to study several psychological phenomena, and several influential theories in cognitive psychology originated directly or indirectly from studies related to chess. However, the use of chess in brain imaging did not show a clear pattern of results, and some of the studies had several weaknesses. Therefore, it is important to investigate further the use of chess as a task environment in brain imaging studies (fMRI in this thesis) using adequate experimental designs.

The second thesis stated that extended practice is a necessary, but not a sufficient, condition to reach high levels of expertise. The review showed that there is a strong controversy. Some researchers state that deliberate practice is a necessary and a sufficient condition to achieve high levels of expert performance, and others indicate that innate talent is essential. Previous studies investigated either the role of practice or they looked for innate talents. In this thesis a less extreme position is adopted, and both aspects are considered.

The third thesis expressed the idea that there are factors not related to practice that influence the attainment of expert performance. No experimental evidence of the existence of any of these factors was found in the literature. However, lack of evidence does not mean evidence of lack. In this thesis, a search for cognitive processes in which individual differences may exist, was implemented.

Before starting with the experimental chapters, in the next one some methodological issues will be considered. In particular, functional magnetic resonance imaging (fMRI) will be extensively discussed.

CHAPTER 3

Methods

In this thesis a variety of techniques were used in order to collect data. These included standard behavioural experiments, questionnaires, eye-movement recording, and functional magnetic imaging. Additionally, not only the standard psychological paradigm of comparing the performance of two groups was used, but also a relatively novel methodology was used (i.e., the cross-tasks study in chapters 6, 7 and 8).

In this chapter I will describe the fMRI apparatus and the rationale of this technique, the eye-tracking apparatus and the cross-tasks paradigm. fMRI, due to its complexity, covers more than two thirds of the chapter. Other methodological issues are discussed in the methodological section of each experimental chapter.

3.1. Functional magnetic resonance imaging (fMRI)

Three fMRI experiments were carried out, and they are presented in chapters 9 and 10. In this section the foundations of the technique are explained, and issues that apply to all the fMRI experiments are reviewed. The design of each experiment is detailed in chapters 9 and 10.

3.1.1. Foundations

Functional MRI affords the possibility to map brain activity while a participant is performing a particular task. However, it is paramount to mention that fMRI does not measure brain activity directly. Instead the fMRI signal is the consequence of a difference in oxygen consumption and blood flow that occurs during the task. This signal is called the blood oxygen level dependent (BOLD) signal. Since the ultimate goal is to measure neuronal activity and not blood flow, there are several studies that compare BOLD signal with more direct measures of neuronal activity such as single and multi unit spiking activity (Logothetis, Pauls, Augath, Trinath & Oeltherman, 2001; see sub-section 3.1.1.2.2). The relevance of fMRI is that, whilst sacrificing temporal resolution, it provides excellent spatial resolution which allows one to determine with high accuracy what anatomical areas are active. The physical basis of magnetic resonance imaging (MRI) will be explained, and several issues related to fMRI will be discussed.

3.1.1.1. Physical principles of MRI

An MRI image of biological tissue is obtained as follows. Some atomic nuclei such as the hydrogen nucleus are spinning charged particles with their own magnetic field. When a biological tissue containing hydrogen is exposed to a strong magnetic field (such as the MR scanner) the hydrogen nuclei change their orientation (outside the magnetic field the orientation is random) with respect to the strong magnetic field. A radio-frequency (RF) coil generates a brief RF gradient— which generates a second magnetic field orthogonal to the scanner magnetic field— that changes the orientation of the hydrogen nuclei away from the scanner magnetic field. Following this excitation, the hydrogen nuclei return to the orientation towards the scanner magnetic field. There are two relaxation rates - T1 and T2. The first one indicates the time needed to recover the orientation longitudinal to the scanner magnetic field, and T2 is the time taken to decay in the plane perpendicular to the scanner magnetic field. These two values vary according to the water composition of different tissues. When the hydrogen nuclei return to the scanner magnetic field orientation, RF energy is released and detected by an antenna surrounding the brain (see Frackowiak et al, 1997, chapter 18). Relaxation time (T1) depends on the type of tissue containing the relevant water molecules. For instance, in cerebrospinal fluid, which is close to pure water, protons relaxation time is about 3 seconds, but in white matter, the T1 is about 0.5 seconds. Two other parameters to take into account are T1* and T2* which are T1 and T2 with inflow (i.e., relaxation times when blood flow increases to the area; see Chen & Ogawa, 1999).

An important issue that it is vital to understand in fMRI is that deoxyhemoglobin contains a paramagnetic iron. Therefore its magnetic susceptibility is higher than that of oxyhemoglobin which does not contain it. This magnetic property generates an increase in the local inhomogeneity of the magnetic field. This produces a quick decay of RF energy, therefore a decreased magnetic resonance signal (D'Esposito, Zarahn & Aguirre, 1999). In the resting state of the brain there is a coupling between cerebral blood flow (CBF) and the cerebral metabolic rate of oxygen consumption ($CMRO_2$) (Siesjo, 1978). When elevated neuronal activity occurs, there is an uncoupling of CBF and $CMRO_2$, the latter being smaller than the former, therefore increasing oxyhemoglobin levels and the BOLD signal. The increase in CMR_{O2} is 0 to 5% and the CBF increase is 40 to

51% during functional activation elevated by visual and somatosensory stimuli (Fox et al, 1988, Fox and Raichle, 1986, Ribeiro et al., 1993)

In the fMRI experiments of this thesis the images used were T2* weighted EPI (Echo planar imaging) images. EPI is a method which is used to form a complete image from a single data sample, or a single "shot", which allows collecting one image in 40-150 ms. The images are T2* 'weighted' because BOLD fMRI has not absolute interpretation, it is not exactly a measure of deoxyhemoglobin concentration, but is a measure that is weighted by this concentration (T2* weighted) (Aguirre & D'Esposito, 1999).

3.1.1.2. Physiological basis of fMRI

Glucose is the energy source for the brain. Whereas the brain weight is only the 2% of the total body weight, it consumes 25% of the total body glucose utilisation (Magistretti & Pellerin, 1999). When a brain event occurs an increase is detected in cerebral blood flow in the area in which this event happens. However, not all the oxygen brought to the area is immediately utilised. This fact produces a change in the ratio between oxy- and deoxyhemoglobin, thus producing a detectable fMRI signal (Ogawa et al., 1990). With the increase of blood flow, the concentration of deoxyhemoglobin decreases (therefore relative concentration of oxyhemoglobin increases), because of the presence of oxygen which is not consumed. This fact decreases the RF decay rate and therefore it produces an increase in the fMRI signal.

3.1.1.2.1. Hemodynamic response function (HRF)

In most of the blocked designs (the design used in this experiment; see sub-section 3.1.2.1.1) the HRF is convolved to a box-car function in order to model the data (see sub-section 3.1.3.3.5). HRF is the function that describes the behaviour of the BOLD signal when a neuronal event occurs.

When neuronal activity starts due to a brief period of visual stimulation or motor activity (e.g., finger tapping for 2 seconds), the BOLD signal in the visual and the motor cortices respectively changes. The BOLD signal starts increasing approximately 2 seconds after stimulus onset (some laboratories observed an initial dip in the BOLD signal lasting from 500 ms (Henning et al., 1995) to 2 seconds (Hu et al., 1997; Menon et al, 1995)) reaching the peak of activation after 4 to 6 seconds and returning to baseline after approximately 10 seconds. In visual cortex—more than in motor cortex—a post-undershoot has been found, the timing depending on stimulus duration (Davis et al., 1994, see Bandettini, 1999 for a more detailed explanation).

HRF is also used as a low-pass filter, which eliminates the high frequencies of the BOLD signal. The advantage of using HRF as a low-pass filter is that the statistical power of the experiment increases. The disadvantage is that reduces the temporal resolution. The higher the frequency of the paradigm the less efficiently the variance of the task will be passed into the BOLD signal.

3.1.1.2.2. Relation of the BOLD signal with physiological measures

Provided the BOLD signal is not a direct measure of neuronal activity, it is important to compare this signal with more direct measures of neuronal activation such as local field potentials (LFPs), which measure synaptic activity, and multi unit spiking activity (MUA), which is electrical activity of neurons. Logothetis et al. (2001) showed several important issues. First, LFPs contribute to BOLD signal more than MUA, therefore fMRI signal might reflect the incoming input and local processing in a particular area and not spiking activity which is thought to reflect the output of the area. Second, there is linear relationship between the BOLD and the magnitude of neural signal (i.e., LFPs).

3.1.2. Methodological issues

3.1.2.1. Design

The sluggishness of the BOLD signal puts some constraints on the type of experiments that it is possible to carry out. Here, two of the most frequently used methodological techniques will be explained, and it will be argued why one of these was chosen to be used in the series of experiments to the detriment of the other.

3.1.2.1.1. Blocked design paradigm

This is the prototypical fMRI design (Aguirre & D'Esposito, 1999). The rationale is quite simple: in the activation condition the cognitive process of interest is present as well as other cognitive processes of no interest; in a second control condition, all the non-interest processes are present but none of the processes of interest. The subtraction of the brain activity of the control condition from that of the activation condition gives the activity related to the cognitive process of interest. Additionally, more than one activation condition can be used. It is called 'blocked' because the unit of analysis is a block and not a trial; that is, there are several trials of the same type in a block. As mentioned in section 3.1.1.1, the HRF needs about 10 to 12 seconds to return to baseline. Therefore it is a good practice in a design to separate trials, having them 12 seconds from each other. This constraint makes a trial-based design time-consuming and there are health and ethical limits to the time that a volunteer can spend within a scanner. To solve this problem, a number of trials of the same type are put one after the other forming a block and separated by 12 seconds from another block of trials of different type.

There are several advantages and disadvantages with this type of design. The fact that trials are blocked does not allow one to randomise trials - a common practice in experimental psychology; therefore, the predictability of the trials within a block could be a confound. There are two assumptions in this design that are not always satisfied (Zarahn et al., 1999). First, 'pure insertion'; the addition of a new cognitive process to the control condition could produce an interaction, i. e., the activation due to the processes of no interest could change with the insertion of the new cognitive process. If this happens - thus, pure insertion does not hold - activity attributed to the processes of interest could be due to a non-interest process. The second assumption is linearity. It is assumed that the summation of the HRF generated by the different trials within a block is linear. This assumption does not always hold (Zarahn, 1999). Another problem of this design is that it is not possible to tease apart the activation from correct trials from that due to incorrect trials.

There are several advantages to a blocked design and there are situations in which the use of this paradigm is optimal. The most important feature of this design is that it has the strongest statistical power. If this design has the problem of detecting false positives (detecting activation where there is not), other paradigms have the problem of having false negatives (not detecting activation where it exists). The use of this paradigm is acceptable when the trials produce a homogeneous response (i.e., there are very few incorrect responses) and also for exploratory studies in which brain regions of interest are not well documented (see Aguirre & D'Esposito, 1999).

In the first two fMRI experiments of this thesis simple tasks were chosen in order to have homogeneous responses; therefore, avoiding the problem of having mixed correct and incorrect trials within blocks in most occasions. In pilot studies, this was the case, with subjects performing above 80%. Similar results were obtained in the actual fMRI studies (especially in the first study with a mean above 90% both in chess players and non-chess players).

The block design paradigm was chosen for a number of reasons. First, the use of a block design is desirable in an exploratory study in which regions of interest are not well documented in the literature. The shortage of studies in the field make my studies exploratory ones, therefore the choice of a blocked design is justified. Second, in a new field it is important to use a design with strong statistical power, such as the blocked design. Third, the homogeneity of the responses was obtained in a pilot study. Therefore, one of the problems of blocked designs was not present in my studies. Fourth, the main interest in these studies is not the exact location of particular processes but the general pattern of brain activity that they produce; therefore, the problem of false positives is alleviated.

3.1.2.1.2. Event related paradigm

The introduction of event-related designs in the late 90's (e.g., Dale & Buckner, 1997) was aimed at overcoming the difficulties of the blocked design. The rationale is to use the trial as a unit of analysis. It has been already pointed out that the HRF takes about 12 seconds to return to baseline; hence, a separation of this period is needed between trials, making the experiment very long.

Dale and Buckner (1997) considered the possibility of reducing the spacing between trials. In short spacing, the probability of detecting differences between the trial and the inter-trial interval is lower than that of the blocked designs; however, sensitivity in detecting differences between different types of trials increases because the assumption of linearity is optimally satisfied. Additionally, including some jittering in the timing of the inter-trial interval increases the sensitivity because the participants are not able to engage in anticipation processes. Another advantageous feature of event-related designs is the possibility of randomising trials and assessing the differential activity of correct and incorrect trials. However, the event-related designs are still not as powerful as the blocked designs. That is, differences in brain activity between conditions are more difficult to detect in event-related designs.

3.1.3. Data acquisition and processing

3.1.3.1. Apparatus

The three fMRI experiments were carried out at the University of Nottingham Magnetic Resonance Centre. The MRC is equipped with a 3 Tesla scanner developed in the Physics department with a TEM Nova Medical head-coil. The stimuli were presented on a screen that was placed at 220 cm in front of the volunteer. Participants wore prism goggles in order to see the stimuli.

3.1.3.2. Acquisition

In the three experiments, images of the whole brain were obtained. Twenty-two coronal slices were obtained at a rate of 136 ms each, hence the TR (time between the acquisition of one volume [the whole brain] and the following one) was 2,992 ms. the images were T2* weighted Echo-Planar images (EPIs). The size of the images was 64 x 64 voxels. The voxel size was 3 mm x 3 mm in-plane, and the slice thickness was 9 mm. At the end of the session, two types of anatomical images of higher resolution were obtained in order to plot the activations. Sixty-four (normal and inversion recovery) slices to cover the whole brain, instead of 22, were collected; hence, increasing the resolution. High-resolution images afford the possibility to observed in detail the sulci and gyri of the brain. The experimental paradigm started 12 seconds after the scanner started recording, in order to allow for magnetic saturation effects. The 4 volumes obtained during these 12 seconds were discarded.

3.1.3.3. Data analysis

The raw data obtained went through several steps of pre-processing before acquiring SPM format—which is a standard software package for carrying out the statistical fMRI analysis (see below). The software used for the pre-processing was developed by the Nottingham Magnetic Resonance Centre. This software allowed one to eliminate part of the ghost (i.e., shadows produced by the scanner signal not related to brain structures) from the raw images and to transform the coronal images into axial images which is needed to perform statistical analyses in SPM99.

The processing of the data was carried out with Statistical Parametric Mapping (SPM99, Wellcome Department of Cognitive Neurology, London, UK; Friston et al., 1995). Another piece of software utilised in the thesis and available on the Internet is the Talairach Daemon (Lancaster et al., 1997; http://www.mrc-cbu.cam.ac.uk/Imaging/) which was used to obtain Brodmann areas given Talairach coordinates as input (see figures 3.1 and 3.2 for lateral and a medial-sagital views of the brain with the Brodmann areas). Also a formula[1] provided by Mathew Brett on the website www.mrc-cbu.cam.ac.uk/Imaging (see also, Duncan et al., 2000) was used to transpose the Montreal Neurological Institute (MNI; Coscoso et al., 1997) coordinates provided by SPM99 to the Talairach and Tournoux (1988) atlas coordinates.

In the next sections the standard procedures of SPM will be explained. It is worth noting that all the participants' data underwent all the steps detailed below. SPM99 runs under Matlab (Mathworks Inc).

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[1] For the regions above the anterior commissure of the brain ($Z=>0$) the following formula was used: $X'= 0.9900X$,$Y'= 0.9688Y +0.0460Z$, $Z'= -0.0485Y +0.9189Z$. For the regions below the anterior commissure ($Z < 0$) the formula used was: $X'= 0.9900X$, $Y'= 0.9688Y -0.0420Z$, $Z'= -0.0485Y +0.8390Z$ (see figure 3.3 for the x, y, z axes).

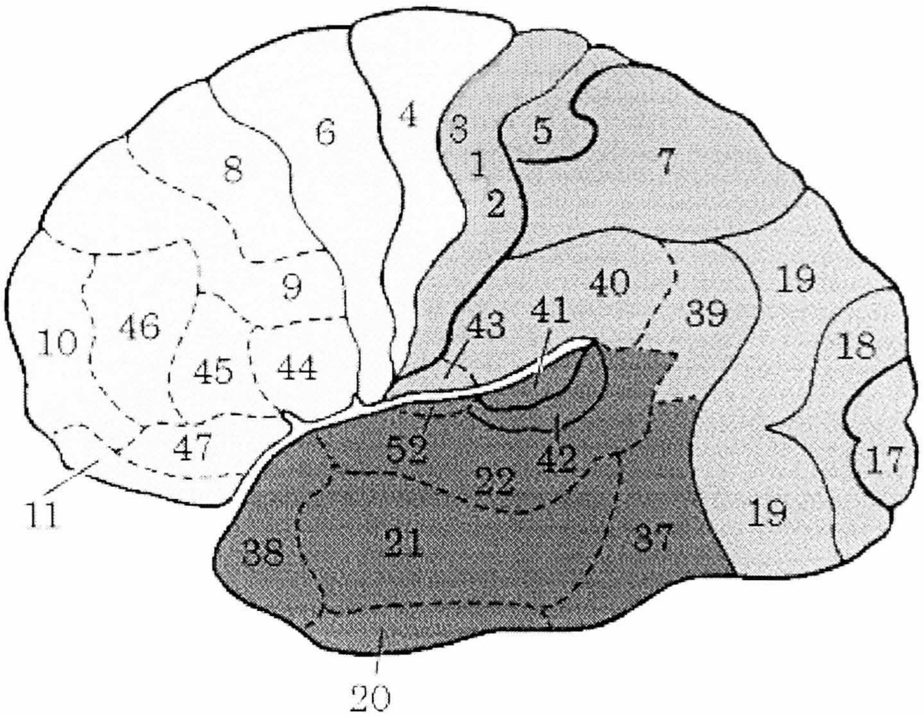

Figure 3.1. Lateral view of the brain with its Brodmann areas. Obtained from the website of the Cognitive Neuroscience Laboratory, University of Michigan (http://www.umich.edu/~cogneuro/jpg/Brodmann.html).

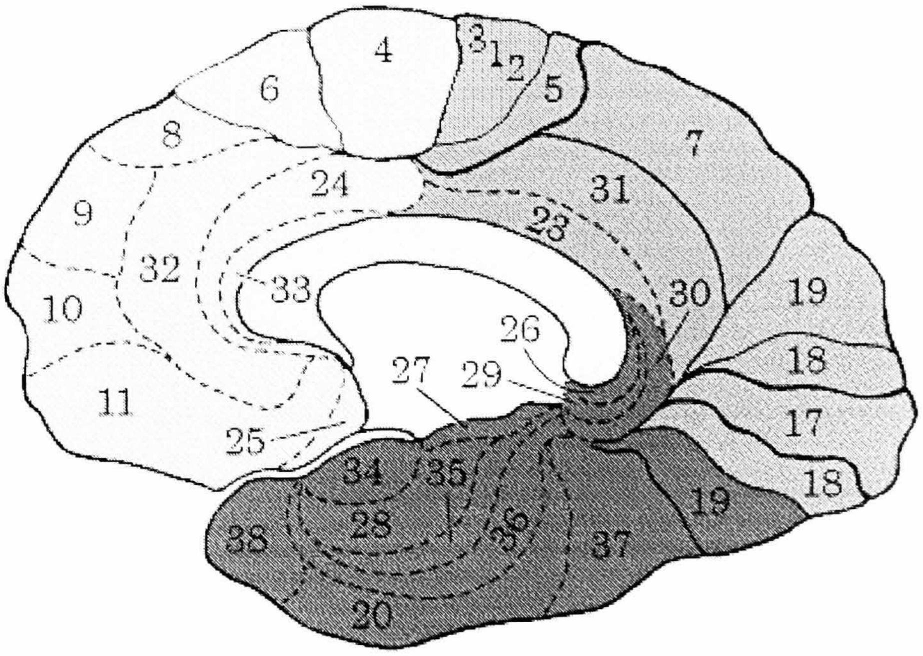

Figure 3.2. Medial sagittal view of the brain with its Brodmann areas. Obtained from the website of the Cognitive Neuroscience Laboratory, University of Michigan (http://www.umich.edu/~cogneuro/jpg/Brodmann.html).

3.1.3.3.1. Reorientation

When functional 3D brain volumes are in SPM format, the first standard procedure is to establish the location of the Anterior Commissure of the brain which will be the 0, 0, 0 in the x, y, z axes (x-axis is from left to right—negative numbers from the midline to the left—y-axis is back to front—negative numbers from the anterior commissure to the back—and z-axis is bottom to top—negative numbers from the line joining the anterior and posterior commissures to the bottom) and horizontally aligned with the posterior commissure.

This is achieved by rotating the image in any of the three axes (yaw, pitch, roll) and moving in any of the three directions (up-down, right-left, forward-backwards). When this is done, SPM is able to set the 0,0,0 origin to all the images and to rotate and translate them the same way as the first one.

3.1.3.3.2. Realignment

The second procedure is realignment. All the images are realigned to the first one. It also calculates the deviation of each of the volumes compared to the first one in terms of rotation and translation. A mean image is also generated, which will be used for the next steps.

In the three studies of this thesis, volunteers that translated their heads more than 5 mm in any of the directions or rotated their heads more than 5 degrees in any of the axes, were discarded and their data were not further analysed.

3.1.3.3.3. Spatial normalisation

In order to locate in which brain area the activation of each volunteer is present, it is necessary to standardise the individual brain volume into a template in which analysis of brain areas had been previously accomplished. Each volume was normalised to a standard EPI template volume (based on the Montreal National Institute reference brain; Cocosco et al., 1997) by transforming the mean image of each volunteer into a standard space.

3.1.3.3.4. Spatial Smoothing

The purpose of performing spatial smoothing is to increase the statistical power. Smoothing produces a loss in spatial resolution; therefore, the bigger the smoothing kernel used the higher the probability in detecting a significant effect, but the coarser the spatial resolution. Smoothing with an 8 mm x 8 mm x 8 mm Gaussian kernel is the standard procedure for group comparisons.

3.1.3.3.5. Specification and estimation of model

In the specification of the model, the researcher has to input a range of data into SPM99.These data are: TR, number of volumes in the entire session, number of conditions, a vector indicating the starting point (in scans or volumes) of each block for each condition, the duration of each block (in scans), the type of design (e.g., blocked or event-related), function to model the design (e.g., boxcar function convolved or not convolved with hemodynamic response function). The output of this procedure is a design matrix with one column per condition indicating which volume corresponds to which condition. With this matrix SPM99 calculates the statistics for each column. All the statistics used are special cases of the general linear model (GLM),

$$Y=BX+e \tag{1}$$

where Y is a matrix of the brain activity for each voxel at a particular time, X is the design matrix for each voxel, B is the parameter obtained for each voxel, and e the error for each voxel. The first step of analysis is to test for each voxel and for each condition the null hypothesis that there is no effect. The outcome of this procedure is a map of statistically significant voxels.

Before doing this, the researcher has to set a high-pass temporal filter (that is, only variations at frequencies higher than the threshold will be taken into account) which in my experiments was established using the default (2*number of scans per cycle*TR) and a low-pass temporal filter (the hemodynamic response function was chosen).

The second statistical procedure is to perform t tests between the conditions. This procedure has as its output a map of voxels with t values (or z values)[2]. In this process it is important to establish the statistical threshold. For that purpose it is important to consider that a great number of comparisons are carried out, and that, by chance, several significant activations can be false positives. To solve this problem of multiple comparisons, the solution adopted in this thesis' experiments is the Bonferroni correction (Friston et al., 1995) in which the threshold p value of .05 is divided by the number of voxels. In one of the contrasts of experiment 3, a less stringent value of $p=.001$ overall was adopted.

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[2] In fMRI the contrast between conditions are usually referred as condition A > condition B, which shows the voxels that remain activated when the activation due to condition B is subtracted from that of condition A. The opposite contrast, condition A < condition B means the voxels that remain activated when the activation of condition A is subtracted from that of condition B.

3.1.3.3.6. Post-processing

Once the clusters of activation of the different contrasts with their respective coordinates were obtained using SPM99, the coordinates were transformed from the Montreal Neurological Institute (MNI) coordinates provided by SPM to the Talairach and Tournoux (1988) atlas stereotaxic system. This process was carried out using the formula provided by Mathew Brett (see sub-section 3.1.3.3). The purpose of this process is that Talairach and Tournoux is the only atlas classified in terms of Brodmann areas. The Brodmann areas were obtained by the Talairach Daemon software (see sub-section 3.1.3.3) or by visual consultation of the atlas when the software did not provide a Brodmann area.

3.2. Eye-movement recording

In one of the experiments of chapter 8, recordings of eye-movements were obtained. The eye tracker used was an ISCAN RK-726PCI Pupil/Corneal Reflection Tracking System (PCI Card Version) (1/1/00). The eye tracker consists of a video-based, dark-pupil-to-corneal-reflection method to track eye movements. An infrared light beam is directed towards the right eye of the participant. The pupil absorbs the infrared light beam, and a reflection is produced on the cornea. A remote video camera detects the image of the eye, and uses the pupil and the corneal reflection to determine the position of fixation. Once the device is calibrated to the eye, it is able to track the eye pupil and the corneal reflection determining moment-by-moment the actual position of the fixation.

A template stimulus was presented at the beginning of each experiment. The experimenter asked the participants to direct their sight alternatively to the four extremes of the stimulus, as well as to its centre. In this way, the location of the stimulus in terms of pixels is known, and also the space of the participants' fixations is determined by these borders.

The eye tracker sampled at a rate of 60Hz. and was able to track a subject's eye position with accuracy typically better than 0.3 degrees over a +/- 20 degree horizontal and vertical range. The camera and infrared light of the eye tracking device were situated midway between the CRT VDU and the subjects' eye (420mm from the eye) but sufficiently low down so that the view of the screen was unobstructed (approximately 30° from the line of sight perpendicular to the screen). The optimum set-up was determined as a result of various configurations investigated in a pilot phase of testing the new equipment.

In order to restrain head movements, a device consisting of a chin rest attached to a g-clamp that could be adjusted in height was used. A chair with height adjusted was used. The most comfortable position was obtained, modifying the height of the chair and the height of the chin rest until the participant felt comfortable. A helmet was comfortably secured in a fixed position on top of the subject's head to further restrict movement.

3.3. Cross-tasks study

Chapter 6, 7 and 8 contain a study in which an atypical paradigm was used. The tasks performed by the participants were standard. The novelty was that each of the participants went through numerous tasks and techniques and the number of subjects in the study was small.

Gobet and Ritter (2000) put forward an approach called individual data modelling in which the data acquired in several studies should be analysed on an individual basis. This suggestion follows Newell's (1990) idea that psychological researchers should intend to develop unified theories of cognition. Gobet and Ritter recommend that individual data modelling is the ideal paradigm to develop general theories of cognition. They proposed that data of an individual or a few individuals analysed in an individual basis should be acquired in a number of tasks and that these data should be simulated by a computer model. The idea is to reduce the problems of the standard approach of aggregating data and using the mean of a sample as the value that represents it, and probably does not represent any individual of the sample. Another important aspect of the approach is to estimate parameters. For the importance for parameters estimation and use of individual data see Estes (2002).

In a totally different approach, Masunaga and Horn (2000, 2001) carried out the study in expertise with the highest number of volunteers (N=263). The participants were all GO players ranging from novices to master-level players. They used standard tests of fluid intelligence, short-term memory and cognitive speed and they specially designed similar tests using domain-specific (i.e., GO) stimuli.

The purpose of my study was to give the first step in the Gobet and Ritter's (2000) approach and, for this, I followed Masunaga and Horn's (2000, 2001) idea of using general and domain-specific stimuli and of using players of different levels as participants. In general the rationale in choosing the tasks was the opposite to Masunaga and Horn inasmuch as tasks that are relevant from the chess point of view were chosen, and general tasks similar to the chess ones were specially designed. However in some cases, Masunaga and Horn rationale was carried out as well.

Six participants took part in the study (1 grandmaster, 1 international master, 1 expert, 1 class B player and 2 non-chess players). All of them were submitted to numerous tasks, the chess players also carried out 3 additional experiments and the 2 strongest players participated in an fMRI study as well (the fMRI study presented in chapter 9). A number of techniques was used: fMRI, eye-movement recordings, think aloud protocols, a questionnaire, and standard behavioural measures such as response time and accuracy were also recorded in a number of tasks. The tasks performed were: simple reaction time, short-term memory spans, reconstruction of a chess board, long-term memory recognition, learning of sequences, looking ahead, and problem solving. The results were analysed individually- as proposed by Gobet and Ritter (2000) -but also the differences among levels (masters, intermediate, non-players), between players and non-players and within the master level were taken into account. This is an exploratory study which has the purpose of providing data towards a general theory of expertise. As stated earlier, this endeavour does not start from scratch and an extant theory is taken as a starting point (i.e., template/CHREST). In chapter 11, the results obtained in this study were used to improve the theory by estimating parameters and proposing a new memory structure.

CHAPTER 4

The role of practice in expertise

This chapter aims to give support for the second thesis stated in chapter 1, which proposes that extended practice is a necessary, but not a sufficient, condition to attain expert performance. Moreover, the third thesis—that there are factors not related to deliberate practice that influence the attainment of expert performance—is also considered. In so doing, two of the four sources of individual differences pointed out in chapter 2 are examined; an environmental influence during pregnancy (measured by handedness) and the age at which serious deliberate practice started. Additionally, the role of a number of activities to improve chess skill is evaluated.

In chapter 2 (section 2.2) a review of the debate 'innate talent vs. deliberate practice' has been presented. Ericsson et al. (1993) put forward the 'deliberate practice' framework, which emphasises the role of practice in the acquisition of expert levels in several fields, including chess. From the opposite perspective, Cranberg and Albert (1988) stressed the role of innate factors for the achievement of high levels of expertise.

This chapter's study is an extension of Charness et al.'s (1996) study. The next section will concentrate on the latter and the framework presented in it. This first empirical chapter gives a general view of chess expertise. Once this broad picture is presented, then it will be possible to tackle more specific aspects in the following chapters.

4.1. Charness et al. (1996) study

The skill acquisition framework of Charness et al. (1996) has been presented in chapter 2; it postulates the existence of five factors to the acquisition of skill: (a) external social environment, (b) internal motivation and personality, (c) external information, (d) practice, and (e) cognitive system (software and hardware).

Using retrospective questionnaires and multiple-regression techniques, Charness et al. studied different hypotheses derived from their framework in chess players. External-social factors were addressed by questions about the role of coaching. They found that these factors were not as important as in other sports. External information was measured by the number of books owned and the age at which the players joined a chess club. It was hypothesized that books are important knowledge sources, and that joining a club allows one to access dissemination channels such as journals, books, and databases. The role of practice was assessed by asking about the number of hours spent studying alone and the number of hours spent studying or practicing with others. It was found that individual practice predicted skill better than practice with others (.60 vs. .35, respectively). Like internal motivation and personality, the role of the cognitive system was not directly assessed in their study; however, Charness et al. suggested that the cognitive system (both the hardware and the software) changes with practice, enabling skilled individuals to break normal information-processing limits.

Another piece of intriguing data presented by Charness et al. (1996) and Elo (1978)—but not addressed in this study—is the loss of chess rating as a function of age. Chess players show a peak of performance between 30 to 40 years of age and their rating starts declining after that period. The fact that this trend is similar to that of scientists (see Simonton, 1996), and differs from the curve of sportsmen who peak and decline earlier, may suggest that the acquisition of knowledge is critical for chess.

4.2. Overview of experiment

In order to explore the joint role of practice and talent, a large sample of players were submitted both to a questionnaire similar to that used by Charness et al. and to the Edinburgh Handedness Inventory (Oldfield, 1971). In comparison to Charness et al., some new questions about the amount of practice were added, such as use of computer databases and computer programs, playing blindfold chess, reading games without seeing the board, and number of rapid chess games. These items were analysed in a hierarchical way. At the first level, the issue 'innate talent vs. deliberate practice' was considered. Then, an attempt to identify the best predictor of chess skill within the two practice variables was made, by comparing the number of hours of study alone with the number of hours of practice or study with others. Finally, the frequency and the importance of each of the chess activities to improve skill were examined. With respect to the hardware factors, the Edinburgh Handedness Inventory (Oldfield, 1971) was utilised to test Cranberg and Albert's (1988) theory that processes underlying chess skill should be performed mainly by the right hemisphere. The higher prevalence of non-right-handed individuals can be seen as a marker of the role of right-hemisphere processing.

A further improvement over Charness et al. (1996) is that not only was the dependent variable Elo rating for standard games used, but also the rating for speed chess. While standard games are played with an average of three minutes per move, in speed chess each player has only five minutes to finish their game. To my knowledge, the latter measure has not been used in previous research. Questions related to the skills required by this special modality of chess, where pattern recognition plays an important role (Gobet & Simon, 1996c) were addressed.

4.3. Methods

4.3.1. Participants

The participants were 104 chess players (101 males and 3 females). They filled in a three-section questionnaire that was left on a desk in the Círculo de Ajedrez Torre Blanca, one of the most important chess clubs in Buenos Aires (Argentina). Posters asking for volunteers were also put on the notice board of the club. Additionally, I went to several tournaments, both in the Círculo de Ajedrez Torre Blanca and other chess clubs in Buenos Aires, and distributed the questionnaires to the players participating in these tournaments. Three grandmasters, 10 international masters, 12 FIDE masters, 40 untitled players with international rating, and 39 players without international rating filled in the questionnaire. (Not all players answered all questions, with the result that the number of data points varies across measures.) Since not all players had international rating, the national rating was used in order to measure chess skill. Note that the two ratings are closely related: for the 65 players having both international and national rating, the correlation between the two scales was .89.[1] The range of the sample was 983 points (from 1490 to 2473), with a mean of 1990.8 and a standard deviation of 221.5. Since the Elo rating has a normal distribution with a theoretical SD of 200, the sample had a range of nearly 5 SD. The mean age was 30.8 years (SD = 14.5).

4.3.2. Materials

The questionnaire was divided into three sections. The first section contained questions about date of birth, age, profession, international rating, national rating, speed chess rating (rating of the *Círculo de Ajedrez Torre Blanca*),[2] chess title, chess category, age when starting to play chess (henceforth, starting age), age when starting to play chess seriously (henceforth, age for starting seriously),[3] age at joining a chess club (club age), years of coaching, number of books owned, number of speed games played, and type of training (blindfold chess, reading games without seeing the board [henceforth, blindfold reading], use of chess databases, use of chess programs). The second section contained a grid in

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[1] The scores were somewhat lower in the national rating, due to differences in the results taken into account. For instance, the four best players had 2520, 2491, 2490 and 2488 in the international rating and 2438, 2473, 2400 and 2463 in the national rating, respectively.

[2] The speed chess rating, where, in some cases, the calculation is based on more than a thousand games, is computed independently from the national rating.

[3] What did the players consider by "seriously"? Apparently, they assumed that this term referred to the time they joined a chess club. The question about starting playing seriously yielded similar results to the question about the age of joining a chess club (age for starting seriously: M=15.0, SD=8.0; club age: M=15.0, SD=8.2; r=.89, p<.001).

which the participants had to fill out the number of hours per week they spent studying chess alone at each age (henceforth, individual practice). They also had to fill in a second row with the number of hours per week they spent studying or practicing with other chess players, including tournament games (henceforth, group practice).[4] Note that, when considering the role of practice as a whole, these two variables will be combined—by adding the absolute values—in order to obtain a single variable called 'dedication'. The third section contained a Spanish translation of a modified version (Ransil & Schachter, 1994) of the Edinburgh handedness inventory (Oldfield, 1971).

4.4. Results

4.4.1. Handedness

The three women were excluded from the analysis since the trend in handedness is different for women and men (Cranberg & Albert, 1988). It was found that 17.9% in the present male sample were non-right-handers. Using the normal approximation to the binomial distribution, it was found that the difference with the general population (10 to 13.5% of non-right-handers; Bryden, 1982; Geschwind, 1983; Porac & Coren, 1981) is statistically significant ($z = 1.86$, $p < .05$). Within the present study's sample, there were no reliable differences in handedness between players with international rating ($N = 60$; percent of non-right-handers = 15%) and players without international rating ($N = 35$; 22.8%), nor between titled players ($N = 24$; 8.3%) and untitled players ($N = 71$, 21.1%). If

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[4] In Charness et al.'s study (1996, table 2.4), players considered active participation in chess tournaments as the most relevant activity.

anything, the pattern of results was in the opposite direction to what is predicted by Geschwind and Galaburda's theory.

The present study's results show the same pattern as that found by Cranberg and Albert (1988): chess players are more likely to be non-right-handed than the population, but, within chess players, handedness does not correlate with chess skill. To explain the latter result, Cranberg and Albert hypothesized that the group of weaker chess players contained numerous young players who could become masters and would be in the master group in the future, resulting in an increase of the proportion of non-right-handers in the population of high-level chess players. In this study's sample, the age gap between the two groups was not as wide as in Cranberg and Albert's sample, so this explanation does not seem to apply.

4.4.2 Innate talent and practice: A multiple-regression analysis

Are high levels of chess skill acquired simply by extended practice or is there a biological determination? Should other factors be taken into account? One way of dealing with these questions is with a multiple regression analysis predicting chess skill with the following variables: dedication (combination of individual practice and group practice), starting age, age for starting seriously, handedness, and age. Dedication was included as a measure of chess practice. Handedness is a biological indicator of talent according to Cranberg and Albert. The starting age for playing chess and the starting age for playing seriously were set into the formula in order to test the role of the critical period proposed by Elo (1978). Finally, Charness et al. (1996) proposed age as a predictor of chess skill.

These independent variables have been log-transformed because of the skewness of their distributions.

Table 4.1. Predictors of chess skill: Bivariate correlations.

	Speed rating	Log Dedication	Log Age seriously	Log Starting age	Log Age	Log Handedness
National rating	.83** (72)	.57** (89)	-.37** (100)	-.28** (104)	.08 104)	-.07 (95)
Speed rating	—	.37** (63)	-.46** (70)	-.23 (72)	-.04 (72)	.12 (65)
Log. Dedication		—	-.08 (85)	-.17 (89)	.42** (89)	.11 (83)
Log. Age seriously			—	.59** (100)	.54 (100)	-.01 (92)
Log. Starting age				—	.29** (104)	-.19 (95)
Log. Age					—	.14 (95)

Note. ** p < .01, * p < .05. Number in parentheses are number of subjects. Not all the players have speed rating and some of them did not answer all the questions.

Zero-order correlations were first analysed (see Table 4.1), using as dependent variables national rating and speed chess rating, which measure chess skill in long games and in quick games, respectively. Age and handedness did not correlate significantly either to national rating or to speed chess rating.

National rating had the higher correlation with dedication, followed by age for starting seriously and starting age. With respect to speed chess rating, age for starting seriously had the highest correlation, followed by dedication. Two stepwise multiple regressions, respectively with national rating and speed chess rating as dependent variable, keep only Log dedication and Log age for starting seriously as predictors. These variables yielded the following multiple regression equations, where the adjusted R^2 were .39 for national rating and .34 for speed chess rating:

$$\text{National rating} = 1448.3 + 239.2 \text{ Log dedication} - 357.3 \text{ Log age for starting seriously} \quad (1)$$

$$\text{Speed chess rating} = 1981.9 - 536.2 \text{ Log age for starting seriously} + 150.7 \text{ Log dedication} \quad (2)$$

4.4.3. Practising behaviour

Within dedication to chess, which is more important: the number of hours of study alone or the number of hours of practice or study with others? This question directly addresses one important result in Charness et al.'s (1996) study, in which individual practice was found to be a better predictor than group practice.

When variables are strongly correlated, as it is the case here, the use of stepwise multiple regression may lead to arbitrary decisions: the variable chosen to be the most important, and entered first in the equation, will also account for the variance shared with other independent variables. Hence, the analyses were limited to the bivariate correlations (see Figure 4.1).

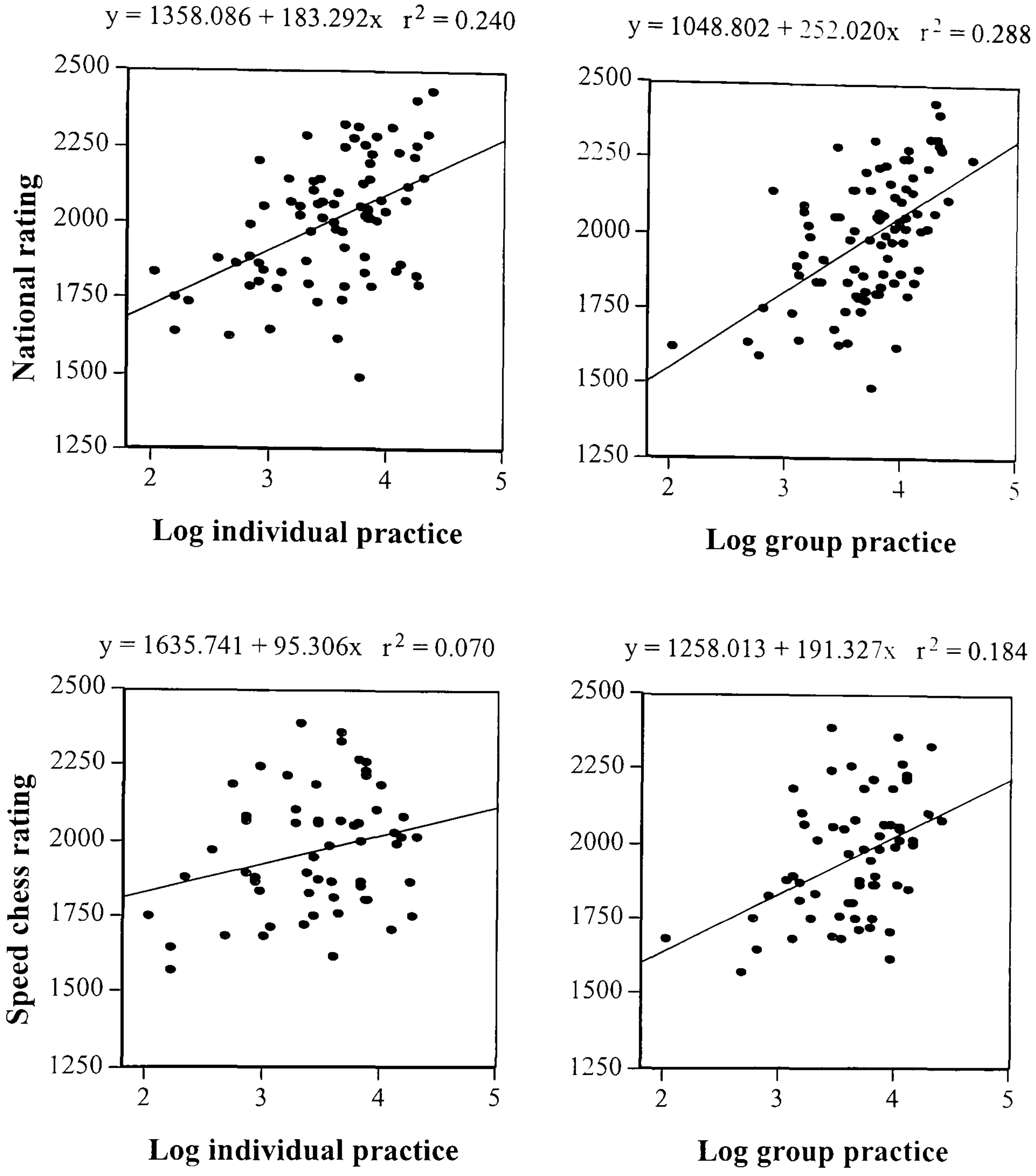

Figure 4.1. Scatter plots of national rating and speed rating as a function of log individual practice and group practice. (The plots for individual practice have excluded nine players who reported zero hours of practice. With these players included, the equations are 1754.508 + 73.490x (r^2 = 0.175) for national rating, and 1817.242 + 43.808x (r^2 = 0.063) for speed rating.)

The results suggest that national rating and speed chess rating are better predicted by group practice than by individual practice (see Figure 4.1). Both variables are correlated with national rating, but individual practice is not correlated with speed chess rating at the .01 significance level. These results are different from those found by Charness et al. (1996), in which individual practice turned out to be the best predictor of chess skill. In the present study, group practice predicted chess skill at least as well as individual practice.

4.4.4. Activities used to improve chess skill

The items in the questionnaire corresponding to chess activities could be classified in two categories: activities performed with others and activities performed alone. Variables that correspond to the first group are: coaching, Log individual coaching, Log group coaching, blindfold chess, playing speed chess and Log speed chess games. Study alone is represented by the following activities: blindfold reading, databases, chess programs and Log number of books. The latter variable was one of the predictors identified by Charness et al. (1996). Book ownership is not an activity but it can be assumed that if chess players have books they read them, or at least some of them. So, the number of books owned could be a predictor of hours spent reading books, which is an activity performed alone.

The percentages of players reporting the practice of these activities were as follows: playing speed chess (83.6%), coaching (80.5%), use of databases (67.3%), use of programs (66.3%), blindfold reading of games (55.7%) and blindfold chess (23%). The zero order correlations between these practice activities and chess skill were assessed. With national rating used as dependent variable, the correlations were .44 for Log number of books, .35 for the presence of coaching (0,1), .32 for the use of databases (0,1), .27 for playing speed chess (0,1), and .27 for Log speed games (all $\underline{p} < .05$). There was no significant correlation between skill and blindfold chess, blindfold reading of games, use of chess programs, Log years of individual coaching, and Log years of group coaching.

The most popular activities—speed games and coaching—were correlated with chess skill and, thus, seem to be useful activities as well. Use of databases and computer programs had the same level of popularity, but the mean national rating of players using databases was higher than that of players using programs. Howard (1999) showed a historical trend in which young players are increasingly occupying top positions in the world ranking. Gobet, Campitelli and Waters (2002) suggested that Howard's data could be accounted for by the use of new technologies. The lack of correlation between Use of chess program and chess skill is somehow surprising. It may be the case that playing with a chess program that uses a very different strategy (i.e., brute force in look ahead search) than that of humans does not help to improve the level playing against humans. However, the use of chess data bases is correlated with national rating, suggesting that good players are selective when choosing the appropriate technologies for their training.

Playing blindfold games was neither popular nor useful, as players that did not play blindfold chess were not weaker than the ones who did. With speed chess rating used as dependent variable, the correlations were .38 for Log number of books, and .35 for coaching (0,1) (both $p < .05$). There was not a significant correlation in the other variables.

Taking into account the activities measured in the questionnaire, it can be concluded that reading (as inferred by the number of books), an activity performed alone, is the most important predictor of chess skill. On the other hand, contrary to Charness et al.'s results, Log speed games and coaching, two activities that included practice with others, were also good predictors of chess skill.

4.4.5. Test of Simon and Chase's (1973) hypothesis

Simon and Chase (1973) estimated that it is necessary to dedicate between 10,000 to 50,000 hours to chess to achieve master level. They also roughly estimated that it is necessary to spend from 1,000 to 5,000 hours to attain the level of a class A player. In the present study's sample, the mean number of hours of dedication accumulated when players attained 2200 Elo points (master level) was 10,528, with a standard deviation of 5,327, and a range of 20,384 (from 3,224 to 23,608). Thus, the lower bound of Simon and Chase's estimate coincides with the mean of this study's data. However, it is worth highlighting the variability of the data. One player attained master level with just 3,224 hours, while another needed 23,608 hours (a 1:7 ratio). Furthermore, some players in the present sample had spent more than 25,000 hours of deliberate practice without attaining the master level.

These data suggest that extended practice (more than three thousand hours) is necessary to achieve master level; however, extended practice is not sufficient to acquire master level, and the same amount of practice does not have the same effect in all the players.

4.4.6. Differences with Charness et al.'s (1996) results

While the overall pattern of results of the present study are consistent with Charness et al. (1996), several important differences may be noted. First, Charness et al. concluded that individual practice is more important than group practice. In this study's sample, group practice was at least as important as individual practice. Second, Charness et al. rejected the influence of coaching. The present study showed that the presence of coaching is important, but the quantity of years spent in coaching is not. Third, although Charness et al. found negative correlations between chess skill and starting age, age starting seriously and age joining a chess club (-.35, -.36 and -.42 respectively), they also found that these variables did not explain additional variance in their regression analysis beyond practice and age. Accordingly, they proposed that the correlations were accounted for by amount of practice (i.e., earlier starters had more time to study than later starters). A different pattern emerged in this sample. Controlling for the number of hours of dedication with a partial correlation analysis, it was found that the correlations between national rating and starting age, age for starting seriously and club age were -.11 ($p > .10$), -.45 ($p < .001$) and -.40 ($p < .001$), respectively. In all cases, the correlations were calculated over 80 players. Similar partial correlations were found with speed chess rating, where the correlations were computed with over 56 players: starting age = -.27 ($p < .05$), age for starting seriously = -.53 ($p < .001$) and club age = -.49 ($p < .001$). Therefore, the present data are consistent with Elo's (1978) proposal of the presence of a critical period.

A final difference is that in the present study some variables were added in comparison to Charness et al's (1996) work. One of them, Log speed chess games, turned out to be one of the activities predicting chess skill.

Several reasons may explain the differences between the present results and Charness et al.'s. First, the sample of this study was drawn from a homogeneous population, while Charness et al.'s sample combined sub-samples from cities (Toronto, Berlin, and Moscow) located in three different countries.

Second, different statistical techniques were used in some cases, in particular to estimate the role of practice in the correlation between starting ages and skill. Third, there may have been differences in the organisational structure that produced differences in the environment of the two samples. The data of this study were obtained from players in Buenos Aires, which is a city with several chess clubs open more than 8 hours daily. This allows players to meet regularly to play and study in groups. Also, most of these clubs offer both group and individual coaching.

4.5 General Discussion

This study addressed four of the five factors mentioned in Charness et al.'s (1996) framework (no measure of internal motivation or personality factors were taken). Here follows a summary of the most important findings with respect to their framework.

4.5.1. External social factors

Like Charness et al. (1996), the importance of external social factors was explored by examining the role of coaching in chess. Contrary to what was found by Charness et al. (1996), group practice was strongly correlated with chess skill. Individual practice was also correlated, but not to the same extent. In this study's sample at least, the presence of a coach at some point of the players' career (but not the number of years of coaching) was a good predictor of skill.

4.5.2. External information factors

Two activities performed by chess players highlighted the role of external information factors in acquiring chess skill: reading books (indirectly measured by the number of books owned), and the use of game databases (but not the use of programs to play chess). Gobet, Campitelli and Waters (2002) discussed the impact that changes in information technology have had on training practices in chess of skilled players, and they concluded that this factor explains the decrease of age in the top chess players in the world.

4.5.3. Dedicated practice

The third factor mentioned by Charness et al. (1996) is practice. While the role of practice has been emphasized for a long time (e.g., by De Groot, 1946/1978), Ericsson et al. (1993) have taken the extreme position that deliberate practice is a sufficient, not merely necessary, condition for expertise. The present results are not consistent with this position. Although the overall correlations both between individual practice and chess skill and group practice and chess skill show a reliable pattern, there were a number of exceptions: some players with relatively few hours of practice achieved master level, while others with a huge amount of practice did not reach this level. This pattern is apparent in the scatterplots of Figure 1 and in the numerical estimates of variability provided.

As to the detail of the activities in which players engage in practice, the data of this study differ in several ways to those reported by Charness et al. (1996). The importance of group practice in the present study's sample, which was not found in

Charness et al.'s sample has been already discussed. A new result of the present study was that playing speed games was a good predictor of chess skill.

4.5.4. Hardware of the cognitive system

Charness et al. (1996) emphasized the changes that practice may cause to the cognitive system (both hardware and software). Given the lack of clear empirical evidence, they were more reserved about the effects that individual differences in hardware may have on the acquisition of knowledge through practice. Waters et al. (2002), who reviewed the literature on intelligence and visuo-spatial abilities in chess, found a complex pattern of results, with some pointing to abilities developed by domain-specific practice, and others pointing to abilities not specific to chess and perhaps innate. Two outcomes of the present study relate to this question: handedness and the starting age.

It was found that handedness and chess were related (non-right-handers were more represented in the chess sample than in the general population). However, there was no relation between handedness and skill level. These results replicate Cranberg and Albert's (1988) using a well-validated measure of handedness. One possible explanation for the relation between chess and handedness, but the lack of relation between handedness and skill level, is that having a more developed right hemisphere does not always lead to being non-right handed (Geschwind & Behan, 1984). In other words, there may be chess players with more developed right hemispheres who are right-handers. Indeed, there is evidence that only one third of the people with more developed right hemisphere are not right-handed (Geschwind & Behan, 1984). If this is the case, the failure to identify a correlation between skill and handedness as a marker of brain asymmetry—a factor not related to chess practice—does not mean that brain asymmetry is irrelevant, but that other measures of brain asymmetry, including measures of structural differences using MRI, are needed to test this hypothesis.

Starting age showed a correlation between skill level and the age of starting playing seriously; critically, this correlation remained strong after hours of deliberate practice were partialed out. The correlation was even stronger with speed chess skill. Indeed, the correlation between starting age and speed chess rating is stronger than that between dedication and speed chess rating. Calderwood et al. (1988) and Gobet and Simon (1996c) have proposed that efficient pattern recognition is essential to play high-quality games in speed chess, because there is no time to calculate variations. It may be the case that starting to play seriously early influences the speed in which pattern-recognition processes are carried out.

4.5.5. Software of the cognitive system

This study has not investigated this aspect of chess expertise. In the following chapters cognitive processes related to imagery, memory and thinking will be considered.

4.6. Conclusion

This chapter has investigated different variables—some related and some not related to domain-specific practice—in order to investigate two of the theses stated in chapter 1.

Regarding the thesis that extended practice is a necessary—but not sufficient—condition for the acquisition of high levels of chess skill, the present study has shown that, although the time spent studying and playing chess was a good predictor of skill, this variable on its own did not explain all the variance. Thus, the data suggest that practice is necessary, but not sufficient, to acquire master level. In this study, the minimum number of hours of deliberate practice required to reach international-master level was 9,360 hours. It might be argued that the necessity of extended practice has not been proven, because the correlational nature of this study does not allow one to establish causal relation. This point is well taken; however, there is no case of a player with few hours of dedication attaining high levels (3,224 hours was found as the minimal time to reach 2200 Elo points, and 9,360 hours for international master). Therefore, this position may be adopted as correct until new data disconfirm it.

In order to consider the second thesis (factors not related to domain-specific deliberate practice influence the acquisition of expert performance), one of the possible sources of individual differences, environmental influences during pregnancy, was investigated indirectly by measuring handedness. It was found that the proportion of non-right-handers in the chess population was greater than that of the general population. However, no differences in handedness within the chess population were found.

Another of the non-domain-specific practice factors that contributed to explain chess skill was the age at which players started studying seriously. Almost all players who obtained a title started studying seriously or joined a chess club when they were 12 years old or earlier. In contrast to previous studies, the results of my research indicated that the age at which players started playing seriously predicted speed chess rating *better* than hours of dedication. These results support Elo's (1978) proposal of a critical period in skill development. In the present study a suggestion was put forward that being actively exposed to a chess environment at an earlier age (i.e., not just playing chess with friends or relatives, but reading chess books, solving problems and receiving feedback from advanced players) is important for developing efficient pattern-recognition skills.

In summary, starting to play chess seriously before twelve years of age, carrying out individual practice such as reading chess books, playing chess with others, receiving feedback from a coach and playing speed chess games are all important factors to attain a high level of expertise in chess. There was some evidence that individual differences in abilities not related to the chess environment differentiate between players and non-chess-players (handedness and starting age). Together, these results refute strong interpretations of Ericsson et al. (1993) and Cranberg and Albert's (1988) theories, suggesting that the talent/practice debate is based on a false opposition.

Having given a broad view of expertise in chess, now the study of the cognitive system will begin, with the next chapter focussing on expert imagery.

CHAPTER 5

Expert imagery

One of the purposes of this thesis stated in chapter 1 is gathering data towards a general theory of expertise. The template theory (Gobet & Simon, 1996a) implemented in the CHREST (e.g., Gobet & Simon, 2000) computer model was taken as theoretical basis in this endeavour.

This chapter's study aims to understand the relationship between visual perception and imagery (in particular, the overlap of internal and external information within the mind's eye). A further goal of this study is to link empirical data on mental images in chess to the template theory. Particularly, since the amount of information stored in long-term memory (LTM) is crucial in the template theory, I was interested in the role of previous knowledge and its interaction with the problem of overlapping information in the mind's eye.

The template theory was developed as a theory of expertise, therefore it should be able to account for data in blindfold chess. However, one component of the template theory which is vital for blindfold chess, the mind's eye, is not well specified. In the following section (5.1) a tentative explanation of the mind's eye will be put forward. Furthermore, the two experiments of this chapter are aimed at gathering information about this component.

In chapter 2 (section 2.3.1.1) a review of research into blindfold chess was presented. In that review, it has been shown that the most important studies were carried out by Saariluoma (1991) and Saariluoma and Kalakoski (1997, 1998). They explained their results utilising a number of theoretical ideas: Chase and Simon's (1973) chunking theory, Ericsson and Kintsch`s (1995) long-term working memory theory, Baddeley and Hitch's (1974) theory of working memory, and Leibniz' (1704) and Kant's (1781) concept of apperception—that is, conceptual perception (Saariluoma, 1995, p.102). In section 5.2 , it will be shown that most of Saariluoma and Kalakoski's results can be explained within the framework of the template theory.

5.1. The mind's eye in the template theory

In chapter 2 (sub-section 2.1.2) an explanation of the template theory and its computer implementation (CHREST) has been introduced. In this section, more detail about one of its components—the mind's eye—is given.

Like in the chunking theory, the mind's eye in the template theory is considered a visuo-spatial structure preserving the spatial layout of the perceived stimulus, where information can be added and updated (Chase & Simon, 1973; De Groot & Gobet, 1996; Gobet & Simon, 2000). The theory includes time parameters (see chapter 11, table 11.1) for carrying out various types of operations, such as moving a bishop diagonally or a rook horizontally. Search processes are done in the mind's eye: when an anticipated move is carried out, the changes are performed there (Chase & Simon, 1973; Gobet, 1997). The information in the mind's eye is subject to decay and to interference; the latter both from information coming from other memory structures and/or from external information coming through the retina.

5.2. Applying the template theory to blindfold chess

Several mechanisms inherent in the template theory are of importance in the application of the theory to blindfold chess. First, positions that recur often tend to lead to the development of templates; as a consequence, the initial chess position, as well as the positions arising from the first moves in the openings familiar to players, will elicit templates. This will be particularly the case with masters. Second, templates can be linked to each other and can be linked to moves. For example (see figure 5.1), the initial position is linked, among other moves and templates, to the move 1.e2-e4 and to the template encoding the position arising after this move; in turn, this template is linked to the move 1...c7-c5 and to the template describing the position arising after 1.e2-e4 c7-c5.

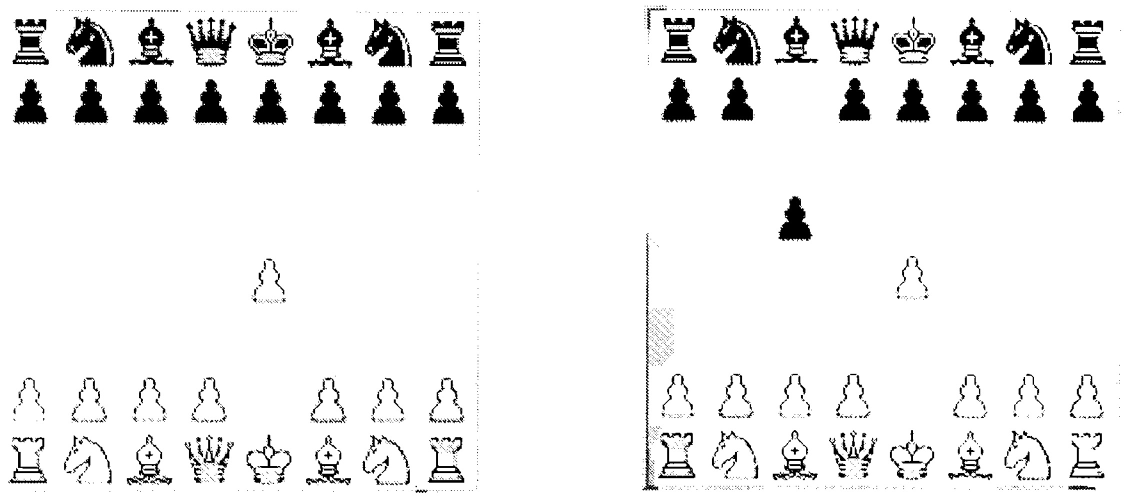

Figure 5.1. The template theory proposes that positions that recur often in a player's practice (such as the position after 1.e2-e4, diagram on the left, and the position after 1.e2-e4 c7-c5, diagram on the right) lead to the creation of templates. Templates may be linked in LTM, for example by the move or sequence of moves that lead from one to another (in the example, the move 1... c7-c5).

I propose here to apply the theory to blindfold chess research, starting with Saariluoma's (1991) results. The role of LTM knowledge and of chunking are obviously at the centre of template theory. For example, the fact that actual games are better recalled than random legal games, which are in turn better recalled than random illegal games, can be explained as follows (essentially Saariluoma's, 1991, explanation): masters, who have more chunks with which they can associate information about moves, are more likely to find such chunks even after random moves. With random illegal games, however, chunks become harder and harder to find, and masters' performance drops. Random legal games drift only slowly into positions where a few chunks can be recognized, and, therefore, allow for a relatively good recall.

The fact that players are sensitive to visuo-spatial interfering tasks when the latter is employed while a stimulus to be remembered is presented, but not when the interference task is executed after its presentation, is explained as follows. Early on, these tasks would interfere with the access of chunks and templates, and with their potential modification; once this has been done, interfering tasks are less detrimental because information is already stored in LTM. The predominant role of visuo-spatial memory over verbal memory is captured by the mainly visuo-spatial encoding of chunks (Chase & Simon, 1973).

Similarly, the results of Saariluoma and Kalakoski (1997) are consistent with the template theory. Information about colour and size may be hidden to players, because it is easy for them to derive them from location, as chunks are location-sensitive (Gobet & Simon, 1996d; Saariluoma, 1994; but see chapter 11 of this thesis for an alternative explanation). The effect of transposing the two halves of the board is explained by the difficulty of accessing chunks (basically the same explanation as Saariluoma and Kalakoski's). Modality of presentation (visual or auditory) does not matter, as long as the information can be used to update the position internally, and therefore access chunks. Finally, the speed of presentation time strongly affects performance, a direct prediction of the template theory, where cognitive processes, including decay of information in the mind's eye and LTM storage, directly depend upon the amount of time available.

With respect to problem solving (Saariluoma & Kalakoski, 1998), the fact that functionally-relevant pieces are better encoded than irrelevant pieces follows from the idea that functionally-relevant pieces are more likely to attract attention and therefore to elicit chunks and templates in the simulations with CHREST. This can already be observed in the early seconds of the presentation of a position (De Groot & Gobet, 1996). Similarly, orienting tasks (e.g., counting the number of pieces) change the object of attention; as a consequence, they affect which chunks will be retrieved, which in turn influences memory performance. Better problem-solving performance with game than with random background is explained by the fact that game background is more likely to elicit relevant chunks, because it offers more context and therefore more opportunity for accessing knowledge. Finally, visuo-spatial interference tasks offer a checkered pattern of results. They affect problem solving because search mechanisms occurring in the mind's eye are impaired. However, these tasks do not affect performance in a memory task if the position is presented before the interfering task (Saariluoma & Kalakoski 1998, exp. 4). On the other hand, if the task is performed at the same time as the presentation of a game, the performance in memory is indeed impaired (Saariluoma, 1991, exp. 6). According to template theory, this result is explained by the fact that, as soon as a template has been accessed, information can be stored there rapidly, which makes memory less sensitive to the operations of the mind's eye.

As has been seen, varying the background affects problem-solving performance, and, presumably, the cognitive operations carried out in the mind's eye. It is also likely that background affects cognition in a memory task as well. To test this hypothesis, and to explore how a possible effect is modulated by skill level, a game was presented blindfold with a background, which is totally irrelevant to the target game.

5.3. Experiment 1

The purpose of this experiment was to understand the relationship between visual perception and imagery within the mind's eye. A method similar to that of Saariluoma and Kalakoski (1997) was used: chess games were presented on a computer monitor 'blindfold'—only the current move was displayed on an empty board. While these authors were interested in the type of information used by chess players (type of piece, colour and location), I was interested in the effect of background interference in blindfold chess, and manipulated the context surrounding the piece being moved. Hence, the moves were presented normally, but, in the interference conditions, pieces not related to the target game were placed throughout the board. Two games were presented simultaneously, and the ability to remember positions was measured three times: after 10 ply,[1] 30 ply, and 50 ply; memory for the entire game was tested at the end.

5.3.1. Methods

5.3.1.1. Participants

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[1] A ply (or half-move) corresponds to a piece movement by either White or Black. A move consists of two ply, one by White and one by Black.

Sixteen Argentinian players volunteered for this experiment: 8 masters (including 3 international masters and 3 FIDE masters) and 8 Class A players. The masters had an average international rating (ELO) of 2,299 and an average national rating (SNG)[2] of 2,193. Class A players had an average national rating of 1,885. (They did not have international rating.) The average age of the sample was 20.5 years (SD = 5.2) with a range from 14 to 31.

5.3.1.2. Material

Six grandmaster games were carefully chosen from Chess Base. They were chosen on the basis that they not been played by elite grandmasters and did not follow very common opening lines. The mean number of pieces for the three stages of reconstruction was 32 (SD = 0) after the 10th ply, 26.7 (SD = 1.5) after the 30th ply, and 20 (SD = 1.2) after the 50th ply.

5.3.1.3. Design and Procedure

The design was 2x3x3 ANOVA, where Skill (masters and Class A players) was a between-participant variable, and where Interference (Empty Board, Initial Position and Initial Position in the Middle) and Depth (10, 30 and 50 ply) were within-participant variables. The orders of the conditions and of the games were counterbalanced.

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[2] SNG (National Grading System) is the Argentinian national rating. It utilizes the same method as Elo (1978) and it is highly correlated to Elo.

The six games were presented on a computer screen 'blindfold,' that is, the players could see only the moves but not the current position. The moves were presented visually on a chessboard. Three experimental conditions were used. In the control condition, the moves were presented on an empty board. In the first interference condition, the moves appeared on a board that contained the initial position of a chess game. In the second interference condition, the moves were displayed on a board where the initial position was transposed to the middle of the board (the 32 pieces were placed on rows 3 to 6, rather than on rows 1, 2, 7, and 8, as in the normal initial position).

In the three conditions, the participants were told that they had to follow two games mentally, starting with the initial position and updating the position with the moves presented on the board. Every move was presented as follows: the target piece was first presented for one second in its origin square and then for two seconds in its destination square. Then this piece disappeared, and the piece corresponding to the next move was displayed on its current location for one second, and then on its destination square for two seconds; then new moves were presented in the same way. The moving piece was always surrounded by a green square border to discriminate it from the interference pieces.

The games were presented as follows. The first 10 ply of game 1 were presented, followed by the first 10 ply of game 2. At this point, an empty board and a box with chess pieces appeared on the screen, and participants had to reconstruct the last position in each game, by clicking the mouse in a piece and then clicking again in the square of the board in which they wanted to place the piece selected. Then, ply 11 to 20 of game 1 were presented, followed by ply 11 to 20 of game 2, and then ply 21 to 30 of game 1, followed by ply 21 to 30 of game 2. At this point, participants had to reconstruct the last position of each game. Finally, ply 31 to 40 of game 1, ply 31 to 40 of game 2, ply 41 to 50 of game 1, and ply 41 to 50 of game 2 were played. At the end, participants had again to reconstruct the final position of each game.

When they had finished reconstructing the positions after 50 ply, participants were presented with a board containing the initial position and had to reconstruct the moves of game 1 and, then, the moves of game 2. Players were allowed a maximum of 4 minutes to reconstruct the two positions and a maximum of 10 minutes to reconstruct the moves of each game. The time spent in reconstruction was recorded with a stopwatch. At the end of this procedure, participants had a five-minute break, after which they started the same cycle with games 3 and 4 in a different experimental condition, followed by another five-minute break and the same cycle with games 5 and 6 with the third condition.

Before starting the experiment, all subjects went through a practice session in order to familiarise themselves with the procedure and the use of the mouse in the reconstruction of positions. The practice consisted of following the procedure explained above, for 6 practice games (2 per condition) until the reconstruction of ply 10 in all the games.

5.3.2. Results

5.3.2.1. Recall of Positions

Figure 2 shows the means for the percentage of pieces correctly replaced. ANOVA indicated a main effect of Depth [$F(2,13) = 92.1$, $MSE = 20.320$; $p < .001$]. Post-hoc Scheffé tests showed that the differences were between Ply 10 and

Ply 30, Ply 10 and Ply 50, as well as between Ply 30 and Ply 50. There was also a main effect of Skill [F(1,14) = 122.2, MSE = 26,956; p < .001]. However, no main effect was found for Interference [F(2, 13) < 1, MSE = 20.7]. There was found only one significant interaction: Depth x Skill [F(2,13) = 25.3, MSE = 5,581, p < .001], due to the fact that Class A players were more affected by depth than masters.

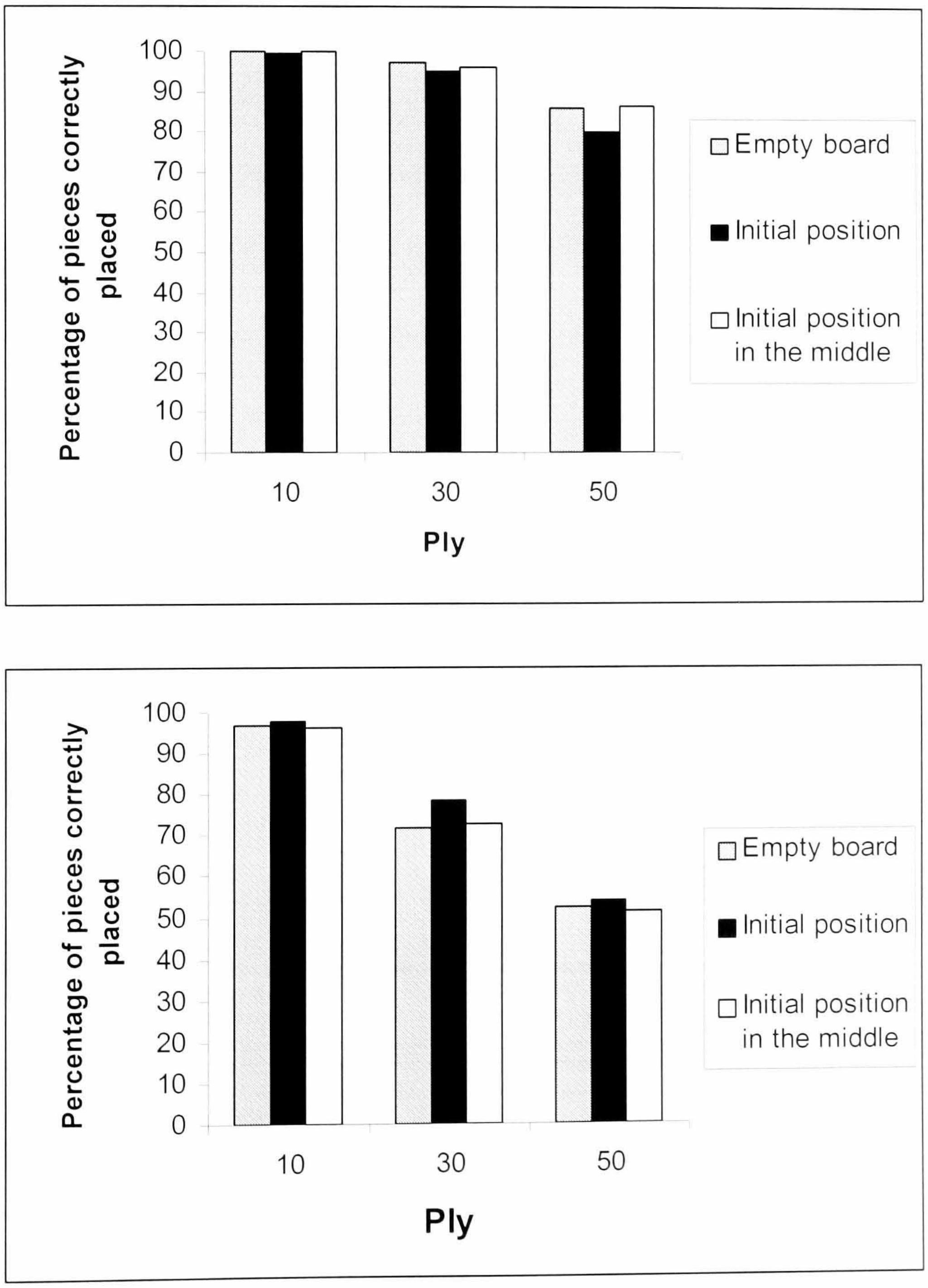

Figure 5.2. Experiment 1. Percentage correct as a function of the experimental condition (empty board, initial condition, and initial condition in the middle) and of the number of ply (top, masters; bottom, Class A players).

Errors of omission (total number of pieces minus the number of pieces replaced) and of commission (pieces incorrectly replaced) were also analysed. Errors of commission consist of pieces placed on the board that were not present in the actual position and pieces placed on an incorrect square. Since the positions did not have the same number of pieces, the results are reported as percentages.

With respect to the percentage of errors of commission, I found a pattern similar to that found with the percentage of pieces correctly replaced. The mean percentages for Skill were 6.0 (SD = 12.0) for masters, and 25.5 (SD = 26.2) for Class A players. The mean percentages for Depth were: 1.7 (SD = 3.8) for Ply 10; 15.5 (SD = 16.3) for Ply 30; and 30.0 (SD = 29.1) for Ply 50. Finally, the mean percentages for Interference were: 16.3 (SD = 23.3) for Empty Board; 14.9 (SD = 21.5) for Initial Position, and 16.0 (SD = 22.8) for Initial Position in the Middle. There were main effects for Skill [$F(1,14) = 109.7$, MSE = 27.332; $p < .001$], Depth [$F(2,13) = 76.8$, MSE = 19,146; $p < .001$], but not for Interference [$F(2,13) < 1$, MSE = 55.34]. Again, Depth x Skill was the only significant interaction [$F(2,13) = 24.1$, MSE = 6,010; $p < .001$]. The same pattern of results was found for the percentage of errors of omission: Skill [$F(1,14) = 12.5$, MSE = 1,842; $p < .001$]; Depth [$F(2,13) = 12.6$, MSE = 1,860; $p < .001$]; Interference [$F(2,13) < 1$, MSE = 13.36]; Interaction Depth x Skill [$F(2,13) = 4.0$, MSE = 592.04; $p < .02$].

Finally, a similar pattern of results for reconstruction time was found, with main effects of Skill [$F(1,14) = 7.7$, MSE = 36,450; $p < .01$] and Depth [$F(2, 13) = 98.9$, MSE = 469,204; $p < .001$], but not of Interference [$F(2,13) < 1$, MSE = 555.96]. No interaction was significant.

5.3.2.2. Reconstruction of games

For this variable a 2 x 3 ANOVA model (Skill x Interference) was utilised. The mean percentages of moves correctly reported were 86.4 (SD = 13.9) for masters and 41.1 (SD = 24.6) for Class A players. Regarding Interference, the means were 60.7 (SD = 32.5) for Empty Board, 67.0 (SD = 28.1) for Initial Position and 63.6 (SD = 30.5) for Initial Position in the Middle. Once again, there was a Skill effect [$\underline{F}(1, 14) = 122.8$, MSE = 49,232; $\underline{p} < .001$], but no Interference effect [$\underline{F}(2,13) < 1$, MSE = 322.4]. The interaction term was not significant [$\underline{F}(2,13) < 1$, MSE = 392.6].

5.3.3. Discussion

In this experiment, the following pattern of results was repeatedly found: (a) a main effect of Skill; (b) a main effect of Depth; (c) an interaction between Skill and Depth, and (d) no main effect of Interference. The first result naturally flows from the template theory, as seen above. As a consequence of their experience with the game and their study of chess literature, chess players have acquired a considerable knowledge base of both chunks and templates, which allows them to recognise familiar patterns automatically. Since masters' knowledge base is much larger than that of Class A players, the main effect of Skill arises.

The second and third findings can also be explained easily by the template theory. The difference in performance between masters and Class A players arises at Ply 30 and increases at Ply 50, but it does not exist at Ply 10. Most of the positions and the moves close to the starting position are well known both to masters and to Class A players; hence, no big differences in the corresponding recall performances were expected. However, as soon as the game progresses, masters can recognize more chunks and templates than Class A players. Interestingly, some of the masters (but not all of them) experienced impairment in their performances at Ply 50. I suggest that this is due to the lack of familiarity with positions corresponding to Ply 50, which makes pattern recognition harder.

The fourth finding is more challenging, and led me to design the second experiment. Surprisingly, performance was not impaired in the conditions displaying the initial position, either on its normal location or in the middle of the board. In addition, there was no sign of interaction for this variable. Two explanations are suggested. First, it may be not necessary for chess players to use the perceived representation of the external chessboard as an aid to update the internal representation of the position in the mind's eye. Therefore, they just process the move that is being presented, and ignore the board and the other pieces. Thus, the interference position never gets processed. Second, chess players use the external board's percept as a help to refresh the image of the current position, but, early on, they can avoid processing the other (irrelevant) pieces on the board in depth, because they are not unexpected (the interference position remained unchanged during the whole task).

In order to tease apart these hypotheses (no processing of the board, or processing-plus-early-filtering), a second experiment was designed where the interference positions changed during the task. It was speculated that the novelty of the position would cause its automatic processing, therefore impairing performance for all skill levels. This assumption flows naturally from the template theory and, and in particular from its computer implementation, CHREST, where novelty is one of the heuristics used to direct eye movements and is at the heart of its discrimination learning mechanism. A further goal of this experiment was to gain additional information about templates by an analysis of the types of errors made during reconstruction.

5.4. Experiment 2

The purpose of this experiment is to test the hypothesis that the lack of main effect of interference in the first experiment was due to the lack of novelty in the interference positions. Two interference conditions, different from those used in experiment 1 were used. In the first condition (move-by-move condition), fifty positions (one for each move in the target game) were used as interference. These positions belonged to an unrelated game, which started with the same opening as the target game. In the second condition (semi-static condition), five different interference positions were displayed, which corresponded to five positions in a game, ordered chronologically.

In a pilot study, it was found that a class A player could not do the task at all. Therefore, I decided to increase the skill level of the two groups in comparison to the first experiment, recruiting stronger masters and having experts instead of class A players. In addition, a FIDE master tested in the pilot study reported that the task had been demanding and that he felt extremely tired in the second part of the experiment. Hence, it was decided to eliminate some components of the experiment, leaving intact the elements that were considered essential for the research questions investigated.

5.4.1. Methods

5.4.1.1. Participants

There were 16 volunteers: 8 masters (4 international masters and 4 FIDE masters) and 8 Experts (all of them with international rating but without any FIDE title). The mean international rating was 2,351 (SD = 45.8) for the masters and 2,113 (SD = 51.9) for the Experts. The mean national rating was 2,256 (SD = 67.85) for the masters and 1,996 (SD = 70.14) for the Experts. The average age of the sample was 25.9 years (SD = 8.1; range 15 to 39).

5.4.1.2. Material

From a pool of grandmaster games with relatively uncommon openings, 6 games were selected for the stimuli to memorise, and other 6 games for constructing the interference positions. For the stimuli positions, the mean number of pieces at the two moments of reconstruction were 26.8 (SD = .75) at Ply 30, and 21.0 (SD = .89) at Ply 50. For the interference positions, the means were 27.8 (SD= .98) at Ply 30 and 21.5 (SD = 1.0) at Ply 50. The interference positions were similar to the experimental games on the first moves. In the move-by-move interference condition, 50 different positions were used; in the semi-static condition, I used 5 different positions.

5.4.1.3. Design and Procedure

A 2x3x2 ANOVA design was utilised. Skill (masters and Experts) was a between-participant variable; Interference (Empty board, move-by-move and semi-static) and Depth (30 and 50 ply) were within-participant variables. The procedure was similar to that in experiment 1, with changes mainly with the interference conditions. In addition, I asked the participants neither to reconstruct the position after 10 ply, nor to reconstruct the games at the end. These decisions were taken in order to keep the length of the experiment within bearable bounds.

Every interference position corresponded to a game starting with similar moves in the first ply. In the move-by-move condition, a different interference position at each ply was presented. In the semi-static condition, the interference positions lasted 10 ply. Hence 5 interference positions, taken after 10, 20, 30, 40 and 50 ply were used. The presentation of the game in the control condition was similar to that in Experiment 1.

Before starting the experiment, all subjects went through a practice session. The practice consisted in following the procedure explained in Experiment 1, for 6 practice games (2 per condition) until the reconstruction after 10 ply in all games. (Note again that during Experiment 2 itself, the players did not reconstruct the positions after 10 ply.)

5.4.2. Results

Figure 5.3 shows the means for the percentage of pieces correctly replaced. There was a main effect of Skill [$F(1, 14) = 42.6$, MSE = 16,894; $p < .001$), Depth [$F(2, 3) = 20.3$, MSE = 8,066; $p < .001$) and Interference [$F(2, 13) = 13.7$, MSE = 5,432; $p < .001$). No significant interaction was found. Post-hoc Scheffé tests showed a significant difference between the means in the empty-board and semi-static conditions (17.3%; $p < .001$), and between the empty-board and move-by-move conditions (14.5%; $p < .001$). However the difference between the two interference conditions (3.1%) was not statistically significant.

A similar pattern of results was found for the percentage of errors of omission: main effects of Skill [$F(1,14) = 16.1$, MSE = 6,958; $p < .001$], Depth [$F(2,13) = 16.7$, MSE = 7,226; $p < .001$], and Interference [$F(2,13) = 4.4$, MSE = 1,927; $p < .02$]. No interaction was significant. The only discrepancy was that the post-hoc Scheffé tests showed that only the difference between the empty-board and semi-static conditions (10.2%; $p < .03$) was significant. The results for the errors of commission were the same in all respects except for Depth: main effects of Skill [$F(1, 14) = 13.4$, MSE = 4,134; $p < .001$) and of Interference [$F(2,13) = 4.4$, MSE = 1,346; $p < .02$], but not of Depth [$F(2,13) = 2.7$, MSE = 837.46; ns]. There was no statistically significant interaction. Post-hoc Scheffé tests showed reliable differences only between the empty-board and semi-static conditions (8.9%; $p <. 02$).

Errors of commission were further classified into the following subtypes: Same (the piece is placed on a correct previous [but not actual] location of the same game), Interference (the piece belongs to the interference position), Pair (the piece belongs to a previous position of the game presented in the same pair), and Inference (the location of the piece is inferred incorrectly). In order to help visualise the relative influence of errors of commission and omission, they were plotted together in Figure 5.4 , which shows the average percentages of errors after 30 and 50 ply, all players included.

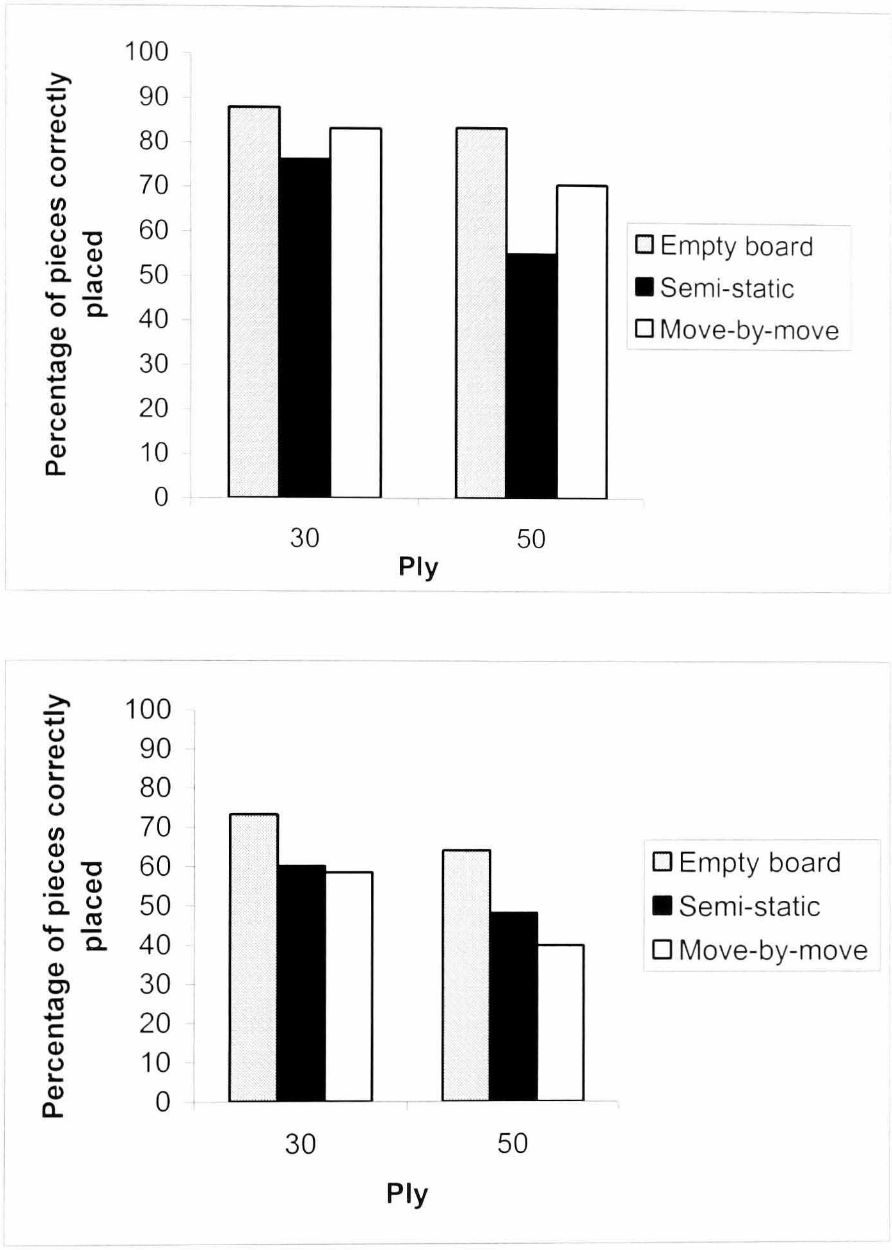

Figure 5.3. Experiment 2. Percentage correct as a function of the experimental condition (empty board, semi-static, and move-by-move) and of the number of ply (top, masters; bottom, Experts).

The use of a template for each game, predicts that there should be few errors where information is confused between the two games (pair errors) and where the information is confused with the interference position (interference errors). On the other hand, the template theory predicts that there should be more errors within the same game (same errors), since players may maintain a template for the game but fail to update it correctly. If, however, games are mainly coded as chunks, interference and pair errors should be more frequent, as an entire chunk may be incorrectly assigned to a game. Errors of omission would reflect more the difficulty of the task, and would not differentiate between these two hypotheses. Figure 5.3 shows that errors of omission and errors of the same game are the more frequent, thus supporting the presence of templates.

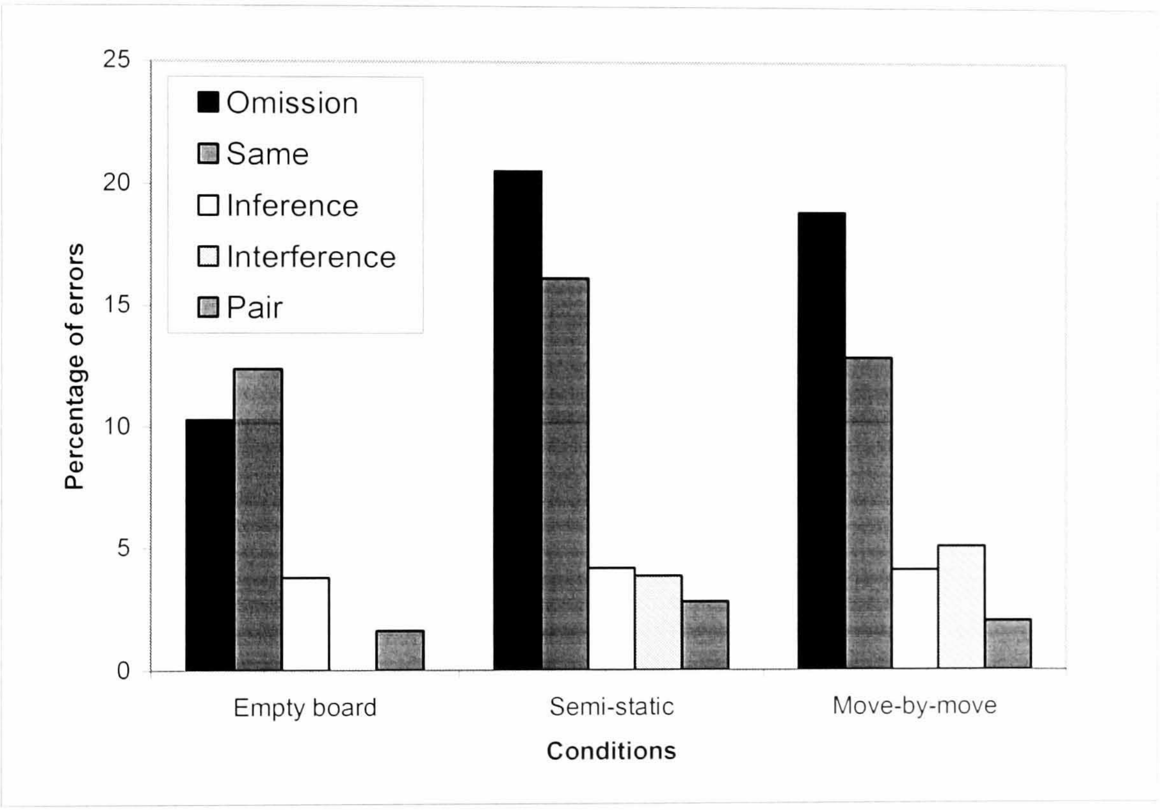

Figure 5.4. Experiment 2: Detail of errors of omission and commission.

5.4.3. Discussion

Five main results were found in the second experiment: (a) even though the skill difference between groups was reduced in comparison to the first experiment (from 308 to 260 in national rating), there was a significant Skill effect (expectedly, the effect was smaller); (b) in the control condition, masters performed worse than in the same condition of Experiment 1; (c) in comparison to experiment 1, the interaction Depth x Skill has disappeared; (d), there was an Interference effect: both Interference conditions differed from the control condition, but there was no difference between them; and (e) the presence of templates was supported by an analysis of the types of errors made during reconstruction.

The first finding has been already explained in the discussion of experiment 1. The second finding is due to the fact that the reconstruction phase after 10 ply was eliminated. It is likely that the reconstruction at that stage helped participants to memorize the game, an opportunity that was not present in experiment 2. The lack of interaction can also be explained easily with the elimination of the reconstruction task at ply 10. Indeed, the pattern of results in experiment 2 for the reconstruction of the positions after 30 and 50 ply is similar to that in experiment 1.

The most important finding is that both interference conditions had a reliable effect, unlike in experiment 1. Somewhat surprisingly, the condition with only 5 different interference positions impaired performance as much as the condition with 50 different interference positions. These results support the second hypothesis —chess players use the board's percept as a perceptual aid to refresh the positions of the game they are following mentally. In the second experiment, unlike in the first, interference positions were varied enough to impair players' performance. It was hypothesised that the novelty of the irrelevant pieces would make it hard to avoid processing them. However, although novelty did cause a decrement in performance, larger amounts of novelty did not cause larger impairment. This result will be addressed in the general discussion. Finally, the analysis of errors provided direct support for the construct of templates.

5.4.4. Subjects' strategies and the role of study time

Given the complexity of the task, it is likely that players developed strategies to memorize games. Informal comments indicate that there are several moments during which players engage in visual rehearsal. One such moment is after the presentation of each move, when, according to the template theory, the new position is updated in the mind's eye. Another such moment is before the shifting between the games. Reports also indicate that, as soon as the game moves further away from the initial position, it becomes harder to update. This is in line with template theory's prediction that middlegame positions are harder to categorize, and hence are less likely to activate a template. The difficulty in updating creates a time pressure: participants have to choose between either continuing rehearsing while the next move is presented, or quitting rehearsing and focusing on the next move. As a consequence, according to the template theory, the image in the mind's eye decays and becomes subject to errors. This general mechanism is also supported by the fact that, in the control condition of the second experiment, there was an impairment in performance as compared with the control condition in the first experiment. The difference was that players had to reconstruct the position after 10 ply in the first experiment, but not in the second. After having reconstructed the position, participants spent additional time studying the position before moving to the reconstruction of the second game or to the continuation of the presentation of moves. I believe that this study time, not available in the second experiment, allowed players to consolidate the LTM encoding of the game, and hence to obtain a better recall later. This explanation is consistent with that given by Gobet and Simon (2000) to account for the role of presentation time in a recall task.

5.5. General Discussion

In the introduction of this chapter, it was shown how the template theory, a general theory of expertise, explains most of the data on blindfold chess available in the literature. It was also noted that the mind's eye is still underspecified in the theory. In order to shed light on this issue, two experiments were carried out, where chess games were presented visually, move by move, on a board that contained irrelevant information; this background information was either static, semi-static positions, or updated after every move. These experiments had the novelty of presenting interference patterns in the context of the stimuli and opened questions about the convergence of images generated by external input and images generated by internal processes.

While the two experiments emphasized memory and involved only a small amount of problem solving, they required players to engage mechanisms that lie at the core of their expertise: the processing of (sequences of) moves. The results were consistent with the template theory. It was found that additional time to process moves led to better recall, a direct (but not surprising) prediction of the model. Another less obvious prediction was that the number of errors of the 'same' game type should be higher than the other errors of commission. Finally, as expected, depth had a reliable impact.

Evidence that changes in the background may affect performance was obtained, and it was proposed that novelty processing may be at the core of this phenomenon. Specifically, results showed that irrelevant information affects chess masters only when it changes during the presentation of the target game. This suggests that novel information is used by the mind's eye in the process of selecting incoming visual information and separating 'figure' and 'ground'. In the conditions used in experiment 1, the lack of novelty of the interference stimuli may have led to their inhibition. However, in the interference conditions of experiment 2, the positions were changed, leading novelty-detection mechanisms to process them automatically.

Applied to the present experiments, the template theory predicts that, at the beginning of a game, all players are able to access a template of the initial position. When the initial moves are dictated, players can access other templates linked to the current one, without the need to generate a visual image in the visual buffer.

However, when no templates are available, which happens earlier in experts than in masters, it becomes necessary to maintain an image in the visual buffer. How does this affect performance? In the first experiment, the irrelevant perceptual information, not being novel, does not attract attention and does not cause interference. However, in the second experiment, the irrelevant incoming perceptual information is indeed novel. This causes interference in the visual buffer between information coming from the retina and the image of the position coming from LTM.

5.6.Conclusion

This chapter was aimed at progressing one of the purposes of this thesis, which is the gathering of data towards a theory of expertise. The template theory, which has been chosen as a starting point was refined in order to account for the data available in blindfold chess. Then, two experiments were carried out to elucidate the role of expert knowledge in imagery and their results were explained using the template theory.

Chapter 4 dealt with the acquisition aspects of expertise. This chapter is the first step in the investigation of the cognitive system from a functional level. This enterprise will continue in the next three chapters in which a non very well known methodological technique was implemented.

CHAPTER 6

Cross-tasks study (1)

The role of practice revisited

6.1. Introduction

The present and the following two chapters deal with a study whose methodological approach has been explained in chapter 3 (section 3.3). Gobet and Ritter (2000) suggested that individual data analysis, combined with individual data modelling, is the best methodological approach to develop a unified theory of cognition. The main characteristic of this methodological approach is the study of one individual—or a small number of participants analysed individually—in several tasks, and the use of these data to set parameters of a computer model, that in turn should simulate the human data.

One of the purposes of this thesis is contributing towards the generation of a general theory of expertise; for that reason, I decided to utilise this methodological approach to study three relevant phenomena: practice, expert memory and expert thinking. This chapter revisits the practice issue, using a similar questionnaire to that of chapter 4; in the present study, looking at the covariation of amount of practice and Elo rating. Hence, this chapter also tackles the thesis stated in the introduction regarding extended practice as a necessary condition to attain expert performance. Chapters 6 and 7 will deal with the thesis about the factors unrelated to practice within the field of expertise.

As pointed out in chapter 2, Masunaga and Horn (2000, 2001) gave 263 GO players domain-specific tasks and general tests. Their results were quite straightforward: there was an expertise effect in GO tasks, but no expertise effect whatsoever in the general tasks. This is in accord with previous chess studies that investigated visuo-spatial abilities or general intelligence (Djakow, Petrowski & Rudik, 1927; Waters, Gobet & Leyden, 2002). The only exception is Doll and Mayr's (1987) study, which found general intelligence differences between chess experts and non-players (paradoxically, no visuo-spatial differences were found).

In this study, the idea of using domain-specific and general tasks was followed. However—as opposed to Masunaga and Horn—only 6 subjects were recruited in order to adhere to Gobet and Ritter's (2000) paradigm. Despite being a quite impressive and very well developed study, Masunaga and Horn's (2000, 2001) work has a caveat. The traditional technique of aggregating data of several individuals loses much relevant information. Analysing data individually—like in the present study—allows one to follow the performance of the same participant in several tasks.

For instance, one expert could have performed very well at general memory tasks and badly at a general speed of processing task, and the reverse could be true for another expert. Aggregating these data will show no differences with the general population. Nonetheless, if the first expert is better than the second one in domain-specific memory tasks and the second one is better in domain-specific speed of processing task, this would have important consequences for the construction of a theory. In this case, the same level of expertise is achieved with different abilities (good memory in the first expert, speed of processing in the second). Any general theory of expertise should be able to account for this phenomenon, which cannot be found with the traditional methodology. By looking at the individual differences, the experimenter can set, for instance, different values for memory capacity and speed of processing in two different models.

The next section (6.2) deals with the methodological issues concerning the whole study, the following section (6.3) shows descriptive data of the participants by using the same questionnaire as chapter 4; finally, section 6.4 analyses the time spent studying and playing chess, in a longitudinal way.

6.2. Methods

6.2.1. Participants

Six healthy right-handed participants signed a consent form and took part in the study (1 grandmaster, 1 international master, 1 expert, 1 class B player and 2 non-chess players; the note in chapter 1, page 5 explains these classifications). The grandmaster (GM) had 2550 ELO and was 21 years of age, the international master (IM) had an ELO of 2500 and his age was 22 (both of them were Spanish speakers). The expert (EX) was 19 years old and his ELO was 2100, the class B player (CB) was also 19 years old and he was internationally un-rated (for comparative purposes his national rating was transformed into 1750 ELO). One of the non-players (N1) was 22 years old and the other (N2) 21 years old. Both of them knew the laws of chess but they had never played seriously (the last four participants were English speakers). Not all of the participants performed all the tasks insofar as some tasks required chess knowledge in order to be performed (non-players did not participate in these tasks). Furthermore, the third fMRI experiment, which is part of this study, was carried out only by the two masters.

6.2.2. Tasks

In this study, participants went through numerous tasks. In the following chapters memory and thinking tasks will be considered. This chapter deals with a questionnaire (similar to the one used in chapter 4) administered to the participants. The non-players only responded to questions not related to chess. Section 6.3 is devoted to the descriptive data and section 6.4 to the issue of practice.

6.3. Descriptive data

The 6 subjects filled in the questionnaire presented in chapter 4. There was a slight difference, however. In the study presented in chapter 4 the grid that the players filled in had the two following items: 'number of hours per week spent studying alone' and 'number of hours per week spent studying or playing with others'. In the present study the items were: 'number of hours per week studying' and 'number of hours per week playing'. The change in the questions was effected because an important number of the players that filled in the questionnaire in chapter 4 told the researcher that they considered the text 'studying alone' as 'studying', and the text 'studying and playing with others' mostly as 'playing'. Obviously, the non-players only filled in the few questions not related to chess. Table 8.1 shows the descriptive data.

Since most of the questions were related to chess, the data of the non-players is not displayed in the table. N1 was a 22-year-old student and his score in the Edinburgh Handedness Inventory was 46 (right-handed), whereas N2 was a 21-year-old student who scored 50 (right-handed) in the same inventory.

Table 6.1. Descriptive data

	GM	IM	EX	CB
Age	21	22	19	19
Profession	chess player	chess player	student	student
Handedness	Right (44)	Right (46)	Right (48)	Right (43)
Rating	2550	2500	2100	1750
Starting age	6	8	8	8
Seriously age	10	11	11	13
Club age	12	11	11	17
Individual coaching	5	5	0	0
Group coaching	6	2	3	0
Books	30	15	6	0
Blindfold playing	no	no	yes	no
Blindfold reading	no	no	yes	no
Chess base	yes	yes	yes	no
Chess program	no	no	yes	yes
Rapid games	20	20	2	5
Cumulative study	6890	7904	1872	416
Cumulative play	7722	7072	2704	1326
Cumulative study (19)	4550	4836	1872	416
Cumulative play (19)	6006	4888	2704	1326
Last year study	1144	728	52	52
Last year play	884	936	208	104

Note. In handedness the number between brackets indicates the score in the Edinburgh handedness inventory (Oldfield, 1971). Starting age = age at which the players learnt how to play chess; Seriously age = age at which the chess player started to play seriously; Club age = age at which the chess player joined a chess club; Individual coaching and Group coaching = years of individual and group coaching received; Books = number of books owned; Blindfold playing = whether the player plays blindfold games; Blind reading = whether the player reads games without using the chessboard; Chess base = whether the player uses a chess base to study; Chess program = whether the player uses a chess software to play games against; Rapid game = number of rapid games per week played in the last year; Cumulative study = cumulative number of hours studied; Cumulative play = cumulative number of hours played; Cumulative study (19) = cumulative study until 19 years of age; Cumulative play (19) = cumulative play until 19 years of age; Last year study and Last year play = number of hours studying and playing in the last year.

The data presented in table 8.1 is quite consistent with the results reported in chapter 4. Although the low number of subjects in this study does not allow the use of correlation analysis (the number of subjects is lower than the number of variables to correlate), some of the variables show very marked differences between the top-class players and the intermediate players. Regarding the critical period measures, in chapter 4 the variable that explained most of the variance was age of starting to play chess seriously. In this study, the data show the same tendency. In chapter 4, unlike Charness et al. (1996), it was found that coaching was indeed important. The present study shows exactly the same result; altogether, masters clearly spent more years being coached than the intermediate players, with individual coaching being the most important of the two variables. As in Charness et al. (1996) and in chapter 4, the number of books owned is a good predictor of chess skill. Surprisingly, the number of books owned is quite low in the top-class players, especially the international master (possibly, chess data bases are replacing books as the means to acquire relevant information).

Consistent with the data of chapter 4, the masters in this study reported neither blindfold playing nor blindfold reading. Since chapter 5 directly measured skill differences in a blindfold chess task, an attempt to link the two results can be employed. In chapter 5, the masters performed better than the experts; however, neither in the questionnaire of chapter 4 nor in the present one was there a skill effect in using blindfold training techniques. A possible explanation is that the ability to play blindfold chess or to perform blindfold chess tasks is acquired implicitly through the practice of plain-view chess. This does not rule out the possibility of developing specific techniques to improve blindfold chess playing (see Fine, 1965). The same rationale can be applied to the well-established skill effect in the reconstruction of chess game positions (see chapter 2, sub-section 2.3.1.2.3); in short, this skill is not acquired by deliberate practice of reconstructing positions, but implicitly as the masters play chess. As with blindfold chess, the skill in reconstructing positions could be specifically trained (see Gobet & Jackson, 2001; Gobet & Simon, 1996a).

The masters' use of software follows the same pattern as in chapter 4. Top-class players use computers to study via chess bases; however, they do not use software to play games. The number of rapid chess games played in the last year is proportional to chess skill.

The pattern of cumulative hours of studying and playing followed the same pattern as in chapter 4. The change in the questions from 'studying alone' to 'studying' and from 'studying and playing with others' to 'playing' did not cause differences with the results obtained in chapter 4. Taking this into account, I think that the way the questions were asked in this chapter is the correct one for further research. The reason why the table shows the cumulative hours of studying and playing until 19 is to control for the different age of the participants. This allows one to compare the time of dedication to chess in the same period of time. The results in this study are consistent with the data reported in chapter 4: there is a strong correlation between dedication to chess and chess rating, and both studying and playing are equally important. Finally, the time spent studying and playing in the last year is quite a good predictor of cumulative study or practice, as also found by Charness et al. (1996). Hence, for a quick screening this question could be revealing.

6.4. Time spent playing and studying chess

The advantage of asking players their time spent studying and playing chess as a function of age is that it allows one to compare the time of dedication to chess of each player with their chess rating curve, which could also be reported as a function of age. Plotting these variables together, gives the possibility to observe patterns of covariation. Unfortunately, I did not have access to reliable national ratings; hence, only international rating (Elo) was used. This does not allow to inspection of the progress of chess skill in the early steps of the chess career, because international rating has a cut-off threshold.

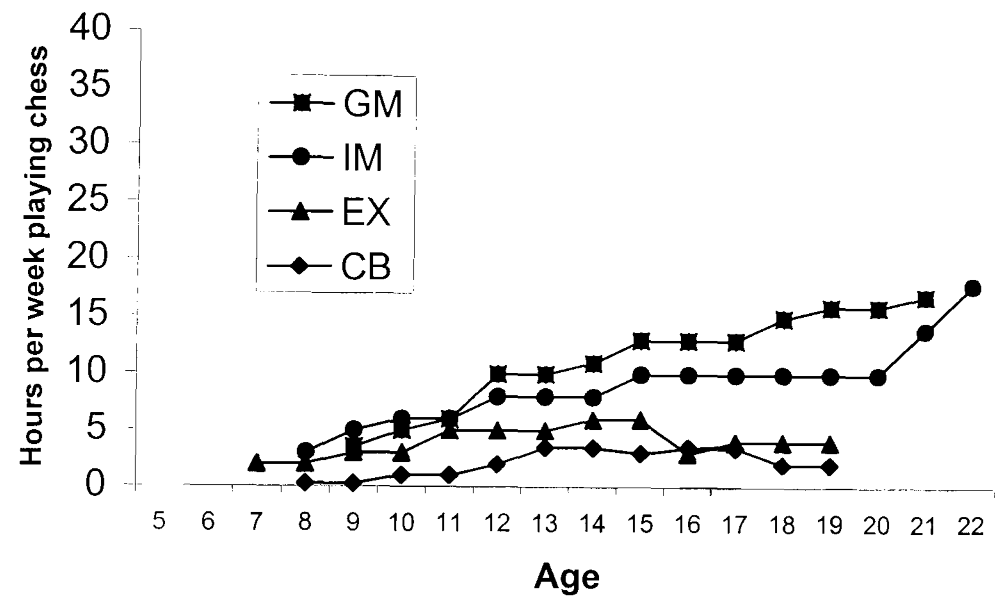

Figure 6.1. Hours of playing as a function of age.

Figure 6.1 plots the number of hours per week playing chess as a function of age. At the beginning (7 to 11 years of age), the amount of hours playing differentiates CB from the others, the former playing less than the latter. At the age of 12, the two masters increased their time playing, and at the age of 16 the difference with EX is quite remarkable. IM displays a plateau from 15 to 20; to a lesser extent the same applies for the GM (15 to 17). After that period, the latter started to moderately increase playing chess until the present day. IM showed a large increase at the age of 21 and 22.

Figure 6.2 depicts the number of hours studying chess as a function of age. The differentiation between the top-class players and EX in terms of playing behaviour started at the age of 12. In studying behaviour, at the same age, GM is studying very little and at the same level as EX; whereas CB is not studying at all. GM begins to increase studying at the age of 15, reaching the level of IM one year after. From 15 to 20 years of age, IM repeats the plateau of playing. On the other hand, GM regularly increases from 4 hours at the age of 14 to more than 20 hours at the age of 21. Finally, IM performs a large jump at the age of 21, repeating the pattern of playing; and at 22 he decreased the number of hours studying.

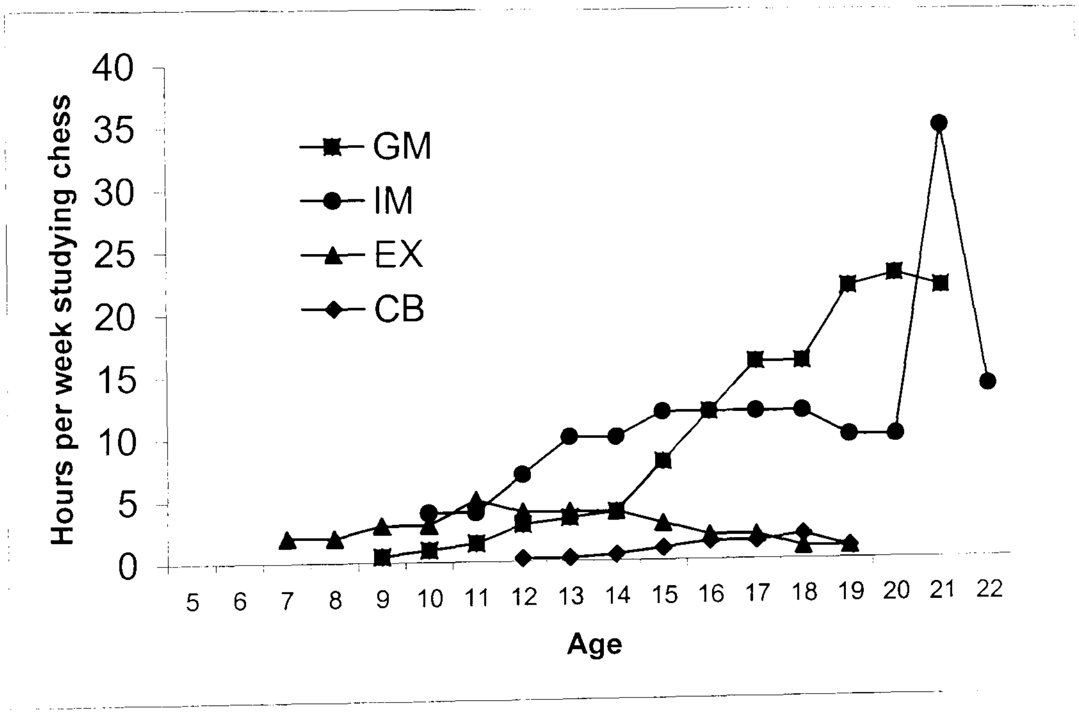

Figure 6.2. Hours of studying as a function of age.

Figure 6.3 plots the chess rating curve as a function of age. As the earlier cut-off threshold used to be 2200, it is not possible to track the progress in chess skill before this level. The cut-off threshold has changed to 2000 and, last year, changed again to 1800. IM entered the Elo rating very high - 2350 - at the level of a

FIDE master (2300). In the following 3 years he lost 45 points, but in following two years he gained enough points to pass the international master level (2400), reaching 2430, gaining about 45 points more in the following 3 years. GM entered the international rating at the same age as IM (14 years old), with a lower rating (2240). The pattern of progression is remarkably different from IM, inasmuch as his progress is quite linear, without a plateau.

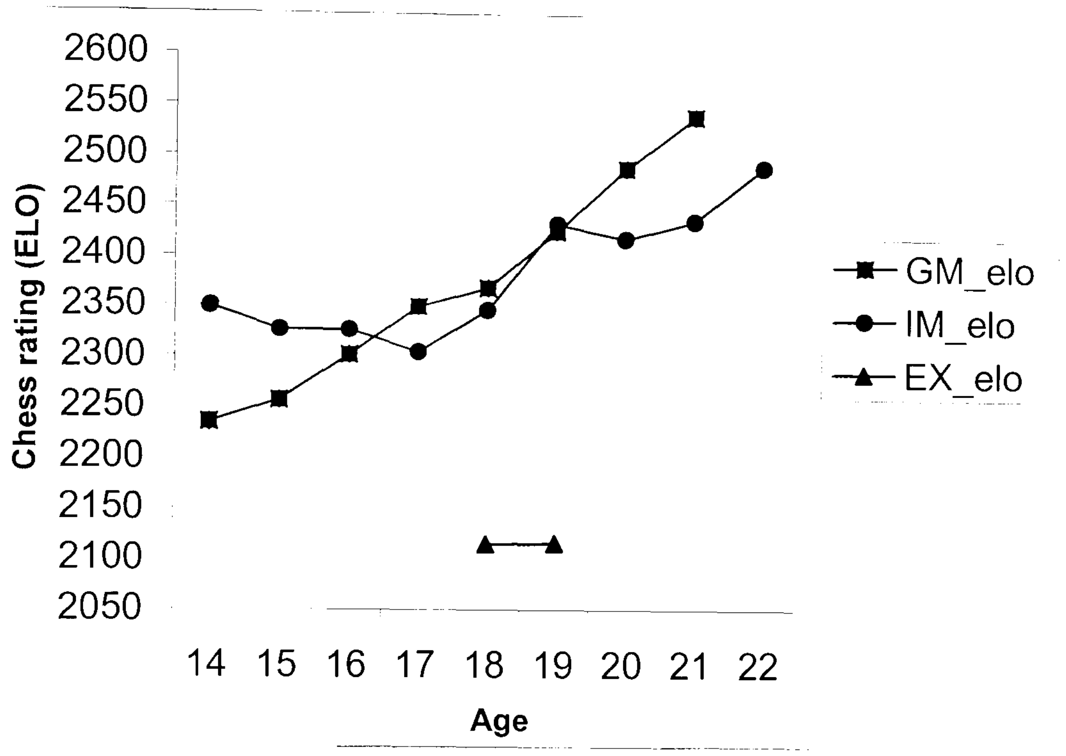

Figure 6.3. Elo as a function of age.

Figure 6.4 shows the three sets of data presented in the three earlier figures, for the two top-class players. The left axis contains the Elo rating scales and the right axis shows the hours per week spent either studying or playing chess. The purpose of plotting the data this way is that it allows one to compare the relation of the variations of practising behaviour with that of the skill level. The patterns displayed by the two masters differ in some respects, but also share other features.

From very early (10 years of age), IM distributes his time approximately equally to playing and studying chess. At 13 years of age his studying time slightly overtook his playing time, and both remain very close to each other for 9 years, with the exception of the age of 21 when IM tripled his study time. On the other hand, GM for a long time spent more time playing than studying. It was only at the age of 16 when something interesting happened.

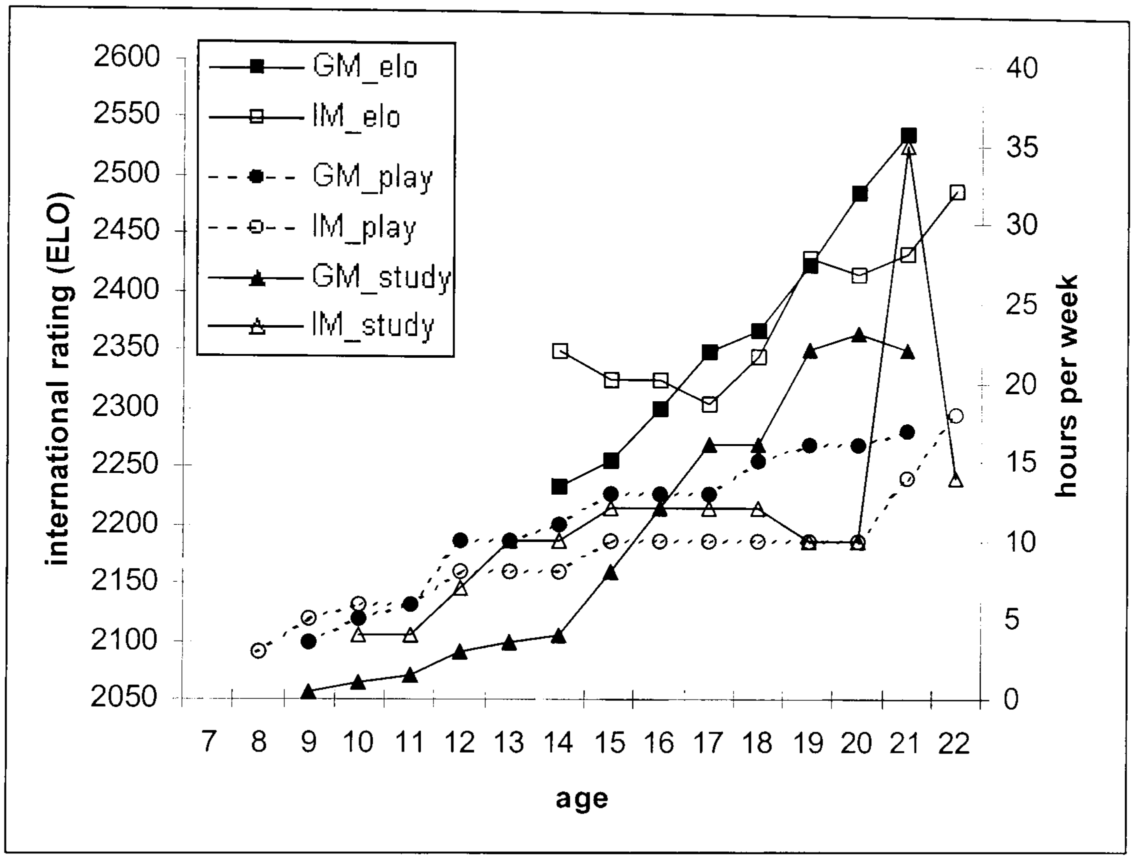

Figure 6.4. Elo and practice time as a function of age.

First, he equalised the time spent studying with that of playing, he also matched the studying time of IM, and the same is true for their international rating. An interesting pattern emerges when comparing GM's increase in hours of studying with his international rating variation. From 14 years of age to 21 these two variables appear to vary at the same rate.

Clearly these two players show a quite different pattern of progress, with GM playing much more than studying in his early ages and IM studying as much as playing. Apparently, in order to reach 2200 (master level), it is not necessary to spend too much time studying, as playing seems the most important. However, in order to cross the hurdle of 2300, studying seems vital. GM only crossed 2300 when he studied more than 15 hours a week. Besides, IM reached international rating at 14 years of age with more than 2300 and by that time he was already studying 10 hours per week.

It is worth noting that with the data presented in this chapter no causal directions can be assessed. Some open questions remain unanswered; for instance, regarding the striking correspondence of increase in chess skill and increase in study time in GM. Is the improvement in chess skill caused by augmenting the study time? or, is it that the increase of international rating is a positive reward that causes more time studying? In any case, it is not necessary to answer these questions in order to progress towards a general theory of expertise. The data gathered here is useful to insert parameters into the theory (chapter 11 tackles this issue).

Summing up, as in chapter 4, the data gathered in this chapter comes from the administration of a questionnaire, and both sets of information are consistent with each other. Once again, extended time spent studying and playing chess seem to be a necessary condition to achieve high levels of expertise; whereas it does not seem to be a sufficient condition. Ericsson et al.'s (1993) deliberate practice framework cannot explain why at the age of 14 EX, with similar cumulative time of dedication to that of GM, did not reach the same level of GM. They might argue that EX's practice was not really deliberate, but in that case, deliberate practice could become a circular concept, impossible to falsify.

This chapter is the first part of the study carried out with the same participants. The following two chapters will move from the general aspects. and undertake the investigation of cognitive processes.

CHAPTER 7

Cross-tasks (2)

Expert memory

The previous chapter commenced the series of chapters which describe the studies carried out with two top-class chess players, two intermediate players, and two non-players. The present chapter and the following are related to the purpose of contributing towards a general theory of expertise. Besides, the thesis regarding the individual differences in non-practice factors that influence the acquisition of expert performance, is also tackled. Essentially, in this chapter I investigated whether there are individual differences of performance in general memory tasks, and whether these differences are replicated in domain-specific tasks. Furthermore, in the following chapter, it will be consider if a difference in general memory processes influences thinking processes. Ultimately, in chapter 11 the results of this chapter will be used in order to set quantitative parameters to a theory of expertise—CHREST.

As seen in chapter 2 (section 2.3.1.2.3), one of the most important findings in the chess psychology literature is the poor performance of chess masters in the reconstruction of random positions from memory (see, Gobet, 1996b for a meta-analysis). This finding led to the conclusion that the skill of chess experts is quite modular and only related to the domain of expertise. In this chapter this issue is further investigated by analysing the results of chess players and non-chess players in a number of memory tasks with chess stimuli and non-chess stimuli. The results are analysed by looking at differences between chess players and non-chess players, using an analysis which also takes into consideration individual differences and the performance of the same participant in different tasks.

The results are presented in three sections. The first (7.1) will be dedicated to 'delayed recall' tasks, the second (7.2) will be devoted to 'immediate recall' tasks, and the third (7.3) will deal with memory for sequences. The first two sections present tasks with static stimuli (e.g., chess game positions), as opposed to the third section, which deals with sequences (e.g., chess game moves). The usual segregation of short-term and long-term memory tasks is not used here, because, sometimes (if not always), tasks that require immediate recall are performed with the use of long-term storages. A common mistake in cognitive psychology is to confound the type of task with the cognitive structure thought to be engaged in that task. Therefore, in this chapter the labels 'short-term' and 'long-term' are used for hypothesised memory structures, and 'immediate recall' and 'delayed recall' are used for the type of tasks.

7.1. Delayed recall

In this section data are reported from tasks that required the recall of information after a delay of at least 30 minutes[1]. The first subsection (7.1.1) presents a study in which the participants viewed a list of 250 stimuli and then went through 4 recognition test sessions (2 minutes after presentation, 6 hours after, 24 hours after, and 6 days after). The second subsection (7.1.2) deals with a delayed

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[1] In the first test of the first experiment, 30 minutes is a rough estimation. The first test was carried out two minutes after the presentation of the 250 stimuli. Since this presentation lasted about 50 minutes, some of the stimuli in the test phase were viewed less than 30 minutes before the test and others were presented more than 30 minutes before the test.

recall fMRI study, whose methodological detail will be discussed in chapter 9. In this chapter, the results of this study are considered in terms of individual differences and also for comparing the performance of the same participants in different tasks.

7.1.1. Recognition of pictures and chess positions

As mentioned in chapter 2 (section 2.3.2), the long-term memory capacity for visual stimuli, measured by recognition tasks, is very high. Indeed, Standing (1973) proposed that it is unlimited, based on the high performance of his participants in a recognition task of 10,000 pictures. On the other hand, Franken and Rowland (1979) showed a decrease in recall over time. Although in chess the most widely used way of measuring memory was the reconstruction task, some recognition experiments were also carried out by Goldin (1978, 1979). She found skill effects for the recognition of chess positions.

In the present experiments, the six participants of the study were tested with pictures and chess positions in several sessions. The rationale of this investigation was to identify whether there is a relation in the chess players between their performance in recognition of pictures and that of recognition of chess positions. Moreover, the relation between chess skill and memory performance is considered.

7.1.1.1 Procedure

This task had two sections, the first one for pictures and the second one for chess positions. In both sections there was a presentation phase in which 250 pictures or chess positions were shown for 5 seconds. There were also 4 test sessions. In each test session 100 stimuli were presented, and for each one the participants had to decide whether the stimulus presented was part of the original list of 250 or not (50 old stimuli and 50 new stimuli were presented).

The pictures were obtained on a website: www.freefoto.com and their size was 19.5 cm horizontal x 12.5 cm vertical. They were presented on a computer screen at a distance of 35 cm. Pictures were not explicitly selected to avoid similarities; however, a few very similar pictures were discarded. The size of the chess positions was 10 cm x 10 cm and they were also presented on a computer screen at a distance of 35 cm. All the positions were middle game positions

In the case of pictures there were some technical problems that changed the number of pictures presented and the ratio old/new. In the presentation section 231 pictures were presented, and the ratio old/new in the test sessions were 48/47 for test 1, 46/46 test 2, 49/47 test 3, and 42/52 for test 4. In the test phase subjects did not have a time limit. The first test session was performed two minutes after finishing the presentation session, test 2 was carried out 6 hours after the presentation, test 3 was executed 24 hours after presentation, and test 4 was carried out 6 days after presentation.

7.1.1.2 Results

Figure 7.1 shows the performance of the six participants in the recognition of pictures. Fifty per cent correct is performing at chance. Supporting Franken and

Rowland's (1979) results, a clear impairment in performance could be observed in the present study. The average of the six participants was 86.49% in the first test, 80.97% in the second, 77.08% in the third, dropping to 69.11% in the last one. It is also interesting that GM performed better than the rest of the participants. The gap between GM and the others was 6.10% in the first test (91.57% to 85.47%), 15% in the second (93.47% to 78.47%), 12.5% in the third (87.5% to 75%) and 11.53% in the last one (78.72 to 67.19%). Regarding IM, he performed at an average level.

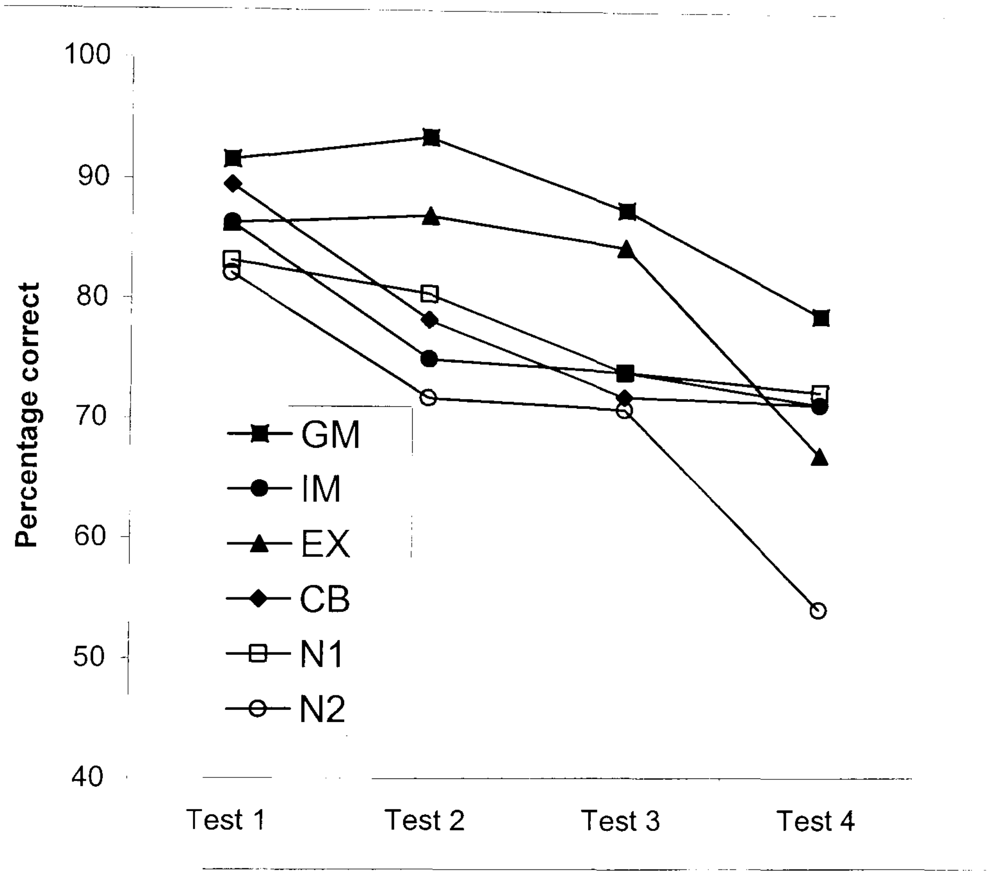

Figure 7.1. Accuracy for pictures. Test 1 = 2 minutes after the encoding phase, test 2 = 6 hours after the encoding phase, test 3 = 24 hours after the encoding phase, test 4 = 6 days after the encoding phase. 50% is chance.

It is interesting to investigate whether GM advantage over IM in memory for pictures is also apparent for chess positions. Figure 7.2 plots the performance for recognition of chess positions in terms of accuracy.

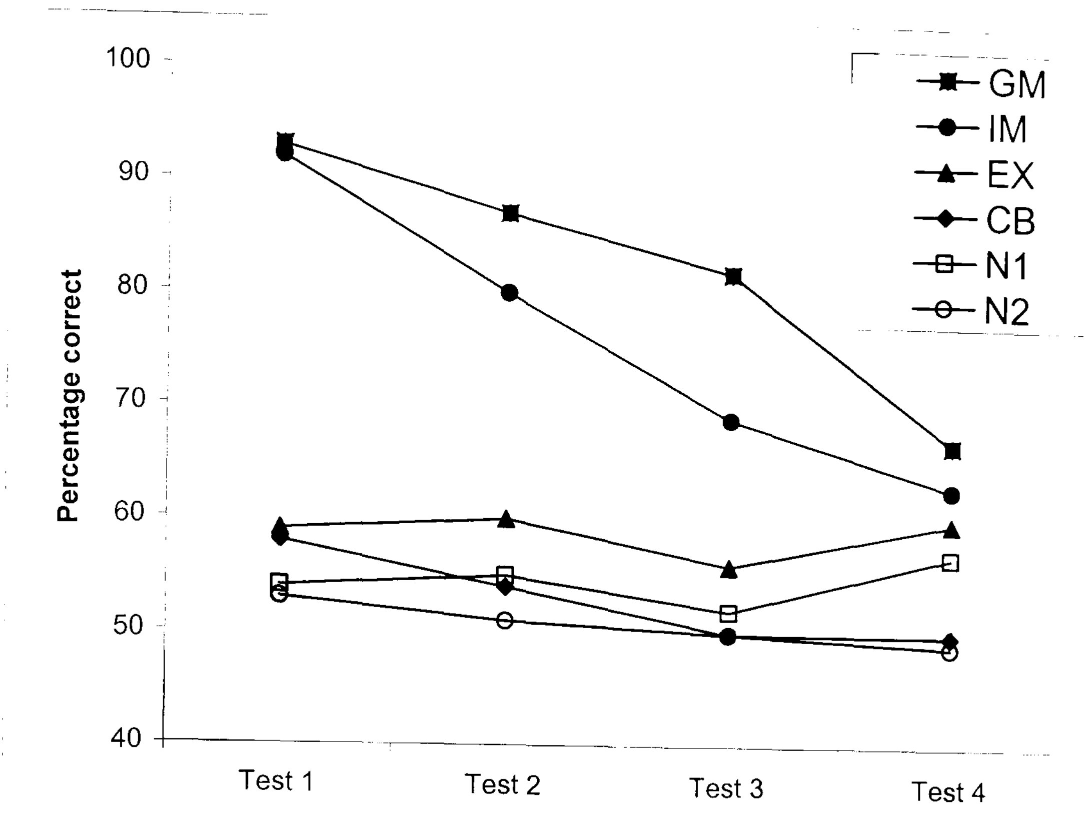

Figure 7.2. Accuracy for chess positions. Test 1 = 2 minutes after the encoding phase, test 2 = 6 hours after the encoding phase, test 3 = 24 hours after the encoding phase, test 4 = 6 days after the encoding phase. 50% is chance.

It is evident that non-chess players were not able to maintain in memory any chess position and the same applies for CB. All of them performed around chance. EX performed slightly better than chance around 60%. Even for the two top-class players the recognition of chess positions was difficult, and, in some of the sessions was even lower than that of the pictures. Table 7.1 shows a comparison between the performance for pictures and that of chess positions in GM and IM.

Table 7.1. Differences in accuracy between pictures and chess positions.

	1	2	3	4
GM	-0.43	6.47	5.5	11.72
IM	-5.69	-5	4.95	8.27

Note. Negative sign means that accuracy for chess positions was higher than that for pictures.

IM's performance is similar for chess positions and pictures. He did better for chess positions immediately and after 6 hours, but he was better for pictures after 24 hours delay and after 6 days. GM performed equally in the first test, being slightly better for pictures in trials 2 and 3, increasing this advantage in the last trial. If we took the scores for pictures as the limit of the memory system, it could be said that GM is not performing at his ceiling for chess positions and there is scope for him to improve his performance.

Table 7.2 depicts the differences between GM and IM for chess and pictures across the tests. GM and IM perform similarly immediately after the presentation session (probably a slight difference for pictures), GM does better in trial 2, much better in trial 3, and the difference diminishes in trial 4. It seems that GM's decrease in performance is more moderate and starts later than that of IM.

Table 7.2. Differences in accuracy between GM vs. IM.

	1	2	3	4
Chess	1	7	13	4
Pictures	5.26	18.47	13.55	7.45

7.1.1.3 Discussion

A number of results were uncovered in this experiment. First, a drop in accuracy was observed for all the participants in both conditions. Second, the performance for pictures is much better than that for chess positions for the non-players and the intermediate players, and moderately better in top-class players. Third, GM performed better than the rest of participants in pictures recognition, whereas IM performance is quite standard. Fourth, GM performed better than IM for chess positions after 6 and 24 hours delay but not immediately or after 6 days.

The first result is in accord with Franken and Rowland's (1979) study in which there was a drop in performance as a function of time. Regarding the second result, the better performance for pictures than for chess positions in top-class players is not surprising insofar as they are not only experts in chess but also in the recognition of everyday objects; indeed, they are more experts in the latter than in the former. This argument will be expanded in chapter 10 (section 10.1) where I will discuss the proposal of Gauthier et al. (1999), who consider that the activation in the 'fusiform face area' is not specific for faces but is due to the expertise that the lay person has in recognising faces.

The third finding is revealing and is one of the aims of this set of experiments. GM showed a clear advantage over all the players. His performance is very good, although it is not exceptional. Following the innate talent vs deliberate practice debate of chapter 4, I suggest that in some cases the individual differences might exist not at differentiating between levels of expertise, but within the same level of expertise. GM's difference from IM in terms of chess rating is not high (about 50 points; also, they came joint first in their country's national tournament the same year as the experiment), although the performance in this non-domain-specific task was quite different.

In chapter 11, I will address a different position on how the analysis of individual differences could be done. Essentially, it may be more informative to use the information of the individual differences to set parameters, predict outcomes in experiments and model data using those parameters (see Gobet & Ritter, 2000). In this case, a different decay rate of memory for each player should be set. IM starting a steep decay somewhere between 30 minutes and 6 hours, and GM doing so somewhere between 1 and 6 days.

7.1.2. Recognition of one's own and others' game positions

The two top-class players participated in an fMRI study that had two purposes: first, investigating autobiographical memory, and second, finding individual differences in these two players in terms of behavioural and neural measures of memory. All the methodological details and the topic of autobiographical memory will be presented in chapter 9. In this section, the focus is on individual differences in behavioural performance and brain activity patterns.

Briefly, the players went through a scanning session in which they saw positions belonging to their own games, positions belonging to other players' games and a control condition. The players were informed that they had to remember the positions because they would be tested on them at some point in the day, after the scanning session. After 4 hours they went through a recall task in which they were required to give information of the games they saw during the scanning session. An hour later, they performed a recognition/ownership task, in which new and old positions were presented and they had to decide for each position whether it was new or old and whether it was a position from one of their own games or not.

7.1.2.1 Behavioural results

In the recall task, GM recalled 83.58% of the total game positions presented in the scanning session four hours earlier. IM also performed reasonably well, though slightly worse than GM: 69.69%. In the recognition task, GM performed at 97.74% (99.74% for own positions; 93.75% for other's positions); IM performed again slightly worse at 94.28% (96.06% own; 89.58 others). Both players did very well in assigning ownership; again GM did better: GM, 97.17% and IM 89.14%.

Since Standing (1973) used both recognition and recall measures, it was thought to be valuable to compare his results to the ones presented in this section. Standing (1973) compared recognition with recall of pictures showing a 93.75% of accuracy in recognition and only 25.8% accuracy in recall. Several issues are worth noting. First, the recognition of positions of other players in the present experiment followed a similar pattern to that of Standing 's (1973) participants. Second, the recognition of own positions in the present study was better than that of other players' positions. Third, the performance in the recall task was much higher in this study (25.8% in Standing, 1973; 83.58% and 69.69% in the top-class players). Thus, the first-hand experience with the stimuli increases the recall performance three-fold, closing the gap to the performance in recognition. The latter result is in agreement with Goldin (1978) who found that the level of processing of the to-be-remembered chess stimuli affected performance (i.e., the deeper the processing the better the performance)

The task in the present fMRI experiment was very similar to the one discussed in section 7.1.1 (5 seconds presentation of stimuli for later recall). The recognition test was performed five hours after the presentation (similar to the six hours delay in the first test of previous section). However, the performance was higher in the fMRI experiment. This could be easily explained by two factors. First, the list of to-be-remembered stimuli in the fMRI study was smaller (around 90) and included quite familiar stimuli. Second, there was a large inter-stimulus interval in the fMRI experiment (13 seconds) that might have allowed the participants to engage in rehearsal.

Despite these different paradigms, the differences between GM and IM remained intact. After 4 hours there is a clear difference in recall and 1 hour later there is a slight difference in recognition.

7.1.2.2 Brain imaging results

The voxel analysis in chapter 9 was carried out in order to find common patterns between the players; thus individual differences were not taken into account. In this section individual differences are considered. Interestingly, there are some differences in the number of voxels activated. GM displayed an activation of 2702, 2190 and 771 voxels for the contrasts own > control, others > control, and own > others, respectively. IM showed the following figures for the same contrasts: 5138, 2221, and 1237. It is apparent that IM required more brain activity (and probably more effort[2]) than GM to perform 'own', but not for 'others'.

7.1.2.3 Discussion

Behavioural data in the fMRI experiment are in accord with the delayed-recall study in section 7.1.1. GM performed better than IM after 4 and 5 hours in the recall and recognition tasks respectively. A hint is provided that this difference

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[2] Chapter 10 will address the issue of effort in terms of brain activity.

could have a neural correlate in the number of voxels activated for 'own'. This proposal is in agreement with the fMRI experiments in chapter 10, in which chess players required less brain activity than non-chess players to perform the same task (i.e., the higher the effort, the greater amount of brain activity).

7.2. Immediate recall

Section 7.1 discussed memory experiments in which the test phase occurred at least 30 minutes after the presentation of the to-be-remembered stimuli. In this section, the focus moves to experiments in which the test phase follows immediately after the presentation of the stimulus or stimuli to be remembered. Both chess-related tasks and general memory tests will be considered.

The first sub-section (7.2.1) deals with the popular reconstruction experiments that started with De Groot's (1946/1978) seminal work. Following the general idea of the present study, the reconstruction of normal positions is compared with the same task with stimuli in which the chess expertise is not involved. The standard random positions were used, but also in this study 'shape' positions were introduced (a similar version of this task was used in Schneider et al., 1993). In the second section the opposite was done. A set of well-known memory tests - span of digits and letters - were carried out and the same task with chess stimuli was created. As was mentioned earlier, one goal of this study is to provide data in order to generate a general theory of expertise. Two important questions arise here: Do the patterns observed in delayed recall remain constant in an immediate recall task? Does performance of players and non-players differ between chess stimuli and non-chess stimuli?

7.2.1. Reconstruction task

Chapter 2 (sub-section 2.3.1.2 3), showed the relevance of the reconstruction task in psychology of expertise. As indicated earlier, a robust finding in the literature is that chess masters outperform chess novices in the reconstruction from memory of a game position. It was also mentioned that this effect almost disappears when random positions are presented instead. In this section the reconstruction task was presented in three versions: 'game', 'random' and 'shape'.

7.2.1.1. Procedure

Participants were presented with a chess position for 5 seconds, then the position disappeared, leaving a black screen; then, after a delay of 2 seconds, the participants had to reconstruct the position previously seen ('game' condition). The second condition is to present a position in which the location of the pieces of a game position is randomly assigned ('random' condition).

The third condition was especially designed for this experiment; instead of using chess pieces, different types of shapes were utilised (e.g., triangles, circles, rectangles), and with this type of presentation both random and normal positions were created ('shape-game' and 'shape-random' conditions). The positions for these conditions were prepared as follows: first, either a game position was chosen from a data base or a random position was generated, and then the chess pieces of the position were replaced by shapes in a way that it was not possible to match a particular shape to a particular chess piece (although black pieces were replaced by black shapes and white pieces by white shapes). For instance, there were more than one type of shapes that appeared 3 times (e.g., three triangles, and three squares), which is almost impossible in a chess position.

In this study, accuracy and eye movements were recorded (though the eye movement data is not discussed in this thesis). Some of the trials within each condition were carried out with the eye-tracker, and some others without the eye-tracker. Since the performance did not differ between the two research settings, the data were pooled together.

There were 5 categories within the game condition: 'quiet', 'complex', 'standard', 'gm' and 'im'. In the quiet positions, it is more likely to find familiar structures than in standard positions, and in these ones more than in the complex positions; therefore, better performance is expected in the quiet condition, then in the standard condition and then in the complex condition. 'Gm' and 'im' positions belonged to games of each of the top players. As could be seen in section 7.1.2, the recognition of one's own games in the fMRI experiment was slightly better than the recognition of positions of other players. It is expected that the same pattern will appear here.

The size of the chessboards in all the conditions was 10 cm x 10 cm, and the stimuli were presented on a computer screen at a distance of 35 cm. The stimuli that were presented during the eye-tracking session, were bigger (13 cm x 13 cm) and the distance was also larger—50 cm—leading to both settings being displayed at a similar visual angle (about 16° and 15° respectively). The second column of table 8.4 shows the number of pieces used in the positions, and the second column of table 8.5 depicts the number of positions used in each condition.

7.2.1.2 Results

Table 7.3 shows the results as percentage correct. In accord with the literature, top-class players performed very well in the game condition (both players above 80%). Also, EX and CB performed according to their level (54% and 47% respectively). Non-chess players performed below 20% as expected. Within the game category the results were as predicted. All the players reconstructed quiet positions better than the complex. GM recalled his positions better than IM's positions and the contrary was also true for IM.

Regarding random positions, once again, the results matched those in the literature. Masters dropped from above 80% to just above 20%, but slightly better than the intermediate players (around 17%). This result is predicted by CHREST and consistent with the previous data (see Gobet & Simon, 1996b for a meta-analysis). In the shape condition the expertise effect totally vanished, with the exception of N2 who performed quite badly.

Table 7.4 shows the same data but presented as total number of pieces correctly recalled, which is important because of the aim of setting parameters for cognitive functions.

Table 7.3. Reconstruction task. Percentage of pieces correctly placed in all the conditions.

	# pieces		GM		IM		EX		CB		N1		N2	
	M	(sd)	M	(sd)	M	(sd)	M	(sd)	M	(sd)	M	(sd)	M	(sd)
Game	**25.47**	(1.2)	**83.17**	(15.2)	**85.04**	(14.5)	**54.39**	(15.3)	**46.91**	(12.7)	**18.13**	(8.52)	**13.83**	(5.89)
Quiet	26	(0)	89.42	(8.52)	95.19	(3.68)	69.23	(17.48)	59.62	(4.96)	19.23	(7.02)	15.38	(7.69)
Complex	25.5	(0.57)	68.81	(20.34)	65.88	(14.45)	44.23	(8.84)	36.35	(13.25)	14.73	(3.9)	12.81	(5.98)
Gm	26	(0)	88.46	(11.32)	78.85	(8)	44.23	(11.1)	48.08	(10.18)	19.23	(8.3)	10.58	(1.92)
Im	25.75	(0.5)	80.62	(9.85)	94.23	(9.15)	57.46	(13.26)	43.38	(14.92)	15.5	(4.31)	12.69	(8.1)
Standard	24.4	(2.19)	87.7	(17.99)	90.16	(12.95)	48.36	(14.59)	46.72	(11.07)	21.31	(15.41)	17.21	(5.32)
Random	**25.11**	(2.66)	**21.7**	(5.97)	**19**	(7.09)	**17.7**	(5.66)	**15.5**	(5.42)	**11.9**	(6.57)	**13.7**	(4.02)
Shape	**25.87**	(0.35)	**15.9**	(3.83)	**15.5**	(10.1)	**15**	(8.12)	**15**	(5.6)	**14.5**	(4.48)	**9.16**	(5.8)
Game	26	(0)	18.27	(3.65)	11.54	(13.65)	15.38	(3.11)	19.23	(3.11)	15.38	(5.42)	10.58	(4.8)
Random	26.25	(0.5)	13.33	(2.17)	19.05	(3.08)	14.29	(11.77)	10.48	(3.61)	13.33	(3.81)	7.61	(7.04)
Total	**25.47**	(1.55)	**54.42**	(34.43)	**54.73**	(36.2)	**37.38**	(22.65)	**32.74**	(18.85)	**15.9**	(7.73)	**12.8**	(5.65)

Note. The second column represents the mean number of pieces with their standard deviations between brackets. M = Mean, (sd) = standard deviation.

The reconstruction of around 4 pieces in the shape condition is in accord with the estimation of 4 items as the normal limit of visual short-term memory capacity (Cowan, 2000; Zhang & Simon). Masters' expert knowledge allows them to increase capacity to around 5 items in the random task, over the intermediate players who still perform at around 4. In the game condition, both masters and intermediate overcome the normal limit: above 20 items for the masters, around 13 items for the intermediate players.

Table 7.4. Reconstruction task. Number of pieces correctly placed in all the conditions.

		GM		IM		EX		CB		N1		N2	
	#pieces	m	sd	M	sd	m	sd	m	sd	m	sd	m	Sd
Game	21	**21.19**	3.86	**21.66**	3.69	**13.85**	3.9	**11.95**	3.24	**4.61**	2.17	**3.52**	1.5
Quiet	4	23.25	2.21	24.75	0.95	18	4.54	15.5	1.29	5	1.82	4	2
Complex	4	17.5	5.06	16.75	3.4	11.25	2.06	9.25	3.3	3.75	0.95	3.25	1.5
Gm	4	23	2.94	20.5	2.08	14	3.16	12.5	2.64	5	2.16	2.75	0.5
Im	4	20.75	2.5	24.25	2.21	14.75	3.09	11.25	3.59	4	1.15	3.25	2.06
Standard	5	21.4	4.39	22	3.16	11.8	3.56	11.4	2.7	5.2	3.76	4.2	1.3
Random	9	**5.44**	1.5	**4.77**	1.78	**4.44**	1.42	**3.88**	1.36	**3**	1.65	**3.44**	1.01
Shape	8	**4.12**	0.99	**4**	2.61	**3.87**	2.1	**3.87**	1.45	**3.75**	1.16	**2.37**	1.5
Game	4	4.75	0.95	3	3.55	4	0.81	5	0.81	4	1.41	2.75	1.25
Random	4	3.5	0.57	5	0.81	3.75	3.09	2.75	0.95	3.5	1	2	1.85
Overall	38	**13.86**	8.77	**13.94**	9.22	**9.52**	5.77	**8.34**	4.8	**4.05**	1.97	3.26	1.44

7.2.2. Measures of memory span

The previous sub-section (7.2.1), replicated several results in the literature. A strong skill effect was found for the reconstruction of normal game positions, almost no differences between masters and intermediate players were found in the random condition, and no differences in any of the shape conditions. Moreover, no individual differences were detected between the two masters. The logical extension taken was to use general memory measures. Taking into account the previous results, there should not be a skill effect in the general memory measures either.

In this section four measures of memory span were used: 'digit', 'letter', 'chess' and 'spatial'. As pointed out in chapter 2 (see sub-section 2.3.1.2.1), digit and letter memory spans are extensively used in memory research, and they are part of intelligence tests (e.g. WAIS, Wechsler, 1939). For instance, it has been shown that the skill effect extant in the reconstruction of chess positions disappears when general memory measures are carried out (see Chi, 1978; Schneider et al., 1993). For this study, a spatial span was created, similar to the Corsi test (see Corsi, 1972). Additionally, a memory span of chess symbols was also used. The four measures of memory span were of visual nature and two versions were presented: sequential and spatial.

7.2.2.1 Procedure

In this section a series of memory span measures were taken: 'letters', 'digits', 'spatial' and 'chess'. For each type, a sequential and a simultaneous span were obtained. In all the measures a series of 2 items was presented; when the series finished, the participants had to say out loud or write down (see below) the sequence in the same order of presentation (in all the sequential spans), or from left to right (in all the simultaneous spans, except the spatial one). The items were visually presented on a computer screen at a rate of 1 item per second. For each participant a span was calculated as follows. If the participant gave the correct sequence for the two-items list a new series of two items was given. If he did it correctly again, two series of three items were presented, then the number of items increased until the participant failed to provide the correct sequence. In that case, the number of items of the previous sequence was that subject's memory span. An explanation of each measure is given below.

Digit sequential. A sequence of digits was presented on a computer screen at a rate of 1 per second, starting with two items and then increasing until the participant failed. The participants had to say out loud the series of numbers in the same order as seen before. They were not allowed to give a group of numbers as a response (e.g., two hundred and eighty two was incorrect; two-eight-two was correct).

Digit simultaneous. A string of digits was displayed on a computer screen for a time that varied as a function of the number of items in the string (one second for each item). When the display disappeared, the participants had to say out loud the string of numbers from beginning to end. The participants were not allowed to give a group of numbers as a response.

Letter sequential. Same procedure as with digits sequential; the participants had to give the name of each letter individually.

Letter simultaneous. Same procedure as with digit simultaneous; the participants had to give the name of each letter individually.

Chess sequential. Same procedure as with letters sequential. Instead of letters, the symbol of chess pieces was presented on an empty background (i.e., no chessboard was displayed). The participants had to say out loud the name and colour of each piece. The non-players knew the names of the pieces.

Chess simultaneous. Same procedure as in letter simultaneous.

Spatial sequential. Spatial span consisted of a 5 x 5 grid in which a red square was presented for one second in one of the cells of the grid, and then the square moved to another cell in which it stayed for one second, and so on. Each location of the square was in a different column, row and diagonal from the previous location. After the sequence was presented the participants had to write down a series of numbers on a blank grid. The cell in which the number was put indicated the location, and the actual number indicated the order. The task was to indicate the correct location and order of the squares shown in the sequence.

Spatial simultaneous. A grid with sequential numbers (i.e., 1, 2, 3, 4, ...) was presented for the number of seconds equal to the number of digits on the grid. The task was to correctly place on a blank grid the digits displayed earlier.

7.2.2.2 Results

Figures 7.3 plots the results for the sequential span and figure 7.4 depicts the data for the simultaneous span. The performance in the simultaneous span is better than that of the sequential spans for all the participants. In terms of comparisons across levels of expertise no clear patterns of any effect could be found. All the participants look quite irregular across tasks; for that reason no strong effects are observed.

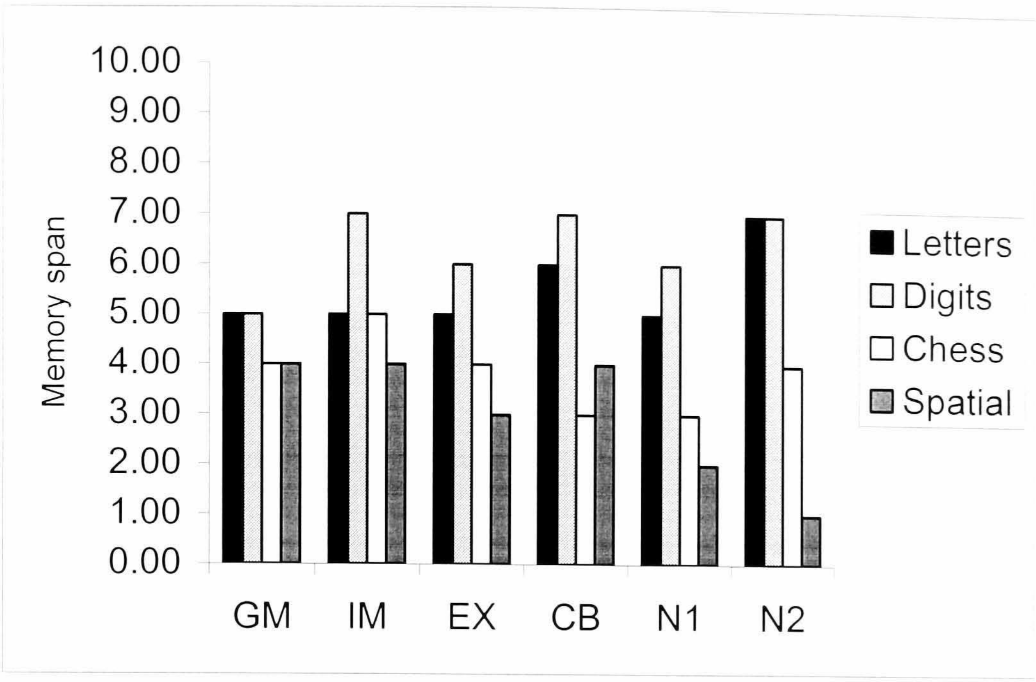

Figure 7.3. Sequential spans

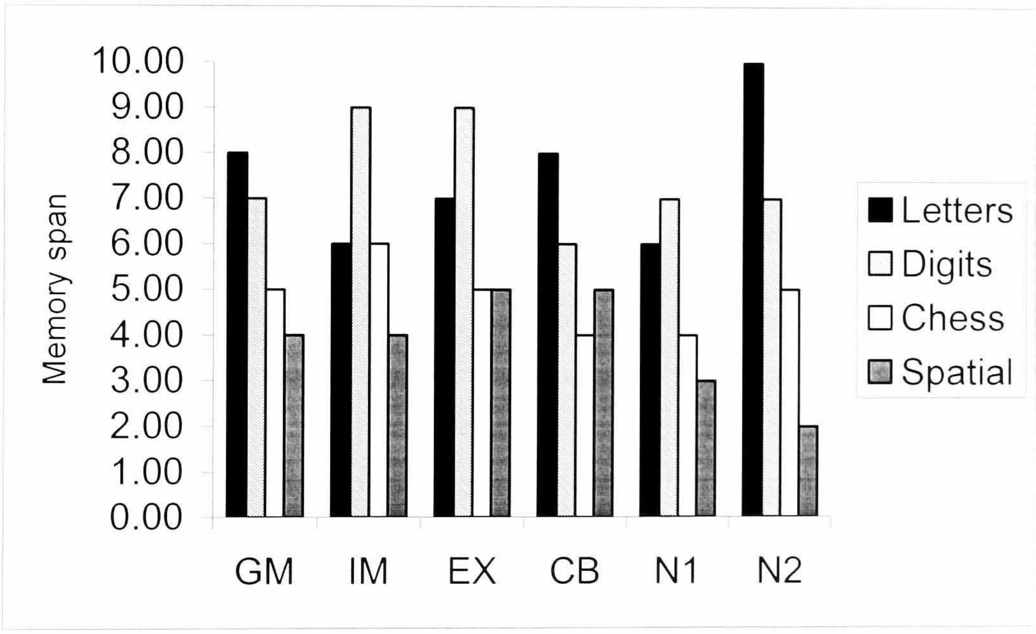

Figure 7.4. Simultaneous spans

Probably, the only condition which showed a difference between chess players and non-chess players is the spatial task in both the sequential and the simultaneous versions. However, within chess players the direction of the difference is not clear. In spatial sequential masters were slightly better than intermediates, and the opposite is true for spatial simultaneous.

A caveat of the study should be pointed out here. The two masters were Spanish speakers and the rest of participants were English speakers. Baddeley (1996) proposed that the capacity limit of working memory is specified by the number of items capable of being rehearsed within two seconds. Therefore, it is important to consider the number of syllables of the letters, digits and name of chess pieces presented in the tasks. The names of 11 out of 26 letters of the alphabet used have one more syllable in Spanish than in English, five out of the ten digits have one more syllable in Spanish, and three of the six chess pieces have one more syllable in Spanish than in English. In the latter case the words for 'white' and 'black'—which the participants had to say out loud for every chess piece— are also one syllable longer in Spanish.

Therefore, it might be the case that the memory span of the chess masters were underestimated. Nonetheless, it does not seem that the digit and letter span would be higher in the masters than in the other participants, even controlling for this problem. On the other hand, it could considerably increase the span for chess pieces and equalise the intermediates in the simultaneous spatial span.

7.2.3 Memory. Immediate recall. Conclusions

Two popular tasks were used in this study. One is a well known paradigm to measure expert memory - the reconstruction task - and the other is a well established test to measure memory span. The results gathered in the chess literature were replicated, i. e., chess experts performed remarkably better than intermediate players in the game condition and the difference among them significantly reduced in the random condition. Nevertheless, there was still a small difference in that case, as predicted by CHREST. This study also used the reconstruction of shapes, showing a lack of an expertise effect, even when the shapes replaced game positions. The memory span task showed a very irregular pattern, without consistent and clear differences.

Overall, the results in the immediate recall experiments are in agreement with mainstream chess psychology: chess expertise is domain-specific (e.g., De Groot, 1946; Chase & Simon, 1973; Gobet & Simon, 1996a). It could be useful to investigate more deeply the spatial task to find out whether the expertise effect shown here is robust or not.

7.3. Memory for chess game move sequences

The previous sections (7.1 and 7.2) mainly discussed memory experiments with static stimuli: different types of chess stimuli, pictures, letters, digits and chess pieces. The non-static type of stimuli—in the task that measured sequential spatial span—was the only non-domain specific task which showed a tendency in favour of the chess players. A logical extension of these findings is to investigate memory for non-static stimuli in chess. There is no more natural material for a chess players than a sequence of chess game moves. Surprisingly, very little research has been done with chess game moves. In chapter 2 (section 2.3.1.2.3), only a handful of studies that presented sequences of moves could be found. Chase and Simon (1973) found a skill effect both for real games and random games. Furthermore, Saariluoma (1991) and Saariluoma and Kalakoski (1997) found the same effect in game and random legal moves presented blindfold, but not for random illegal moves.

In the present study, I investigated the performance in memory for move sequences. Once again, a familiar condition for chess players was used, as well as two less familiar conditions. The participants were submitted to three conditions: 'chess', 'draughts' and 'GO'. The three board games have in common the sequential aspect, i.e., white plays a move, which is followed by a black move, then a white one, and so on. Chess and draughts differ from GO in that the former two games start with an initial display of pieces on the board which changes gradually as the players move the pieces. In GO, the game starts with an empty board and players alternatively add pieces (called 'stones') to the board. Chess diverges from draughts in that there are six types of pieces with different movements, whereas in draughts there is only one type of piece.

7.3.1. Procedure

A sequence of ten chess moves (i.e., 10 white and 10 black; i.e., 20 plies), 10 draughts moves, and 10 moves of a GO-like game were designed for this experiment. The chess moves were reproduced on a chessboard displayed on a computer screen at a rate of 7 seconds per move. After the sequence was fully presented, the participants had to reconstruct the sequence on a wooden chessboard. If they failed to reconstruct the whole sequence perfectly, the sequence was presented once again until they were able to perform the task correctly. Even if the participants did not complete the full correct sequence after 6 trials the experiment was over. The chess moves sequence consisted of a very odd opening, which is not in the repertoire of any serious player.

In the draughts condition the same procedure as chess was followed: draughts pieces were displayed on a chessboard on a computer screen and an odd opening was reproduced. The GO condition consisted of an empty chess board in which white and black circles were added sequentially (it should be pointed out that GO is not played on a chessboard, but in a 19 x 19 grid). The participants had to reconstruct on the chessboard the location of the circles in the correct order.

For the participants the order of the tasks was: chess, draughts, and GO. After the participants went through the three conditions, the experimenter asked them for a description of how they performed the task and took notes of their comments.

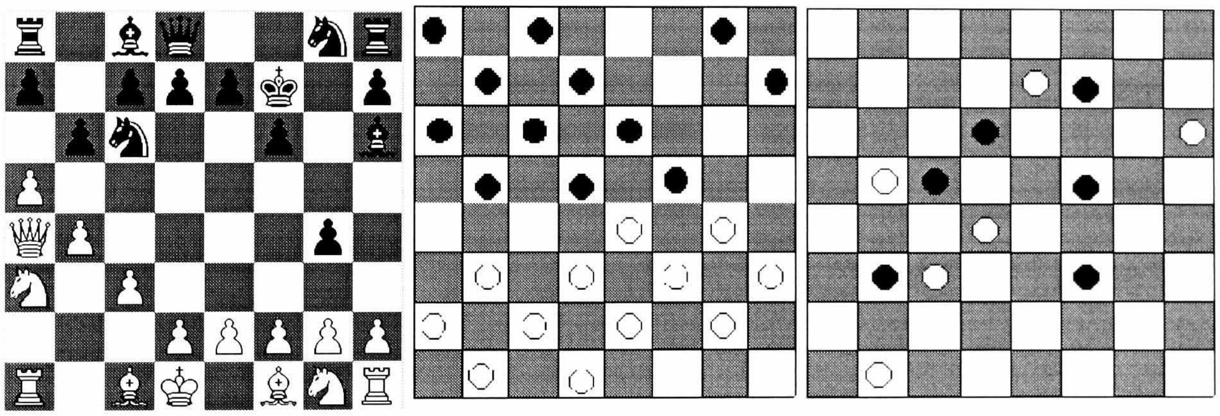

Figure 7.5. Examples of positions in each task. From left to right, 'chess', 'draughts' and 'GO'.

7.3.2. Results

The scores for the three conditions were obtained as follows. The reconstruction of the correct move in the correct order was considered 0 errors; a correct move in an incorrect order was considered 1 error, and no move or an incorrect move was considered 2 errors. The total possible number of errors was 40 (i.e., 2 x 20 moves).

Table 7.5 shows the number of trials needed by each participant in order to reconstruct the sequence perfectly. Figures 7.6, 7.7, and 7.8 plot the number of errors per trial in the chess, the draughts and the GO conditions respectively.

Table 7.5. Trials to learn the sequence

	Chess	Draughts	Go
GM	2	3	3
IM	2	2	3
EX	4	3	5
CB	2	3	5
N1	4	6	6
N2	>6	>6	>6

The results are somewhat surprising. The chess condition clearly differentiated chess players from non-chess players, but the difference between masters and intermediates is not so clear. There are clear differences between the top-class players and EX but no clear differences with CB were found.

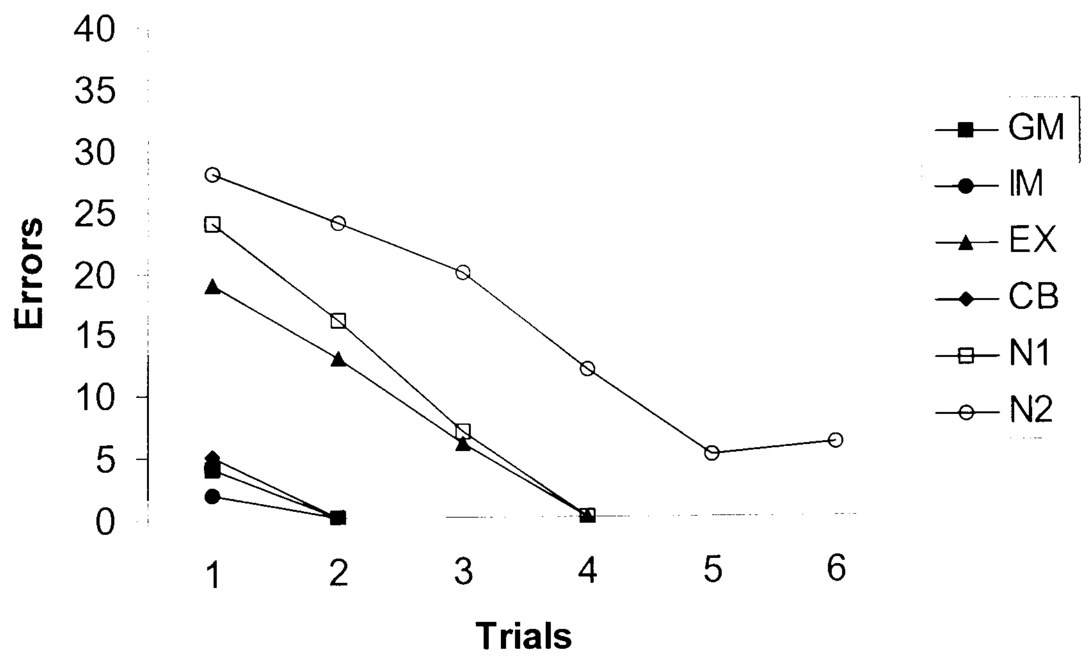

Figure 7.6. Errors per trial in chess (maximum=40)

In the draughts condition there was again an expertise effect. Chess players are clearly better than non-chess players and a small difference could be observed between masters and intermediate players, especially in the number of errors of the first trial (see figure 7.7)

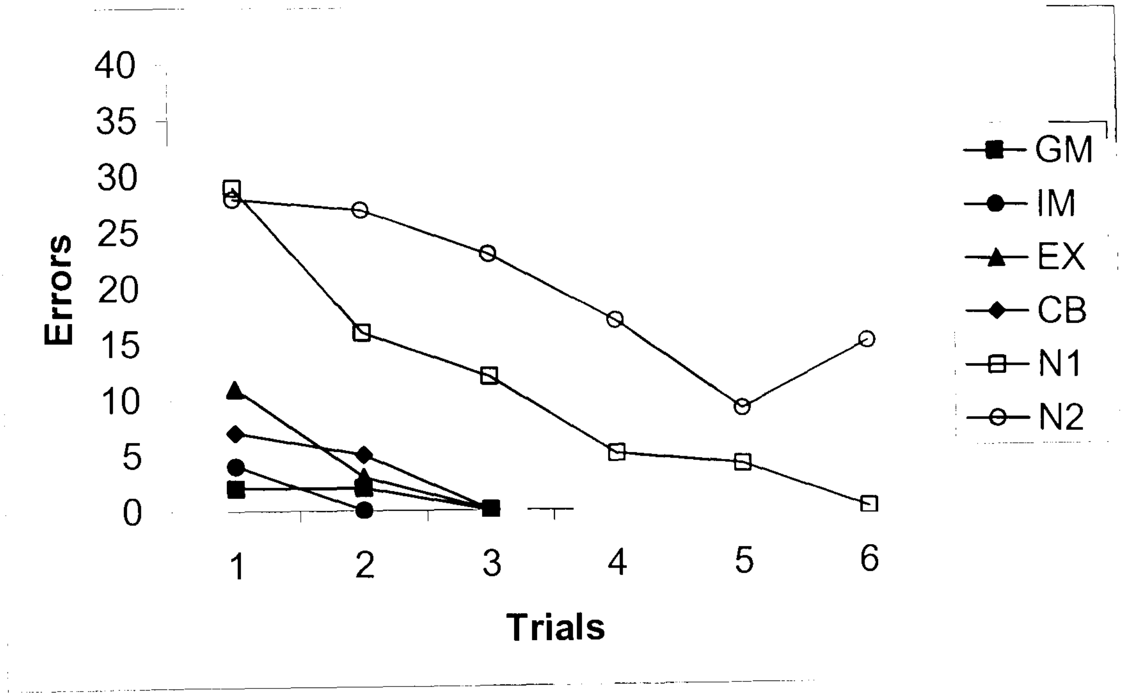

Figure 7.7. Errors per trial in draughts (max=40)

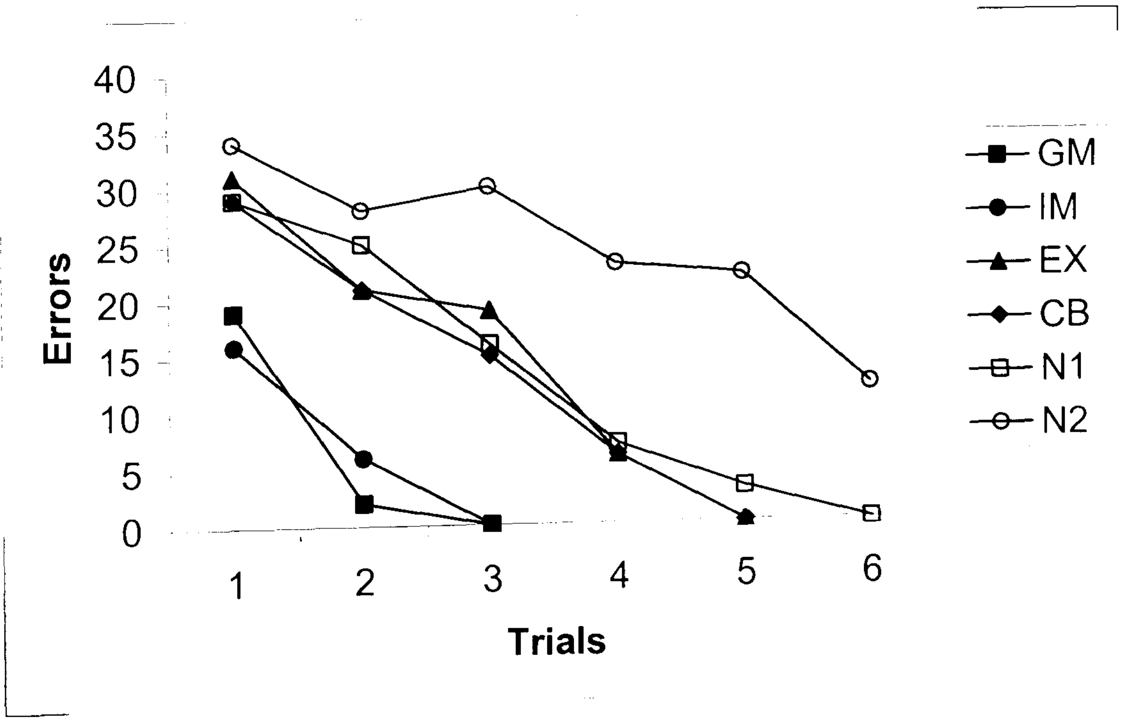

Figure 7.8. Errors per trial in GO (max=40)

Interestingly, in the GO condition the chess masters were better by far than the rest of the participants. Intermediate players were better than N2 but very slight differences could be observed with N1.

7.3.3. Discussion

The difference between chess players and non-chess players in memory for chess sequences is in no way surprising. The most likely explanation is that the experience of the chess players with this environment makes the task easier for them. CHREST predicts small differences in performance within chess players of different levels, since the sequence of moves presented is not logical (although legal) and no memory storage of this sequence is expected to exist in masters. However, as is the case in random positions, some significant moves and sequences of moves could have happened by chance, and that would put chess masters in a better position to perform the task. This is in agreement with Chase and Simon (1973) and Saariluoma (1991) who showed a skill effect with the presentation of real and random games.

One possible explanation is that the knowledge of the topology of the board and the experience with a display of pieces changing location would lead to differences between chess players and non-chess players. This is what may have happened in draughts, although the differences were quite remarkable. Indeed, the difference between masters and non-players was larger in the draughts sequence than with the chess sequence (which is unexpected). The lack of knowledge of the topology of the board of the non-players also existed in chess. Why did they do worse in the draughts condition? Non-players said that chess was easier because of the variation of pieces, whereas chess players mentioned they transformed the draughts moves into chess moves.

In the GO condition, the overall performance was the worst of the three conditions. Surprisingly, the largest expertise effect was found in this task, which is the least domain-specific one. The four chess players stated they drew chess patterns (e.g., knight moves), however the masters were much better than the intermediate. Non-players did not use a chess-like strategy.

One possibility to explain these results is in terms of mnemonics. Chess players may have used their chess knowledge in order to store information in a more efficient way. For instance, Gobet and Simon (1996a) trained an international master to improve his memory for multiple chess positions using the names of chess world champions as retrieval structures.

Another possibility is that chess masters have an advantage in sequences displayed in space. This explanation is in agreement with the possible expertise effect in the only non-static, non-domain specific task considered in the previous section: sequential spatial span. The latter task was, indeed, very similar to the GO condition. However, there were no differences between masters and intermediate players in spatial span, but there were differences in the GO condition.

Another important factor to take into account is time. Gobet and Simon (2000) showed that with an increase from 1 second to 10 seconds in presentation time, the performance in a reconstruction task reaches the highest expertise effect. This is apparent with chess game positions, but there is also a slight increase with random positions. The small difference observed in spatial span, which had a rate of 1 item per second, might increase if more time were allowed. In the present task there were 7 seconds per move; therefore, this additional time might have allowed the expertise effect to arise.

7.4 Conclusions

In this chapter several memory tasks were presented. In the delayed recall tasks, GM showed a more moderate decay rate in the recognition of pictures than the rest of participants; this pattern was also observed for chess positions. This general memory advantage could be fundamental in the learning of chess openings. The immediate recall tasks did not show individual differences between masters. The reconstruction of chess game and random positions replicated the skill effect observed in previous studies. The lack of expertise effect in the reconstruction of shapes and digit and memory span is also consistent with previous literature. The only non-static, non-domain specific task—i.e., spatial sequential span—showed a tendency towards expertise effect. This result could be linked to the remarkable skill effect observed in the GO condition.

In the search for individual differences in factors not related to domain-specific practice, the methodological paradigm used in this study proved to be fruitful. Long-term memory forgetting rate seems to be smoother in GM than in the other participants. Furthermore, a tendency of the chess players to have a larger spatial memory span than that of the non-chess players has been also found. These results will be taken up again in chapter 11, when the estimation of values for some parameters of a theory of expertise—CHREST—will be executed.

CHAPTER 8

Cross-tasks study (3)

Expert thinking

The previous chapter was devoted to memory aspects of the cross-tasks study. GM showed an advantage in the recognition of pictures, which is a general memory task. Would that give him an advantage in his thinking processes? The present chapter is dedicated to thinking and, at the end, an answer to this question will be given. Since thinking in chess requires a high level of chess knowledge, only the chess players participated in most of the tasks of this chapter. Therefore, the comparisons will be made between chess levels (masters vs intermediates), or between the two masters.

In chapter 2 (sub-section 2.3.1.3) a brief introduction to problem solving was given, as well as a more thorough discussion of the studies concentrating on thinking processes in chess. Two approaches to studying thinking processes in chess were used. One group of researchers asked chess players to analyse a position, allowing them long thinking times (Charness, 1981; De Groot, 1946/1978; Holding, 1985; Newell & Simon, 1972). Another approach consisted of asking players to solve a problem giving them a short reflection time (e.g., Charness et al., 2001). A false contradiction arose in this field: search vs. pattern recognition. For instance, Holding (1985, 1992) stated that chunking theory overemphasised the role of pattern-recognition and that a theory stressing search processes was necessary. Gobet and Simon (1998) have already shown that both aspects are important and that, in fact, both are part of chunking and template theory.

In this chapter both pattern recognition and search are considered; in order to do so, four experiments were carried out. The first one (section 8.1) is an experiment especially designed for this study—'search'—in which eye movement recordings and standard behavioural measures were obtained. This design allows one to investigate the maintenance of information during looking-ahead search. The following section (8.2) is concerned with two experiments: quick problem solving and simple reaction times. The first one consists in giving the correct first move of a complex chess problem, in no more than 10 seconds; basically, pattern recognition is more important than search in this task, because no time for searching deeply is allowed (see, Calderwood et al., 1988; Gobet & Simon, 1996c). The simple reaction time measure was obtained in order to find out whether the differences in performance in the quick problem solving task can be partly explained by general speed of information processing. In section 8.3 a series of think aloud protocols during a 30-minutes problem solving task was obtained. Depth of search, speed of search and the quantity of information generated were the variables investigated in this task.

8.1. Search and maintenance

There are some difficulties for the study of look-ahead search in chess. For instance, there is little control over the output produced by the participant and it is very difficult to design controlled experiments. The use of think out loud protocols is a very useful technique which provides valuable data (indeed, it occupies a large part of this chapter; see section 8.3); however, there is no control over the number of moves analysed by the player, his/her depth of search, the number of episodes investigated, and other variables. An attempt is made in this section to investigate one aspect of look-ahead search: maintenance of the intermediate positions.

In so doing, a new paradigm was introduced, which allows the experimenter to manipulate the depth of search, and measures the ability to maintain a position in mind. The pattern recognition processes of chess players operate not only over the percept, but also over positions maintained in the mind's eye (see Gobet, 1998b). It follows naturally that the maintenance of a chess position while looking-ahead is crucial, in order for the pattern recognition processes to operate over that information.

With standard behavioural measures and eye movement data it was possible to measure the ability to maintain information in the mind.

8.1.1. Procedure

The stimuli used in the experiment were presented on a computer screen. Two conditions were used: 'chess' and 'shape', and three games were presented per condition. Within each game there were three different phases: initial inspection, move presentation and test. The first one occurred at the beginning and it was clearly differentiated from the other phases. Move presentation and test phases were intermingled. Before explaining each phase, a description of the most important visual display of the experiment is provided. I will explain the chess condition and at the end I will mention the differences between it and the shape condition.

Visual display. (see figure 8.1). Three objects were part of the visual display: (a) a chessboard displaying a position of a chess game (14° x 14° of visual angle), (b) a grid of 16 columns x 9 rows, on the bottom of the screen (41° horizontal x 11° vertical of visual angle), and (c) a bluish 'test box' on the left-hand side (6° x 6° of visual angle). During each game, the chessboard always remained fixed, only the information presented on the grid and on the test box side squared varied. The numbers on the columns of the grid indicated the move number and the numbers of the rows identified the branch number (see below). Within one branch there was a row for white moves and another for black moves.

Initial inspection phase. Each game started with a text indicating the number of position (1, 2, or 3) and the type of trial ('chess' or 'shape'); this text was presented for 5 seconds; after that, a fixation cross was presented for 5 seconds.

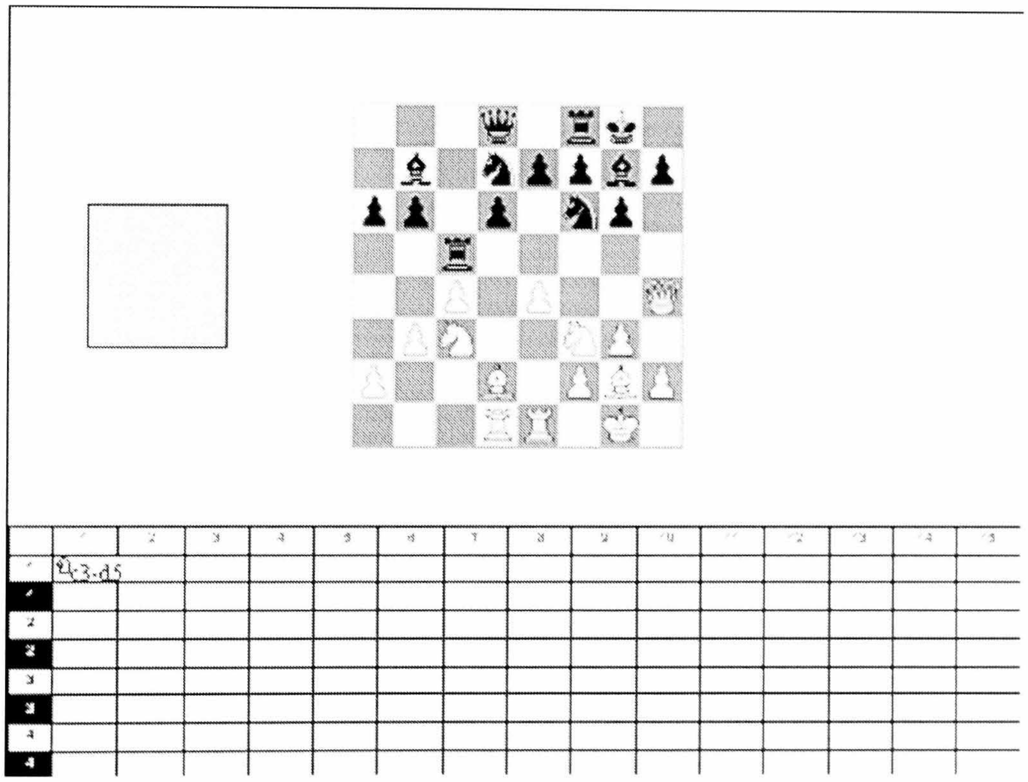

Figure 8.1. Display of the Search experiment (game condition). The grid (bottom) displayed the moves in algebraic notation. The position (centre) remained static, which forced the players to follow the game mentally. The square (left) was used for the test session.

Then, the visual display appeared and remained static for 20 seconds, which allowed the participants to inspect the chess game position displayed on the chessboard.

Move presentation phase. When that 20-seconds period of time elapsed, a sequence of chess moves was presented on the grid in algebraic notation[1]. Each move was shown for three seconds. White moves were presented in red and black moves in black. Since the position on the chessboard remained static, the players had to follow the sequence of moves in their mind.

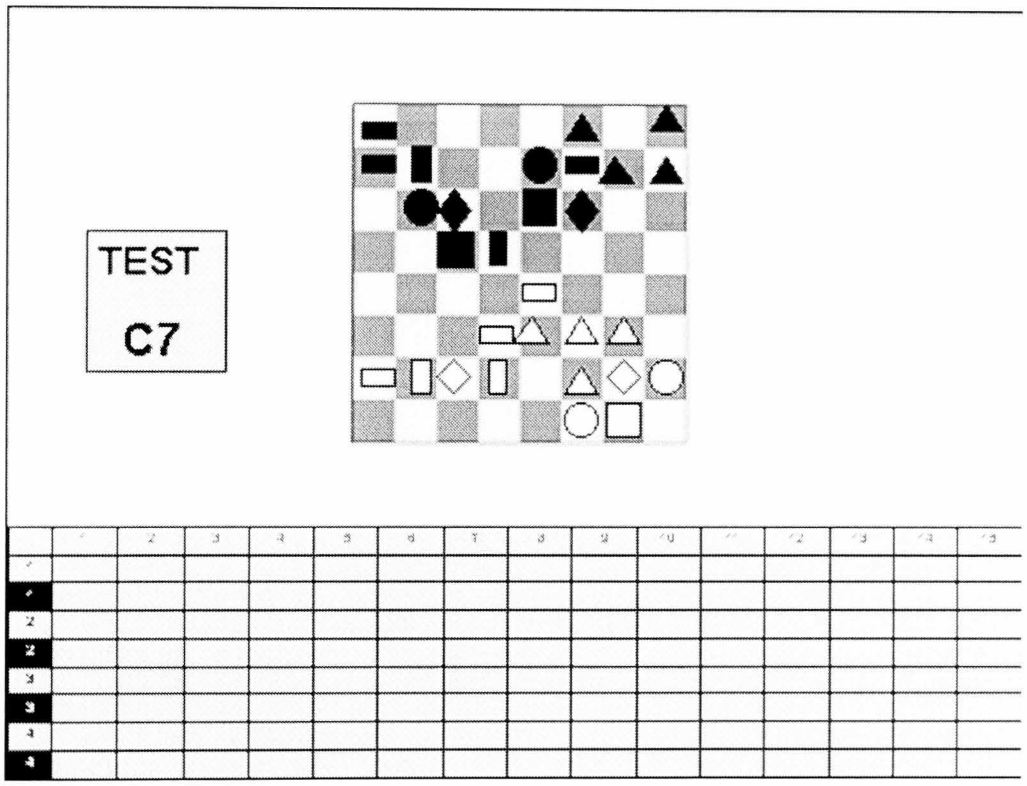

Figure 8.2. Test session. The grid becomes bluish and the square shows names of board squares. The players had to say out loud which piece was located in that square.

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[1] In the algebraic notation all the squares of the board have a name. This name is formed by a letter followed by a number. The letter corresponds to the column (in figure 8.1, column 'a' is the first starting from the left, and column 'h' is the first starting from the right), and the number indicates the row ('1' is the bottom row, '8' is the top row). The move is indicated by including the symbol of the chess piece (e.g., φ for the queen; alternatively, the initial letter of the name of the piece can be used— in this case: 'Q' for queen) followed by the name of the origin square (e.g., b2) and then the name of the destination square (e.g., b7); all together: φ b2-b7, or Qb2-b7. Usually, players use the short form, which includes only the destination square (in this case, Qb7). All the participants in this study were familiar with the algebraic notation.

Test phase. At some point in the sequence of moves, the grid changed to a bluish colour, indicating that a test phase had commenced (see figure 8.2). In the test phase a series of six square names (e.g., 'd4') was presented on the 'test box' for three seconds. The players had to say out loud the name and colour of the piece (if any) they thought was on the square displayed in the 'test box'. In order to complete this task accurately they had to follow the sequence of moves presented on the grid (note that the position on the chess board remained static and did not display the changes according to the moves displayed on the grid). Once the test phase finished, more moves were presented on the grid, starting from the latest stage.

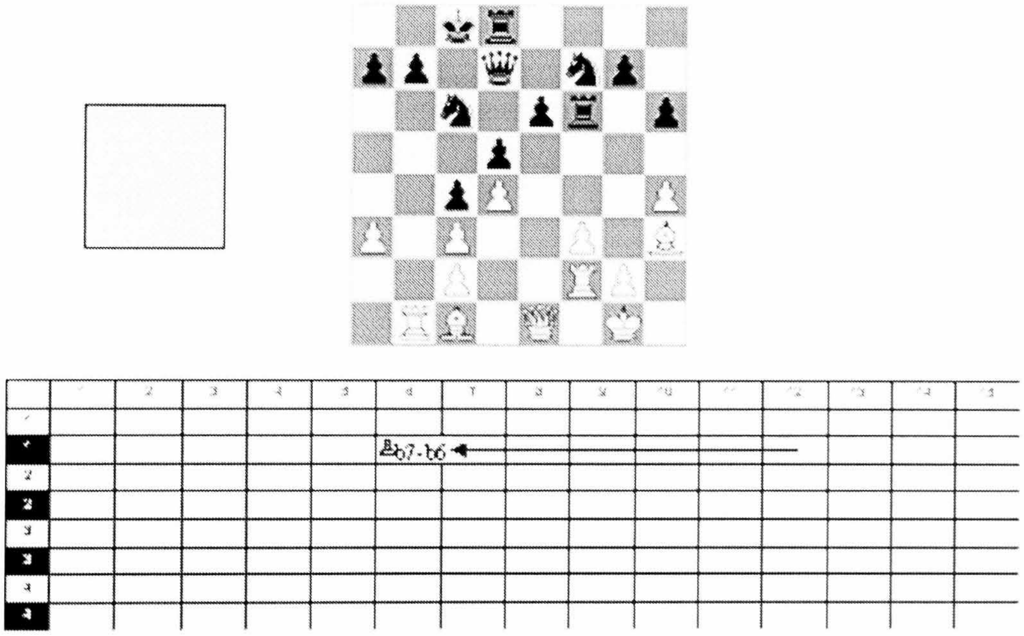


Figure 8.3. Going backwards. Once they had reached position after move 12, players had to come back to the position after move 6. They had to reconstruct that position (backwards), or a new branch started from there (backwards-forward).

Forward, backward and new branch. These are not phases of the experiment per se, they are part of the move presentation phase, but they also affect the test phase; that is why they are presented separately. The sequence of moves begins going forward from move 1, and a test phase happens as explained earlier ('forward test'). In some cases, an arrow indicated a shift to a previous position (figure 8.3 shows a shift from move 12 to move 6). Hence, the player had to 'mentally' go backwards to the position after move 6. In those situations two things could have happened: (a) a test phase started ('backward test') or (b) a new branch started. When (b) happened, a new sequence of moves—going forward again—was presented on the two rows underneath the ones that were used for the previous sequence. After a number of moves were presented, another test phase turned up ('new branch' test).

Shape condition. The shape trials had the same structure as the chess trials (see figure 8.2 for a chessboard displaying a 'shape' position). There were two important differences. First, the pieces of a chess position were replaced by shapes which did not match the chess pieces. This was achieved by two means: using different frequencies for the shapes (e.g. among other shapes, 3 squares, and 3 circles of the same colour; it is not possible to find this frequency of types in almost any chess position, since the only type of piece with more than two is the pawn), and replacing the pieces in a random fashion (however, the colour was maintained). Second, in the move presentation phase, the moves were displayed in algebraic notation replacing a chess piece by a shape in the first term. Third, the moves represented were random moves and not chess legal moves; however, the length of the move (measured as the number of squares) matched the length of the chess moves on average.

Eye fixations and shifts analyses. When analysing eye movements, the eye fixations during the initial inspection phase were eliminated.

8.1.2. Results

8.1.2.1. Percentage correct

Table 8.1 displays the overall data. Very revealing results emerged. First, as expected, the performance for chess is much better than that for shapes. Second, there is a clear expertise effect for chess. Third, the effect remained for shapes, but hugely diminished. Fourth, GM performed clearly better than IM.

Table 8.1. Percentage correct.

	Chess		Shape		Total	
	Mean	sd	Mean	sd	Mean	sd
GM	84.38	22.33	34.38	28.85	59.38	37.01
IM	67.71	33.04	26.04	28.52	46.88	35.91
EX	42.71	31.60	19.79	13.90	31.25	26.69
CB	23.96	21.05	21.88	19.92	22.92	20.19

Note. sd = standard deviation.

Figure 8.4 depicts the performance of the players in all the conditions. Except from CB, who performed at the same level in both conditions, in the chess condition, 'forward' was the test in which they performed better. However, in the shape condition there was not a clear advantage of any of the conditions. IM displayed a symmetrical pattern for chess and shapes. In both tasks he performed worse in the backward condition. The players mentioned that in the new branch condition, sometimes they totally lost the position, but they memorised the last moves. This strategy improved their performance because some of the tests necessarily probed squares involved in the last movements. It is likely, then, that the performance in the new branch condition was due to an artifact and that it does not reflect the maintenance of the image, which had been lost earlier.

In the shape condition, both masters were better than the intermediate players in the forward tests. On the other hand, in shape-backward, IM performed worse than the other players, and GM did not change his performance in comparison to chess-forward.

IM had difficulties when he had to reinstate an image of a previous step in the search path. On the other hand, GM seemed not to have troubles doing so. This difference could be related with the difference detected in the delayed recall tasks. An interesting comparison is whether IM shows the same difficulty in the think aloud protocols (section 8.3)

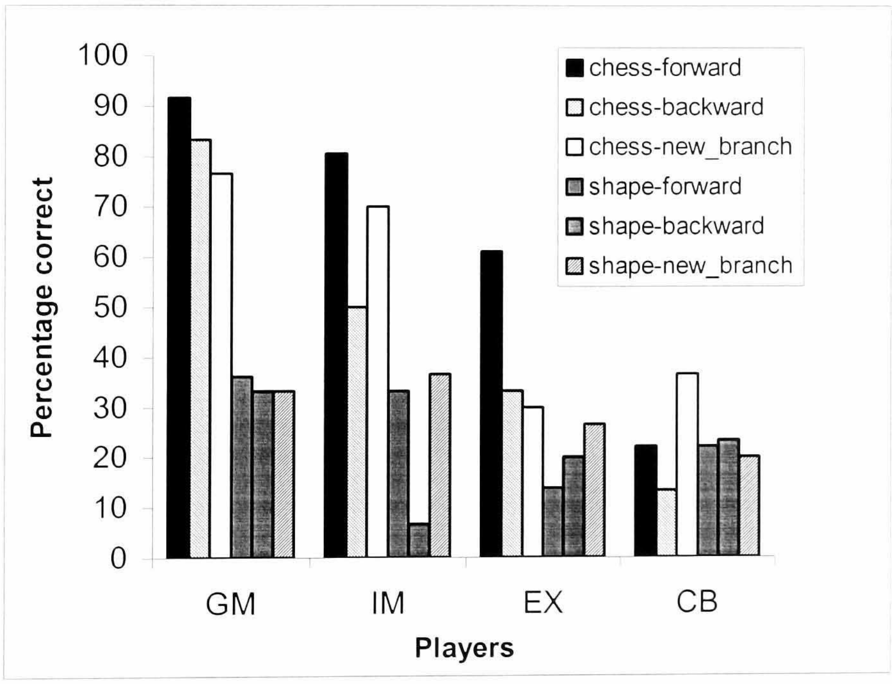


Figure 8.4. Performance in all conditions.

8.1.2.2. Eye-movement data

I was interested in the number of eye shifts from the grid to the chessboard (vertical shifts) and the number of shifts from the bluish square to the chessboard (horizontal shifts). The rationale is to investigate whether the players needed to look at the board when the moves were displayed on the grid or they just followed the game without using the board. The same rationale applies for the horizontal movements.

Figure 8.5 depicts the horizontal (chessboard-test box) shifts and the vertical (chessboard-grid) shifts for the game trials. Figure 8.6 shows the same data for shapes. The number of shifts is independent of the number of fixations. A shift is considered when a participant is fixating on one of the three elements and after a non-determined number of fixations the player starts fixating on another element. The number of fixations that occur between the two objects does not matter for this analysis.

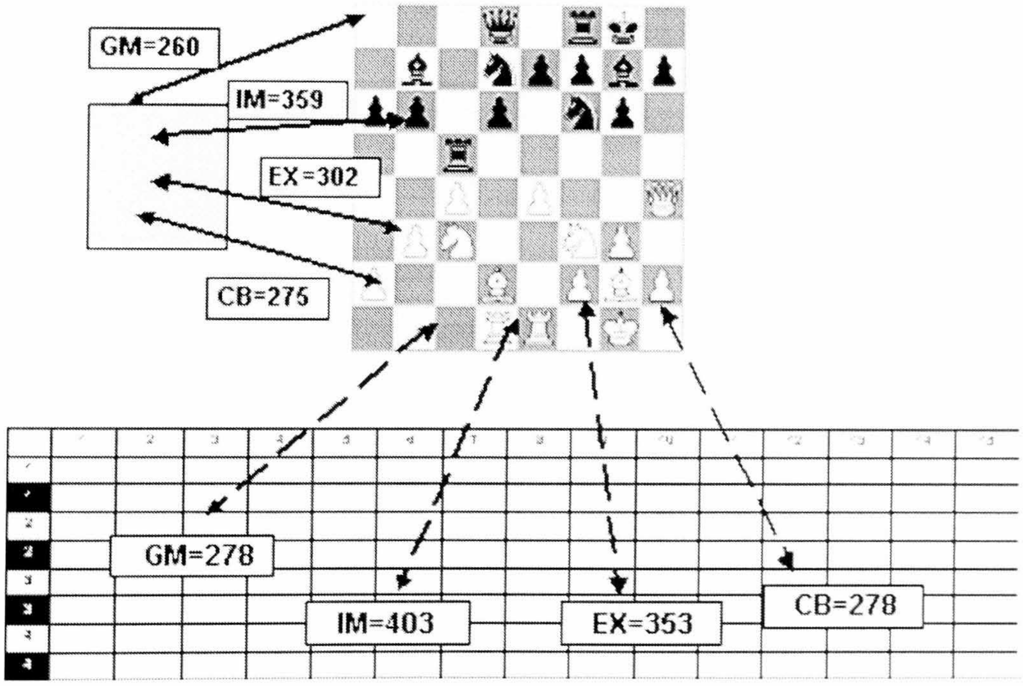


Figure 8.5. Vertical and horizontal eye-movements in the chess condition.

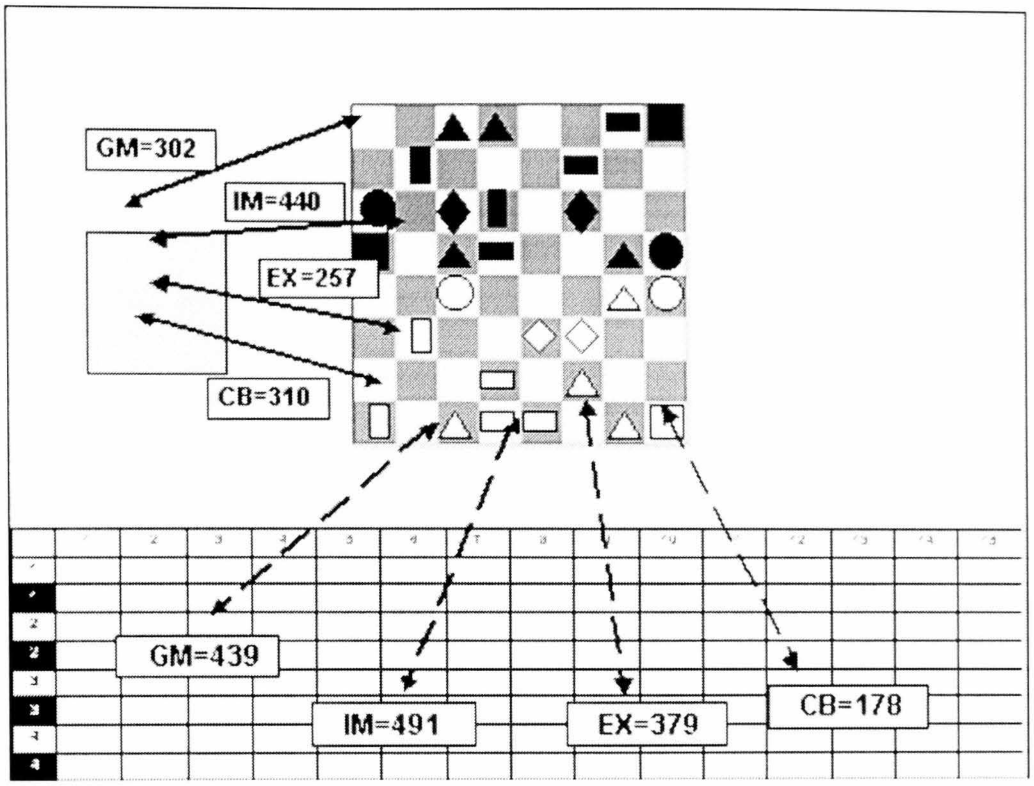


Figure 8.6. Vertical and horizontal eye movements in the shape condition.

The purpose of the shift analyses depicted on figures 8.5 and 8.6 was to link this experiment to those of chapter 5 (see below). However, it is also interesting to analyse these results in another way. Comparing figures 8.5 and 8.6, the masters increased the number of shifts overall (538 to 741 for GM, and 762 to 931 to IM); whereas the intermediate players, if any, this showed a decrease (655 to 636 for EX, and 553 to 488 for CB). It may be the case that masters, in the shape condition, tried to keep track of all the moves, and for that they performed more shifts to the board, because they were losing the position more than in the game condition. Whereas intermediate players may have decided to focus on a handful on moves, so they fixated longer on each object without worring about missing some moves.

Table 8.2 shows the ratio shifts/trials. This ratio is calculated in order to know how many shifts per trial are performed. In chapter 5, which showed two blindfold chess experiments, two hypotheses were put forward. First, participants needed to use the board to pick up the relevant information but they did not use it as an aid to follow the game in mind. Second, players looked at the board for both collecting the relevant information and as an aid to follow the game in their mind. In the present experiment the information to follow the game is gathered outside the chessboard (i.e., on the grid). Therefore, it is possible to disentangle the two hypotheses. If the players do not use the board as an aid to follow the game in mind, then no shifts (or only a few) grid-board are expected. Should they use the chessboard to follow the game, numerous shifts would be observed.

Table 8.2. Ratio shifts/trials.

	Chess		Shapes	
	Board-square	Board-grid	Board-square	Board-grid
GM	1.35	1.18	1.57	1.86
IM	1.86	1.71	2.29	2.08
EX	1.57	1.50	1.34	1.60
CB	1.43	1.18	1.61	0.75

Note. The number of trials for board-square was 118 moves and the number trials of board-grid was 96 tests. The ratio was calculated by this formula: Ratio = Shifts/(2*trials). If there is a shift from the grid to the board, there is a necessary shift from the board to the grid to carry on doing the task, that is why the division by 2 was performed. board-square = board to square shift, board-grid = board to grid shift.

As can be seen in table 8.2 all the players carried out more than one shift per move. This result supports the hypothesis chosen in chapter 5, i. e., chess players use the chessboard to follow the game. The only clear pattern of this table is that more shifts are needed for shapes than for chess.

Figure 8.7 plots the relationship between the total number of eye fixations throughout the whole experiment and the performance.

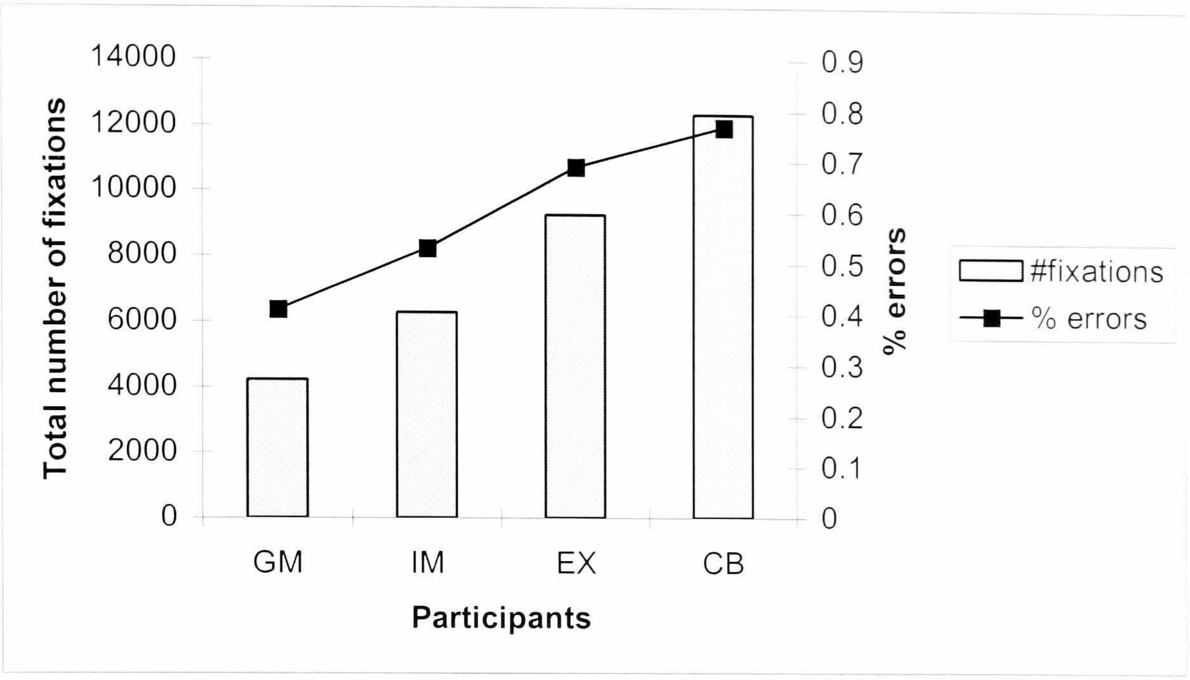


Figure 8.7. Total number of fixations and errors.

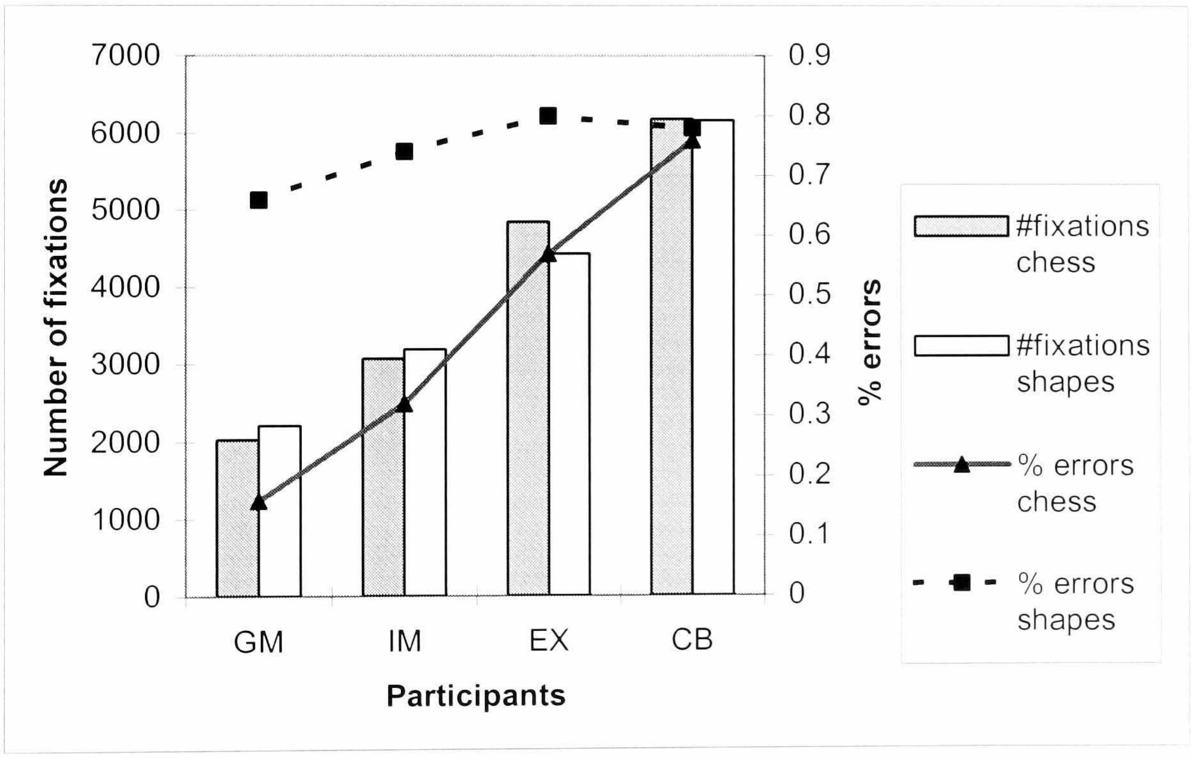


Figure 8.8. Total number of fixations and errors in chess and shapes.

The skill effect observed in the performance (i. e., performance is a function of chess rating) is also apparent in the total number of fixations. The more the total number of fixations, the higher the error rate. Figure 8.8 discriminates chess trials from shape trials. This figure clearly shows that there is an almost perfect linear relation between number of fixations and performance in chess trials. In shapes there is also a clear relation between number of fixations and performance up to an 80% error rate. Probably, there is a ceiling effect at an 80% error rate (i.e., paying attention only to the last moves allows participants to give correct responses to some of the tests). It is evident that players carried out nearly the same number of fixations for chess and shape, though the performance varied across tasks.

Reingold et al. (2001) found fewer fixations in experts in comparison to novices in a simple check detection task, in which the former performed better than the latter. In the same article, Reingold et al. measured visual span. Chess experts showed a much higher visual span than intermediates and novices for chess game positions. However, in random positions the advantage totally disappeared. De Groot and Gobet (1996) and Reingold et al. (2001) proposed that experts acquire more information than novices within each fixation. In the present study, the fewer the fixations the better the performance.

Previous studies have used only chessboards as stimuli, so if one wants to compare the number of fixations in this study to that of the previous ones, it is necessary to segregate the chessboard fixations from fixations outside it.

Figure 8.9 plots the distribution of fixations throughout the three relevant elements (i.e., chessboard, grid, square) and the blank areas. Figure 8.10 illustrates the distribution of time fixating in each area. It is conspicuous that the fewer the total number of fixations, the fewer the fixations on the chessboard and the less the time spent fixating on the chessboard. This is true when we exclude CB from the analysis. It could be the case that CB was quite lost during the task (his overall performance and the lack of difference between chess and shape performances may reflect this), and thus was doing random eye-movements at some periods.

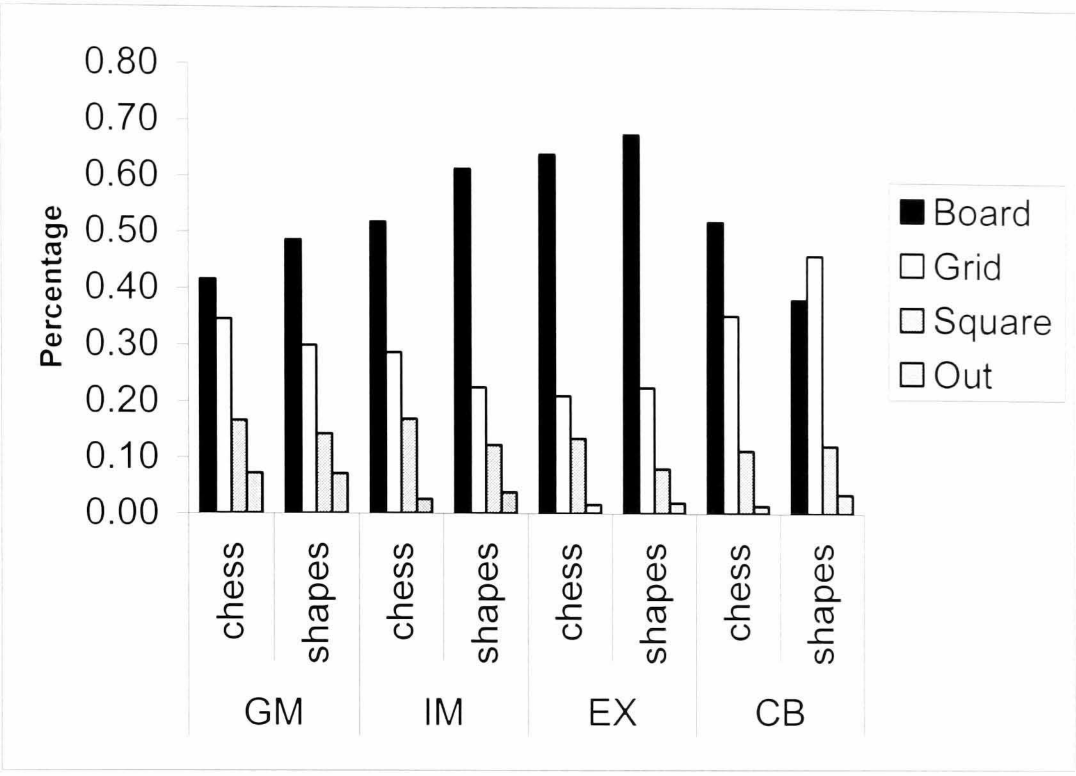


Figure 8.9. Distribution of total number of fixations.

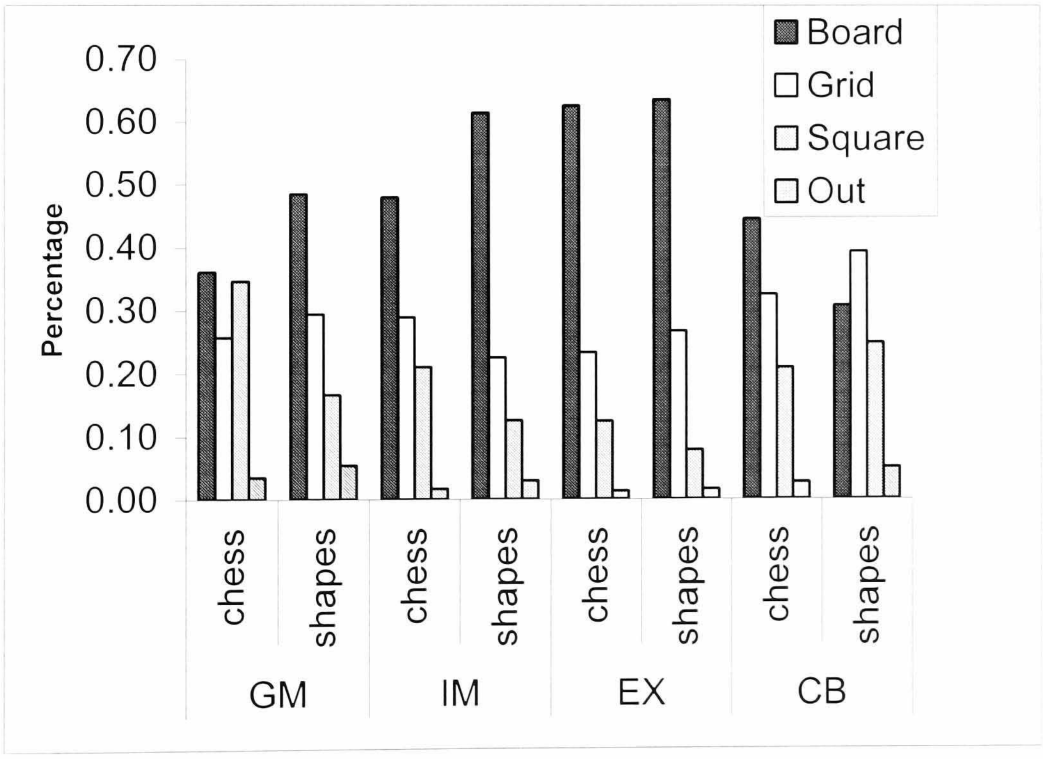


Figure 8.10. Distribution of time fixating.

8.1.3. Discussion

The 'search and maintenance' experiment uncovered the following results. First, the performance on the task showed a remarkable skill effect in chess, and a small one in shape. Second, the ratio shifts/moves was higher than 1, suggesting that players used the chessboard to follow the game. Third, the total number of eye fixations in chess explains almost all of the variance of the performance. Fourth, in three of the four players fewer total fixations meant fewer errors and less time fixating on the chessboard.

The first result was totally expected and is in agreement with CHREST and all the chess memory literature, which show a strong skill effect for game positions and a small effect for random positions. This result was obtained even though the shape task in the present study is not totally equivalent to a random position. In fact, the pattern of pieces corresponds to a chess game position. However, the grammar of chess is destroyed by changing the symbols used (geometrical shapes instead of chess-pieces symbols), as well as the frequency of types of symbols, randomising the location of shapes throughout the game pattern, and performing non-legal chess moves. The mere change of symbol did not cause impairment in performance in previous studies (e.g. Chase & Simon, 1973; Saariluoma & Kalakoski, 1998), but the legality of the moves did (Saariluoma, 1991). In the second fMRI study of chapter 10, the role of the meaning triggered by the symbols that represent chess pieces is investigated.

The second result sheds light on an open question from chapter 5 (first experiment). Do the players use the chessboard as an aid to follow a game mentally? It was proposed that they do, and some support was obtained with the results of the second experiment. The present study gives much stronger support to this hypothesis. All the players carried out more than 1 shift from the grid to the board per move presented in the grid. This is good evidence that the participants made a shift to the board in each move; hence, they needed the board to follow the game in mind.

The third and fourth findings are striking. Almost all of the variance in the game condition performance is explained by the number of fixations during the task (and to a lesser degree by chess rating). In this study no absolute fixation time measures were obtained (although relative time fixating has been presented in figure 8.10); however, the length of the experiment was the same for all participants. Hence, fewer fixations means higher fixation durations. De Groot and Gobet (1996) found shorter fixation durations in masters in a memory task. On the other hand, Reingold et al. (2001) and Charness et al. (2001) found equal fixation durations for experts and novices in a check detection and a choose-the-best-move tasks respectively.

Apparently, there is a disagreement in these studies and more confusion is added with the present result. However, in all the experiments, different tasks were used, in which different problems had to be solved. In the memory task, a short fixation is enough for the master to pick up the relevant information, so (s)he saccades to another location in order to cover the whole board. Time to cover the whole board is the main factor of this task, which otherwise is simple. Novices do longer fixations because they need more time to encode a chunk of chess pieces, causing the lack of coverage of the whole board (see coverage measures in De Groot & Gobet, 1996).

In Reingold et al. (2001) players performed a check detection task in a 3 x 3 square chessboard with only three pieces. Experts needed very few fixations (sometimes only the fixation in the centre of the board was sufficient) to cover the whole board (in agreement with the finding that chess players have a larger visual span for chess position, Charness et al., 2001). Novices fixated on only one piece, used the same fixation time as experts and then fixated on another piece. In this task, experts did not need to hurry to cover the whole board, because one fixation was enough. Novices did not have time problems either, but with one fixation they did not obtain as much information as experts, therefore they had more fixations.

The present study is the most complex of the three. Players had 20 seconds to inspect the initial position (this time was not included in the fixation analysis), then they had to pay attention to the sequence of moves on the grid and update the position. It was shown that the better the performance (and the chess level) the fewer the number of fixations on the chessboard. It is reasonable to think that, on occasions, the increasing number of fixations and time fixating on the board makes the participant miss some moves that are being presented on the grid; so the performance decreases. Since spending too much time fixating on the chessboard leads to a worse performance, why do participants do it? I propose that they need to do it because the memory of the previous position decays. The additional fixations are done to refresh the location of the pieces of the previous positions. When this fading does not occur (most of the time in GM) fewer fixations are needed on the board and the player comes back to the grid and spends more time there.

8.2. Quick problem solving and reaction time

The previous section (8.1) looked at one component of look-ahead search in chess: the maintenance of information. It showed a strong skill effect for a chess condition and a weaker skill effect for a shape condition. This section and the following (8.3) are devoted to chess problem solving tasks in which a skill effect is expected. The present section focuses on another component of search: pattern recognition. Chess players had to solve a complex chess problem and they were allowed only 10 seconds for looking at the position and decide the best move. No time for deep search was available; therefore, pattern recognition procedures were the key to the task.

In chapter 2 (section 2.3.1.3) it was stated that reducing reflection time impairs chess skill only slightly (see Calderwood et al., 1988; Gobet & Simon, 1996c). Charness et al. (2001) showed that experts were faster than novices at solving a simple chess problem and that the former performed fewer eye fixations than the latter. In this case, the problems used were quite simple, and they required only a few nodes to be solved.

In the present experiment, complex chess problems from real chess games were obtained in Livshitz (1988). The rationale was to investigate how well the players do when the time constraints do not allow them to investigate the number of nodes required to solve the task.

Following this experiment, a simple reaction time test was performed in order to identify whether the differences in quick problem solving are related to differences in general speed of processing. In a similar approach, Masunaga and Horn (2000, 2001) found a skill effect in speed and reasoning in domain specific tasks but not in general ones.

8.2.1. Procedure

Eye movements and accuracy were recorded in this task (the eye movement data are not reported in this thesis). A fixation cross was displayed on a computer screen for 1 second, then a position was presented for 5 seconds, followed by a 5 second black screen before starting the next cycle. The positions presented were taken from real games and presented a typical chess problem 'white moves and wins', for which the players had to provide the correct first move out loud. The positions required some look-ahead search to be performed accurately. The limited time (5 seconds presentation of the position plus 5 seconds black screen) did not allow the players to perform serious look-ahead search; hence, pattern recognition procedures are vital. Forty-nine chess problems were selected from Livshitz (1988). This book entitled 'Test your chess IQ' contains different typical tactical themes; each of the positions selected corresponded to a different tactical theme.

In the simple reaction time task, volunteers were presented with either a red or a yellow circle on a computer screen. They had to press the right button for red and the left button for yellow as fast and accurately as possible. Four blocks of 50 trials were recorded.

8.2.2. Results

It was not surprising to find that performance showed a clear skill effect. GM gave the correct move in 23 of the 49 problems (46.94%), IM followed with 18 correct solutions (36.94%), EX with 4 correct (8.16%), and CB 2 correct (4.08%). This result is in agreement with CHREST, which predicts strong skill effects when search mechanisms are minimal.

In the simple reaction time task (see table 8.3), no large differences could be found among the six participants. However, it is interesting to investigate whether the 30 ms difference in mean reaction time between GM and IM is robust. A two tailed t test using the 200 trials was performed, and the difference is highly significant ($t(398) = 4.32$; $p < 0.001$). For instance, in a 4-hour game a disparity of 30 ms to perform a 400 ms process makes a 18 minutes difference in thinking time. In ten seconds (time allowed in the fast problem solving task) there are 750 ms differences in thinking time.

Table 8.3. Reaction time (in milliseconds).

	S1	S2	S3	S4	Mean	SD	Accuracy
GM	376	315	344	323	339	70	0.96
IM	349	392	371	362	369	66	0.99
EX	417	356	339	317	357	61	0.98
CB	371	352	315	333	343	75	0.94
N1	314	340	309	363	332	66	0.90
N2	372	376	380	358	372	66	0.98

Note. S1 to S4 = Session 1 to 4.

It is worth noting that reaction times did not explain the strong skill effect observed in the quick problem-solving task. It is apparent that EX and CB's reaction times are slightly faster than IM's; however, IM performed far better than the intermediate players in the problem-solving task. Nonetheless, once again it is crucial to look at individual differences within the same level of expertise (GM vs. IM). The slight, but significant, difference in mean reaction time between GM and IM might be related to the slight difference in the quick problem-solving task. In a few words, the long-term memory patterns stored in long-term memory via deliberate practice (e.g., similar number of hours were reported by GM and IM, and both of them largely differed from the other players; see chapter 6) might explain the large skill effects between levels of expertise, and speed of processing differences might explain small effects within the same level of expertise.

8.2.3. Discussion

The result obtained in the quick problem-solving experiment is in agreement with CHREST. Strong skill effects are observed even though the time available for searching ahead is minimal. With this time restriction, pattern-recognition processes play the key role. Gobet and Simon (1996c) showed that world champion Garry Kasparov, whilst playing simultaneous games, maintained a strong grandmaster level, diminishing his strength very little. Given that this kind of playing condition hugely decreased the time available for looking-ahead search, Gobet and Simon (1996c) took this result as an important support of pattern recognition processes in chess playing. Furthermore, Calderwood et al. (1988) did not find large differences in the level of moves of games played on regular thinking conditions (2.25 min per move, on average) and rapid games (5 minutes for the whole game, or 6 seconds per move on average).

Gobet and Jansen (in press) proposed that to increase depth of search in chess problem solving, it is better to increase the knowledge base than to increase the speed of search. The present reaction time results seem to agree with that proposal. There are apparently no differences in reaction times in the sample studied (43 ms was the gap between the fastest and the slowest). Moreover, within the chess players there is no relation between reaction times and accuracy. It follows that the largest difference in problem solving in this study (masters vs intermediates) is more related to their long-term memory patterns than to their speed. Nevertheless, assuming that faster reaction time leads to faster search, the small difference in performance in problem solving between GM and IM, might be explained by the small difference observed in reaction times. In chapter 11 general speed of processing will be considered as a parameter to vary in a theory of expertise.

8.3. Thinking aloud protocols

In the previous section (8.2) chess problems with very little time for their solution were used. This type of situation happens in a real game when players are reaching the time limit and they have to play very fast, otherwise they would lose on time. Moreover, there is a discipline within chess—called 'blitz'—in which the time for the whole game is 10 minutes; hence, all the game is played under time pressure. However, in tournament games the normal thinking time is currently two hours per player for the whole game. Under the tournament time limit, during an important part of the game, players do not have to think under time pressure.

In this section three problems were presented to the players and they had 30 minutes to decide the move they would play should they be in a real game. During this reflection time, players had to say out loud their thoughts, and they were tape-recorded. It is interesting to find out whether the individual differences observed in preceding experiments are reflected in a more naturalistic task.

A review of this area of research has been already presented in chapter 2. One controversial issue in this field is depth of search. De Groot (1946 1978) found no reliable differences between the best grandmasters of the world and intermediate players in depth of search. Charness (1981) found a linear relation between chess skill and depth of search (0.5 ply) in mean depth of search and 1.5 plies in maximal depth, for each standard deviation of chess rating —i.e., 200 ELO points.) until the expert level. Saariluoma's (1990) data suggest that international masters and grandmasters sometimes search less than masters. Gobet (1998b) using one of De Groot's positions found a 0.6 ply increase in mean depth of search per standard deviation.

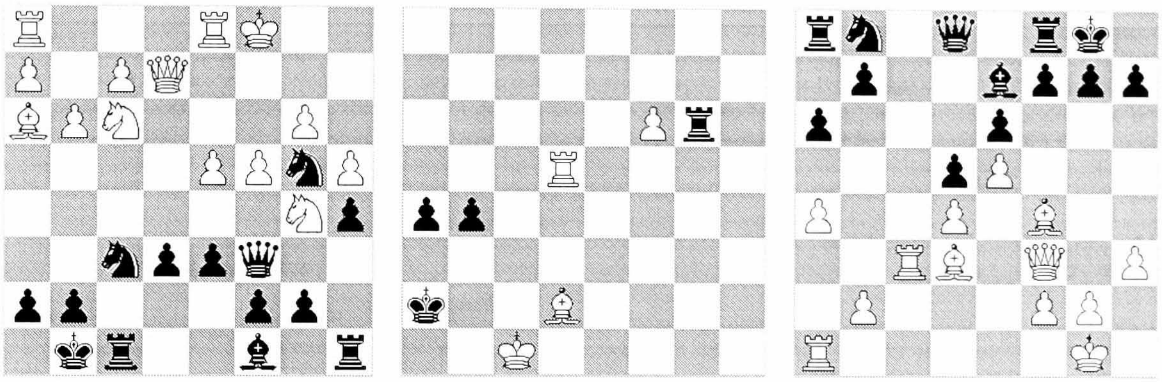

a) Black moves. b) White moves and wins. c) White moves and wins.

Figure 8.11. Positions used in the thinking out loud task. Position A was used by De Groot (1946) and corresponds to a position from the game Pannekoek-De Groot (1935). Position B is a problem created by Kasparyan (1939) and was presented in Roycroft (1972), and position C was obtained from Nunn (1999) and displays a position of the game Polugaevsky-Torre (1984).

Gobet's (1998c) position, which is the position A in De Groot (1946/1978), needs only 9 ply to be solved. Therefore, the lack of the small skill effect in depth of search could be due to a ceiling effect. In the present study, three positions were chosen (see figure 8.11). The first was De Groot's position C, the second was an endgame, and the third was a middle-game position. De Groot's position was chosen in order to make comparisons with his data. The endgame and middle-game positions were especially chosen because they require deep search ahead to be solved. The former needs mainly wide search and the latter mainly deep search.

Gobet (1997) presented a canonical model for search—called 'SEARCH'—based on CHREST. SEARCH used some parameters based on CHREST, others were inferred from data, and other parameters were set arbitrarily. The model predicted that depth of search is a power function of the number of chunks in long-term memory. Since the number of chunks in long-term memory is a good predictor of chess skill (see Gobet & Simon, 2000 for a comparison of CHREST with humans), depth of search might be a power function of chess skill. In the present study this prediction could be tested since there is a range of players from class B to grandmaster.

8.3.1. Procedure

In this experiment, think aloud protocols were obtained using a tape recorder. Three complex chess situations, which required a considerable amount of looking-ahead search and evaluation, were displayed to the players. They were required to put themselves in a tournament situation as if they were to move. Thirty minutes were allowed as maximum reflection time for each position. When the players had reached a decision, they had to literally play the move on the chessboard. Importantly, they were required to say out loud every thought that came to their mind while they were thinking (i.e., moves, plans, evaluations, or whatever they were thinking at the moment).

The instructions for position A were different from those of the other positions. Since the first position used was the same as De Groot's (1946) position

C, and some comparisons were made between his protocols and those of this thesis, the same instruction as De Groot was used. Basically, the players were asked to say out loud their thoughts as if they were playing a game and it was their turn. They were encouraged not to inhibit thoughts that were irrelevant for the solution of the problem. Additionally, I asked the participants to give precise locations of the movements (e.g., instead of saying: 'rook moves there', players were encouraged to indicate the precise location: 'rook moves to e7').

Since this instruction might have obscured the differences in depth of search (i.e., players might chose a decent move but not try hard to find the best move), the two other positions were chosen because they have a unique solution that requires deep and wide search. In order to encourage the players to find that solution, I told them that there was a unique solution that they had to find. Although this addendum to De Groot's instructions causes a slight loss of ecological validity, it is advantageous inasmuch as it allows one to assess properly both depth of search and the size of exploration tree.

Once the tapes with the protocols were obtained, they were transcribed and both problem behaviour graphs (see figure 8.12) and exploration tree graphs (see figure 8.13) were generated for each protocol, following Newell and Simon (1972). Three variables were of interest in this study: depth of search, speed of search, and quantity of information generated. Other variables were also considered, but less attention was paid to them. Below there is an explanation of each variable.

Variables. a) Quality of move: Based on the annotations provided in the literature and my chess knowledge (Elo 2200) I gave a value from 1 (bad move) to 5 (the best move), to the moves chosen. b) Total time: time used until the move was played on the board. c) Number of nodes visited: in the problem behaviour is the total number of plies generated; in the exploratory tree is the total number of plies generated without taking into account the repetitions. d) Number of nodes/minute: in both graphs is number of nodes visited divided by total time. e) Maximal depth (plies): number of plies of the largest episode's branch. d) Mean depth (plies): in the problem behaviour graph, sum of the depth of all the episodes divided by the number of episodes; in the exploration tree, sum of the depth of all the branches divided by the number of branches. e) Number of episodes: number of sequences of plies generated from a base of move. An episode con contain one or more branches. f) Number of base moves: number of first moves. g) Base moves per minute: number of base moves divided by total time. h) Immediate reinvestigation: generation of an episode with the same base move of the immediately precedent episode. i) Non-immediate reinvestigation: generation of an episode with the same base move of a previous episode (but not the immediately preceding one). j) Total reinvestigations: Non-immediate plus immediate reinvestigations. k) Branches: number of sequences generated from a ply which is not the base move, within an episode. l) Branches per episode: Branches divided by number of episodes. m) Nodes per episode: number of nodes visited divided by number of episodes. n) Branches per minute: Branches divided total time.

8.3.2. Results

Figure 8.12 depicts an example of a protocol tree. Each number in the first column indicates an episode. The numbers in the rest of the columns are the moves (grey columns = black moves; white columns = white moves). The moves are displayed in algebraic notation . Base moves are all the moves in the first column.

	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	
1	Bxb4	Rxf6																	
2	Bxb4	Rxf6	Rd3																
3																			
4	f7	Rf6																	
		Rg1+																	
		b3																	
5	Bxb4	Rg1+	+																
		Kb3	Be7	+															
		Rxf6	Rd3	Rc6+															
				Rf1+															
				Rc6+	Bc3	Kb3	-												
6	Bxb4	Rxf6	Kc2																
7	Bxb4	Rxf6	Kc2	Rf2+	Bd2	-													
8	Bxb4	Rxf6	Kc2	Rf2+	Bd2	-													
9	Rf5	Rg1+																	
		b3																	
		Kb3	Rf3+	+															
		Rg1+	Be1	Rxe1+	Kd2	Re8	f7	Rf8	-										
10	Rf5	Rg1+	Kc2	b3+	Kc3														
					Kd3														
					Kc3	b2	-												
11	Rf5	Rg1+	Kc2	b3+	Kd3	b2													
12	Bg5	b3																	
		Rg8																	
13	Bg5	b3	f7	-															
			Rd2+																
14	Bg5	b3	Rd2+	Ka3															
				Ka1															
				b2	Rxb2+	+													
15	Bg5	b3	Rd2+	Ka1	f7	Rxg5	f8=Q	Rg1+	Rd1	b2	Kd2	Rxd1+							
											Kc2	Rxd1	Qa3++						
												b1=Q	Rxb1	Rxb1	Qa3+				
16	Bg5	b3	Rd2+	Ka1	f7	Rxg5													
						a3													
						b2	+												
					f7	Rxg5	f8=Q	b2+	+										
								Rg1+	Rd1	b2	Kc2	+							
17	Bg5	b3	Rd2+	Ka1	f7	b2	Rxb2	Rxg5	f8=Q	Rg1+	Kd2	Rg2+	+						
18	Bg5	b3	Rd2+	Ka1	f7	a3	f8=Q	b2+	K	b1=Q+	-								
									Rxb2	axb2+	Kd2	b1=Q							
19	Bg5	b3	Rd2+	Ka1	f7	Rc6+	+												
20	Bg5	b3	Rd2+	Ka1	f7	a3	f8=Q	b2+	Kd2	b1=N+	Kc2	Rxg5	Qa8+	+					
21	Bg5	b3	Rd2+	Ka1	f7	a3	f8=Q	b2+	Rxb2	axb2+	Kd2	b1=Q	Qa3+	Qa2+					
													Bf6	Rxf6	(Qxf6+)	Qb2+	=		
22	Bg5	b3	Rd2+	Ka1	f7	a3	f8=Q	b2+	Kd1	b1=Q	Ke2	-							
23	Bg5	b3	Rd2+	Ka1	f7	a3	Rd1	Rc6+											
								b2+											
								Rxg5	f8=Q	+									
24	Bg5	b3	Rd2+	Ka1	f7	a3	Rd1	b2+	Kc2	Ka2	f8=Q	Rc6+	Kd2	Rd6+	+				
25	Bg5	b3	Rd2+	Ka1	f7	a3	Rd1	Rc6+	Kd2+	Rd6+	[illegal]								
										Rc8	[illegal]								
								Rc6+	Kd2+	Ka2	f8=Q	+							
26	Bg5	Rg8																	
27	Bg5	b3	f7																
			Rd2+	b2	+														
				Ka3	f7	+													
28	Bg5	b3	Rd2+	Ka1	f7	Rc6+													
						b2+	Rxb2												
						a3	Rd1	Ka2	f7[ille]	b2+	Kc2								
29	Bg5	b3	Rd2+	Ka1	f7	a3	Rd1	Ka2	f8=Q	+									
30	Bg5	b3	Rd2+	Ka1	f7	Rc6+	Kd1	Rc8	Bf6+	Kb1									
										b2	xb2								
										Kb1	Rb2+	(Ka1)	Rxb3+	+					
31	Bg5	b3	+																
32	Bg5	b3	Rd2+	Ka1	f7	a3													
						Rc6+	Kd1	+											
33	Bg5	Rg8	Bh6																
34	Bg5	Rg8	Rd2+	Ka1	f7														
35	Bg5	Rg8	Rd2+	Ka3	+														
36	Bg5	Rg8	Rd2+	Ka1	f7														
					Rc8														
37	Bg5	Rg8	Rd2+	Ka1	f7	Rc8+	Rc2	Rf8	Bf6+	+									
								Rxc2	Kxc2	b3	Kd2	b2	Bf6+	Ka2	Bxb2	Kxb2	f8=Q	a3	+
38	Bg5	Rg8	Rd2+	Ka3															
				Kb3															
				Ka3															
39	Bg5	Rg8	Rd2+	Ka3	f7	Rc8+													
						Rf8	Rf2	+											
					f7	Rc8+	Rc2	+											
40	Bg5	Rg8	Rd2+	Kb3	f7	Rc8+	Kb1	a3	£										

								a3										
42	Bg5	Rg8	Rd2+	Kb3	f7	Rc8+	Kb1	Rh8	Bh6+	Rxh6	Rd3+	Kc4	Rf3	Rh1+	Kc2	b3+	Kd2	+
43	Bg5	Rg8	Rd2+	Kb3	f7	Rc8+	Kb1	Rh8	Rd3+	Kc4	Rd1	a3	Rf1	+				
play	Bg5																	

Figure 8.12. Problem behaviour graph of IM during position 2. '+' stands for 'white is better', '-' stands for 'black is better', '£' stands for 'complex position', and '=' stands for 'equal position'.

Every episode starts when a base move is visited. Sometimes, as in episode 3, moves were not generated; that means that the player was performing a general evaluation of the position without mentioning any particular move. At the end of each branch, the players sometimes gave an evaluation of the position, which is represented by the signs "+", "-", "=", "£". They stand for 'white is better', 'black is better', 'equal position' and 'complex position', respectively.

	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9
1	Bg5	b3	Rd2+	Ka1	f7	a3	f8=Q	b2+	Rxb2	axb2+	Kd2	b1=Q	Bf6	Rxf6	(Qxf6+)	Qb2+	=	
2													Qa3+	Qa2+				
3									Kd2	b1=N+	Kc2	Rxg5	Qa8+	+				
4									K	b1=Q+	-							
5							Rd1	b2+	Kc2	Ka2	f8=Q	Rc6+	Kd2	Rd6+	+			
6								Rc6+	Kd2+	Ka2	f8=Q	+						
7										Rd6+	[illegal]							
8										Rc8	[illegal]							
9								Rxg5	f8=Q	+								
10								Ka2	f8=Q	+								
11									f7(ill)	b2+	Kc2							
12						Rxg5	f8=Q	Rg1+	Rd1	b2+	Kc2	Rxd1	Qa3++					
13												b1=Q	Rxb1	Rxb1	Qa3+			
14											Kd2	Rxd1+						
15								b2+	+									
16						b2	Rxb2	Rxg5	f8=Q	Rg1+	Kd2	Rg2+	+					
17						Rc6+	Kd1	Rc8	Bf6+	Kb1	Rb2+	(Ka1)	Rxb3+	+				
18										b2	xb2							
19				Ka3	f7	+												
20				b2	Rxb2+	+												
21		Rg8	Rd2+	Kb3	f7	Rc8+	Kb1	Rh8	Bh6	Rxh6	Rd3+	Kc4	Rf3	Rh1+	Kc2	b3+	Kd2	
22									Rd3+	Kc4	Rd1	a3	Rf1	+				
23											Rf3	+						
24								a3	£									
25							Rc2	+										
26						Rf8	Rf2	+										
27				Ka1	f7	Rc8+	Rc2	Rxc2	Kxc2	b3	Kd2	b2	Bf6+	Ka2	Bxb2	Kxb2	f8=Q	a3 +
28								Rf8	Bf6+	+								
29			Bh6															
30	Bxb4	Rxf6	Kc2	Rf2+	Bd2	-												
31			Rd3	Rc6+	Bc3	Kb3	-											
32				Rf1+														
33		Kb3	Be7	+														
34		Rg1+	+															
35	Rf5	Rg1+	Kc2	b3+	Kd3	b2												
36					Kc3	b2	-											
37			Be1	Rxe1+	Kd2	Re8	f7	Rf8	-									
38		Kb3	Rf3+	+														
39		b3																
40	f7	b3																
41		Rg1+																
42		Rf6																

Figure 8.13. Exploration tree of IM in position 2.

Another way of generating a tree protocol is shown in figure 8.13 ('exploratory tree' in Newell & Simon, 1972). In this case, all the repetitions of moves were eliminated and the tree does not follow the temporal order of the protocol. With the exploratory tree, it is possible to analyse the real size of the tree generated by the player.

Table 8.4. Performance of the four players in each position using the problem behaviour graph.

	Position 1				Position 2				Position 3*		
	gm	im	ex	cb	gm	im	ex	cb	gm	im	ex
Quality of moves	3	4	2	4	5	5	5	2	5	5	2
Total time (min)	30	30	25.7	27.9	30	30	23	30	30	30	18.9
#nodes visited	310	374	144	90	313	385	186	86	487	456	128
Nodes/minute	10.33	12.46	5.61	3.22	10.4	12.8	8.09	2.87	16.2	15.2	6.78
Maximal depth (plies)	17	25	12	12	19	18	21	9	39	28	20
Mean depth (plies)	4.82	7.29	4.63	2.96	8.53	7.85	10.23	2.68	19	16.3	7.23
#episodes	57	41	30	28	32	43	17	31	14	20	17
#base moves	13	9	8	9	4	4	2	14	4	1	6
Base moves/min	0.5	0.3	0.31	0.32	0.13	0.13	0.09	0.47	0.13	0.03	0.32
Immediate reinvestig.	27	29	15	8	26	37	15	2	8	19	6
Non-immed. reinvest.	15	3	5	11	2	1	0	11	2	0	5
Total reinvestigations	42	32	20	19	28	38	15	13	10	19	11
Branches	81	104	34	37	53	83	29	34	71	77	21
Branches/episode	1.42	2.53	1.13	1.32	1.65	1.97	1.7	1.17	5.07	3.85	1.23
Nodes/episode	5.44	9.12	4.8	3.21	9.78	8.95	10.9	2.77	34.8	22.8	7.53

Note. *Due to a technical problem, CB's data for third position is not taken into account.

Table 8.4 gives an overview of the results for each player in each position, using the problem behaviour graph as reference. The dependent variables that are of most interest in this thesis are depth (maximum, mean), speed of search (nodes per minute), and quantity of information generated (number of nodes visited, branches).

Table 8.5. Performance using the exploratory tree.

	Position 1				Position 2				Position 3*		
	gm	im	ex	cb	gm	im	ex	cb	gm	im	ex
#branches	49	47	18	21	29	42	20	20	53	41	16
#nodes visited	176	152	83	56	149	160	121	61	221	173	88
Mean depth (plies)	6.18	9.91	6.38	3.71	9.48	8.4	11.2	3.55	21	15.3	8.18
#branches/minute	1.63	1.57	0.7	0.75	0.97	1.4	0.87	0.67	1.77	1.37	0.85
#nodes/minute	5.87	5.07	3.23	2	4.97	5.33	5.26	2.03	7.37	5.77	4.66

Table 8.5 offers another way of looking at the data. After eliminating all the moves repeated in the problem behaviour graph, an exploratory tree was generated (see figure 8.13). Some of the variables— e.g., mean depth— are more accurately measured using the exploratory tree. This kind of tree was used by Newell and Simon (1972) and informally by Kotov (1978).

Table 8.6. Averaged performance of participants using the problem behaviour graph.

	qm		im		ex		cb	
	m	sd	m	sd	m	sd	m	sd
Quality of moves	4.33	1.15	4.66	0.57	3	1.73	3	1.41
Total time (min)	30	0	30	0	22.51	3.41	28.95	1.48
#nodes visited	370	101.3	405	44.51	152.7	29.96	88	2.82
Nodes/min	12.33	4.1	13.5	1.67	6.77	1.23	3.16	0.25
Max. depth (in plies)	25	12.17	23.67	5.13	17.67	4.93	10.5	2.12
Mean depth (in plies)	13.77	7.4	10.48	5.04	7.36	2.8	2.82	0.19
# of episodes	34.33	21.59	34.67	12.74	21.33	7.5	29.5	2.12
# of base moves	7	5.19	4.66	4.04	5.33	3.05	11.5	3.53
Base moves/min	0.13	0	0.08	0.07	0.23	0.13	0.39	0.1
Immediate reinvestig.	20.33	10.69	28.33	9.01	12	5.19	5	4.24
Non-immed reinvest.	6.33	7.5	1.33	1.52	3.33	2.88	11	0
Total reinvestigations	26.67	16.04	29.67	9.71	15.33	4.5	16	4.24
Branches	68.33	14.19	88	14.18	28	6.55	35.5	2.12
Branches/episode	3.36	2.41	2.78	0.96	1.35	0.3	1.24	0.1
Nodes/episode	16.67	15.84	13.63	7.94	7.75	3.07	2.99	0.3

Tables 8.6 and 8.7 show the overview of the variables calculated from the problem behaviour graph and the exploratory tree, respectively. In both tables, the average of the three games is considered.

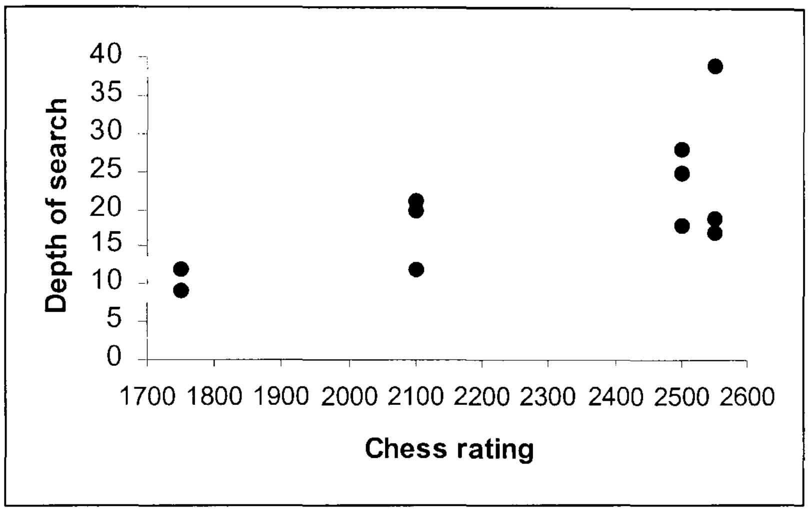
Table 8.7. Averaged performance using the exploration tree.

	qm		im		ex		cb	
	m	sd	m	sd	m	sd	m	sd
Branches (non rep.)	43.67	12.86	43.33	3.21	18	2	20.5	0.7
Nodes (non rep.)	182	36.37	161.7	10.6	97.33	20.65	58.5	3.53
Mean depth (no rep.)	12.22	7.78	11.21	3.63	8.57	2.4	3.63	0.11
Branches per minute	1.45	0.42	1.44	0.1	0.8	0.09	0.7	0.05
Nodes per minute	6.06	1.21	5.38	0.35	4.38	1.04	2.01	0.02

8.3.2.1. Depth of search

In all measures of depth there was a very strong linear relation with chess rating. Figure 8.14 shows the scatter-plots of mean depth of search and maximal depth of search as a function of chess rating showing the 11 data points.

A)



B)

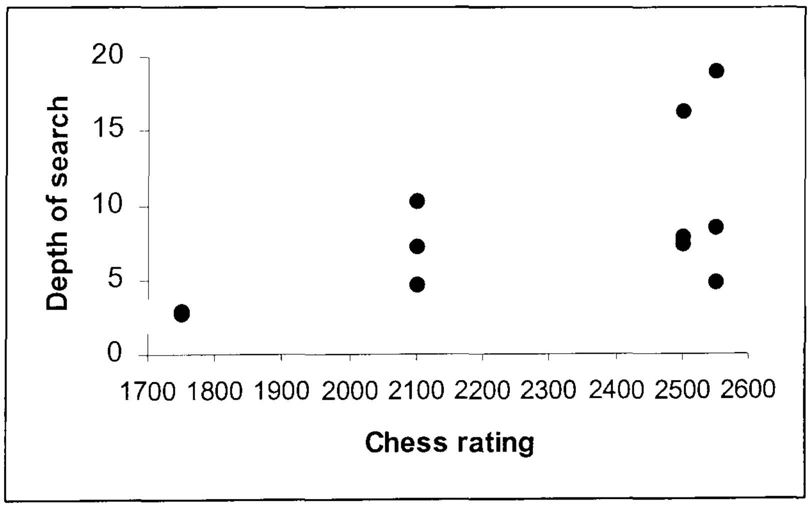


Figure 8.14. Depth of search as a function of chess rating (all data points).A)Maximal depth (in plies); B) Mean depth (in plies).

In order to compare the results of this study with those of Charness (1981) and Gobet (1998b), mean depth and maximal depth were put into a regression formula. In both cases chess rating was used as predictor. The following linear relation was obtained predicting mean depth from chess rating: Mean depth = -

18.23 + 0.012 * Elo (the coefficient for Elo is significant at .029 level and the r^2 was .94). Mean depth of search increases 2.4 plies for each standard deviation of chess skill (200 Elo points). Linear relations of 0.5 and 0.6 plies per standard deviation were obtained by Charness (1981) and Gobet (1998b) respectively. However, Saariluoma (1990) found that international masters searched shallower than master players. The range of Elo in those studies was 1284 to 2004 in Charness (1981), 1600 to 2450 in Gobet (1998b) and 1900 to 2500 in Saariluoma (1990). In the present study the range was 1750 to 2550. Charness (1981) suggested that there might be a linear relation until the expert level and after that level there would not be any increase. Similarly, Gobet (1997) suggested that mean depth is a power law of chess skill, and the reason why linear relations were found was that the whole range of chess skill was not measured in the same experiment. Gobet (1997) tested this hypothesis with SEARCH and found a power function.

The present study did not measure the whole range—as required by Gobet (1997)—but the linear relation obtained was much higher than that of the previous studies. Therefore, the present data suggest a linear relation between Elo and mean depth of search.

Moreover, maximal depth showed even a stronger linear relation. The data was analysed in two ways. First, the maximal depth of each player was obtained (i.e., the maximal depth of search showed in any of the three games). With these data the following formula was obtained: Maximal depth = -38.45 + 0.028* Elo; $r^2 = .88$, $p < 0.06$. This implies a 5.6 plies increase per standard deviation. The higher value was obtained by GM with 39 plies. Although the relation is quite high it is not significant. However, taking the mean maximal depth of search of the three positions the equation achieved was: Maximal depth = -19.96 + .017* Elo; $r^2 = .99$, significant at 0.003 level). In this case the increase per standard deviation dropped to 3.4 plies. This is the way previous studies calculated maximal depth; Charness (1981) found a 1.5 ply increase per standard deviation and Gobet (1998b) did not find any skill effect.

8.3.2.2. Speed of search

There is also a strong skill effect in speed of search, measured by nodes generated per minute. Table 8.6 shows that GM generated 12.33 nodes per minute; IM 13.5; EX 6.77; and CB 3.16. Figure 8.15 depicts a scatter-plot with nodes per minute as a function of chess rating. De Groot (1946) and Gobet (1998b) found that masters searched faster than experts, and Gobet (1997) showed that the rate of search is a power function of the number of nodes in CHREST's long-term memory. On the other hand, Charness (1981) did not find a skill effect. In those studies players did not search faster than 6 nodes per minute. However, Scurrah and Wagner's (1971) participant searched at around 10 nodes per minute. In the case of speed of search, the higher values of SEARCH are in agreement with GM and IM speed, and EX and CB data are not very far from those predicted by SEARCH. Predicting chess rating from nodes per minute yields the following formula: Elo = 1664 + Nodes per minute*63.88 ($r^2 = .82$, $p < .001$).

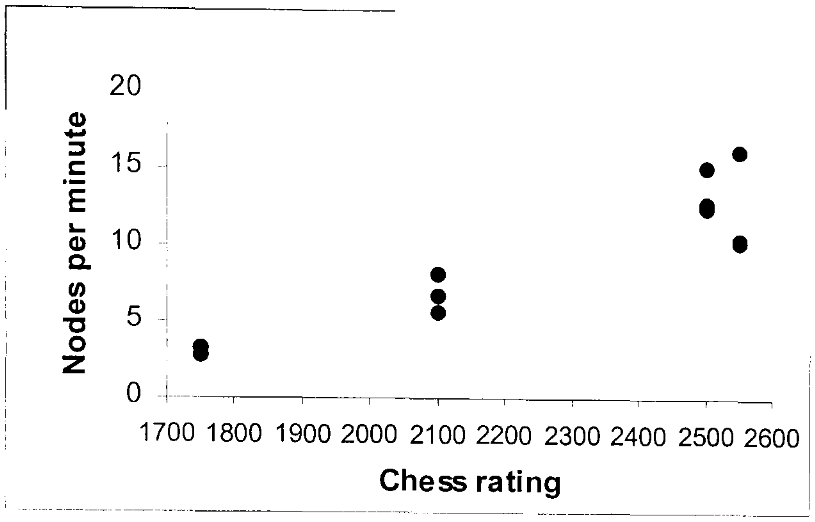


Figure 8.15. Speed of search (nodes per minute) as a function of chess rating (all data points). The data of the three positions are presented. CB's data points correspond to 1750 in the x-axis, EX's to 2100, IM's to 2500, and GM's to 2550.

8.3.2.3. Quantity of information generated

Once again, a linear relation between total number of nodes visited and chess skill was found (GM 370 nodes; IM 405; EX 153; and CB 88). Figure 8.16 depicts the scatter-plot of the data points of all the positions. In previous studies the number of nodes is usually smaller than those of the present thesis. There is only one exception, Scurrah and Wagner's (1971) class C player[2] visited 328 nodes in one of the positions. The small number of nodes visited in De Groot (1946/1978) could be an artifact of the fact that he took notes to record players' protocols. However, Gobet (1998b) used a tape recorder and the values were similar to those of De Groot. The main reason for differences seems to be the type of position used. De Groot's position A requires only 9 plies to be solved, reducing the need to search longer. In the present study, two positions were specially selected because they required long trees of variations to be solved.

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[2] Later it was discovered that this player was an expert (see Holding, 1985).

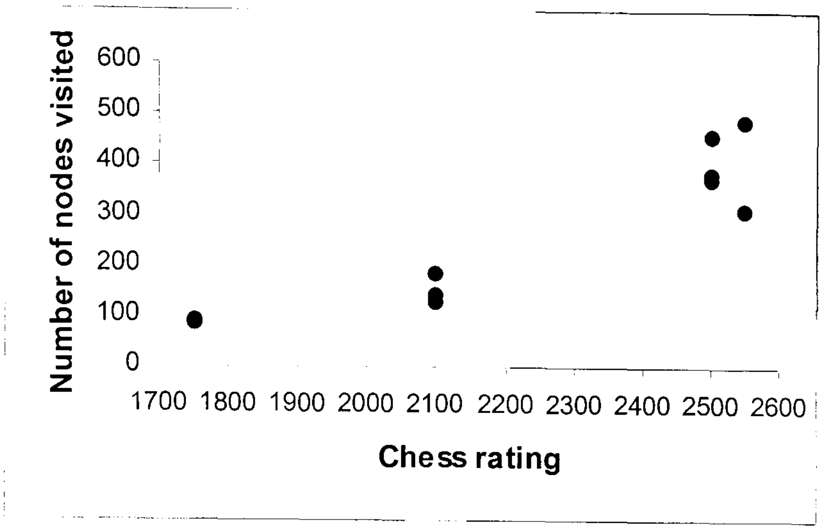


Figure 8.16. Quantity of information generated (number of nodes visited) as a function of chess rating.

A difficulty arises when one wants to measure width of search from the problem behaviour graph. On the one hand, if one uses the number of episodes as a measure of width, the following could happen. A grandmaster could chose only one base move and search ahead from that move. He could spend the whole trial analysing this episode generating numerous branches, and never coming back to the base move; hence, there would have been only one episode, and his width would be low. However, this does not reflect the master's behaviour (i.e., he generated numerous branches and only one episode, which will be taken as his measure of width). On the other hand, if one uses number of branches as a measure of width, a weak player may produce several branches of the same move because he needs to come back to the initial position very often, so he would show a very wide tree of analysis, when in fact he is not searching wide at all. For these reasons, a tree without repetitions was designed (see the exploratory tree of figure 8.13 for an example). From the exploratory tree, a table with new data was obtained (see table 8.7). Masters generated more branches than the intermediate players. The number of nodes show the same effect as the one explained earlier (i.e., a strong skill effect).

8.3.2.4. Comparison with De Groot's (1946) position C.

The first position of this study is De Groot's (1946) position C. Gobet (1998b) replicated the results obtained in De Groot's position A. It is interesting to find out if the results could be replicated in a more complex position. Basically, position C—unlike position A—does not have a unique solution. From the information provided in De Groot's book, I worked out the maximal depth, nodes per minutes, and the number of nodes visited, to have a measure of the three aspects analysed in the present study (depth of search, speed of search and quantity of information generated). Table 8.8 shows the data. Protocols from five players were obtained by De Groot: Euwe ('GM1', world champion, higher level than GM), Tartakower ('GM2', slightly better than GM), Cortlever ('IM1', same level as IM), Van Scheltinga ('IM2', same level as IM), Roodzant (1938 Women's champion of The Netherlands; difficult to measure the level, probably somewhere between EX and IM).

Table 8.8. De Groot's position C data.

	Minutes	Nodes visited	Maximal depth	Nodes per minute
GM 1	7	25	6	3.57
GM 2	15	45	9	3
IM 1	30	203	15	6.76
IM 2	21	88	14	4.19
Roodzant	20	24	4	1.2

There are clear differences between the data presented in table 8.8 and the data of the players of the present study (see table 8.4, position 1). All the players in this study spent more than 25 minutes. GM and IM used the whole 30 minutes allowed and they would have continued if they have had more time. GM1 and GM2 either did not try as hard as they could or they did not need more time to reach a decision. Regarding the number of nodes, except from IM1, all the players visited less nodes than CB. In maximal depth there was an advantage for the players in the present study; GM and IM searched deeper than all the players in De Groot's study. Nodes per minute shows a similar pattern. Overall, players in this study searched more, deeper and faster than those of De Groot's study.

Inspecting the protocols gives a hint that players in De Groot's study had difficulties in putting themselves in a tournament situation. In two of the five protocols, De Groot reminded the participants that they had to do so. Furthermore, there were many important factors of the position that were taken into account by GM and IM that the players in De Groot's study did not notice. Even, M1 overlooked a very rudimentary threat during the whole protocol.

8.3.3. Discussion

This study showed a linear relation between chess skill and depth of search, speed of search and quantity of information generated. Charness (1981) and Gobet (1998b) found a weak linear relation between chess skill and mean depth. Charness (1981) proposed that the linear function observed might be seen up to the expert level, and that beyond that level no increase in depth of search would be found. Gobet (1997) suggested that if the whole range of chess levels is tested a power function would be found. The latter presented a computer model which predicted a power function as well. The present data does not support the model inasmuch as a linear relation was found.

Regarding speed of search (nodes visited per minute), SEARCH (Gobet, 1997) predicts values similar to the ones found in the present study, especially at the higher levels. In comparison with the other human studies, the present one showed a stronger linear relation between speed of generation of moves with chess skill. Concerning the quantity of moves, a linear relation was also found, in contrast to previous studies.

A relatively novel way of looking at the data was used in this study, i. e., the exclusion of the repeated moves in order to create an exploratory tree as opposed to a temporal one. No important changes in the patterns were found. The advantage of this procedure is that a good measure of width of search could be taken. In this study, a non-linear skill effect was found.

De Groot's study was a pioneering one and emphasis was put on the qualitative analysis of the data, which is quite rich. Paradoxically—as mentioned by Gobet et al (in press)— most importance was given by later researchers to his quantitative analysis. The comparison in this sub-section shows that perhaps more caution should be observed when using De Groot's quantitative data. The conditions in which the protocols were obtained (some on a ship, others in a laboratory) might have affected the results obtained.

It is worth noting that power functions fit the data obtained, even better than linear regression. However, that function is similar to the linear function and it does not reach an asymptote. Looking at the graphs in Gobet (1997, p. 307), it is evident that a power function with asymptote—and not any power function—was what Gobet proposed.

8.4. General discussion

In the search task GM showed an advantage over IM. That task measured maintenance of information during search. Not only did GM perform better than IM, but also IM needed more grid-board eye shifts and more fixations over the chessboard than GM, which suggests a better maintenance ability for GM. Is that advantage apparent also in the think aloud problem solving tasks in which maintenance during search is vital? If this were the case, more reinvestigations in IM would be expected and higher depth in GM would be found. Briefly, if GM is better than IM at maintaining the positions generated, then he is less likely to lose the positions generated; thus, he can carry on generating more positions. Regarding the reinvestigations, if IM has problems at maintaining a position, then he is more likely to lose positions that were generated; hence, he needs to restart the variation from the base move.

Indeed, GM had a higher mean depth (13.77 plies compared to 10.48 plies) and the maximal depth found was also much higher for GM (39 plies to 28 plies). However IM did not show more reinvestigations than GM. It was apparent during the analysis of the protocols that IM used a strategy suggested by the strong grandmaster Kotov (1978) in an influential book about chess training. IM proposed to himself the candidate moves and then started analysing them one at a time. When he finished analysing one candidate move, he passed to a new one. This is also evident insofar as the ratio of immediate reinvestigations to non-immediate reinvestigations was much higher in IM (21.3 to 3.21). GM acknowledged during the analysis of one of the positions that he was very disorganised. This better organisation of thinking IM compensated GM's maintenance advantage, so IM was slightly faster than GM.

8.5 Conclusions of the cross-tasks study

A great variety of tasks and different techniques with a low number of participants were used in this study. This methodology was suggested by Gobet and Ritter (2000), who proposed to gather data and then to estimate parameters which would be useful to design computer models in order to test theories. In this chapter the data gathering was carried out, followed by the report and interpretation of the results. Furthermore, numerous connections among studies were done in order to explain one set of data in the light of previous results.

The second step—estimation of values for some parameters—will be one of the sections of the general discussion in chapter 11. The third step—modelling the data—is beyond the scope of the present work.

Table 8.9 gives a summary of all the experiments of chapters 6, 7 and 8. The information is summarised in three comparisons: GM vs IM, masters vs intermediates, and chess players vs non-chess players. The information presented in the table will be used in conjunction with the previous experiments in order to estimate the value of some parameters of a general theory of expertise. As mentioned earlier, Template/CHREST will be used as a starting point.

There was clear agreement in the psychology literature about the existence of a skill effect in the reconstruction paradigm and the decrease in the advantage between experts and novices in the reconstruction of random positions. On the other hand, De Groot (1946) failed to provide any difference in the macro-structure of a more natural chess tasks—think-aloud problem solving. In this study, I replicated previous findings in the reconstruction paradigm, and also I found a strong linear relation in all the parameters in the think-aloud problem solving task.

Table 8.9. Summary of cross-tasks study (chapters 6. 7 and 8). Differences GM vs IM, Masters vs Intermediate and Chess players vs Non-chess players.

		GM vs IM	Masters vs Intermediate	Chess players vs Non players
Descriptive & practice		IM started studying earlier	Hours playing, studying, books.	
Memory	-Delayed recall	GM better for pictures, and to a lesser extent in chess.	only differences in chess	only differences in chess
	-fMRI	GM better at recall and slightly better at recognition		
	-Immediate recall. Reconstruction.	No differences	Strong effect for games, small effect for random, no effect for shape.	Strong effect for games, small effect for random, no effect for shape.
	-Immediate recall. Span.	No differences	No differences	Only spatial.
Learning		no differences	differences in chess, draughts and GO	differences in chess, draughts and GO.
Thinking	-Search task	GM better performance in both, fewer shifts and fixation on chessboard	Better performance in both, fewer shifts and fixation on chessboard.	
	-Quick problem solving/RT.	GM advantage in performance. Only 30 ms. faster in RT.	Advantage in performance. No differences RT	No differences RT
	-Think aloud protocols.	GM deeper; IM more nodes, slightly faster and better organised; = width.	deeper, more nodes, faster, wider	

It was hypothesised that GM's better performance in long-term memory for pictures may be reflected in other tasks. He also performed better than IM in recognition and recall of chess positions. In the search task and the quick problem solving, GM performed better than IM; and the same was true in the simple reaction task. However, no differences were found in the reconstruction paradigm. This could lead to a link between speed of processing and long-term memory (fast problem solving and delayed recall task) but not with immediate recall task.

The advantage of GM in the search task was also reflected in the depth of search in the think out loud task. However, the better organisation of IM thinking made him slightly faster in the generation of moves, and equalised GM in the width of search. These results will be used to set values to parameters of memory, learning rates, fading of information in long-term memory—all of them primary cognitive processes—but also to meta-cognitive processes like organisation of thinking.

In the next chapter, an fMRI study in which GM and IM were the participants, is presented (a small part of the analysis was presented in the preceding chapter; sub-section 7.1.2). The aim of next chapter's study is to show how chess as a task environment is a powerful tool to investigate the phenomenon of autobiographical memory.

CHAPTER 9

Brain imaging (1)

Autobiographical memory

Thus far, the studies reported in this thesis have investigated the cognitive aspects of expertise, imagery, memory and thinking. Studies in expertise have at least two purposes: the investigation of expertise per se, and the study of other psychological phenomena. The preceding experiments put more emphasis on the expertise side, while the experiments in this and the following chapter put more emphasis on the study of psychological phenomena.

This chapter discusses the topic of autobiographical memory. As part of the cross-tasks study reported in chapters 6 to 8, GM and IM went through an fMRI experiment (see methodological issues in chapter 3, section 3.1). Part of the results—the ones focused on individual differences—were discussed on chapter 7. This chapter deals with the issues related to autobiographical memory and its neural basis. This study is a clear example of the use of expertise in order to study a psychological phenomenon; and, in so doing, it will be shown that chess is a powerful tool to study neural basis of autobiographical memory. The expertise issue will not be analysed in the whole chapter.

In chapter 2 (section 2.3.2.2) a review of the theories, behavioural and brain imaging studies about autobiographical memory, has been provided. Only a handful of brain imaging studies was found, suggesting that the probing of this phenomenon using brain imaging techniques has enormous difficulties. In this chapter, a solution to these difficulties is presented using the chess masters' own games as stimuli. The general methodological fMRI procedures have been extensively discussed in the methods chapter (section 3.1); hence, in this and the following chapter, I will only present the specific methodological aspects of each experiment. In this chapter and the following the interest is in the neural basis of memory and expertise.

9.1 Overview of the experiment

One of the problems in all of the autobiographical memory studies reviewed is that the researchers had to interview the participants in order to obtain information about their lives (e.g., Fink et al., 1996; Maguire & Mummery, 1999). With this procedure, the memory that has been investigated might have been affected, since it was rehearsed during the interview, therefore making the claims about memory age unsound. Alternatively, Conway's team (Conway et al., 1999; Conway & Pleydell-Pearce, 2000) used a cue word and asked participants to generate a memory of a personal event. The problem in this approach resides in the fact that sometimes the subjects could not retrieve any memory. Another caveat is that the manipulation of the memory age under the control of the participants, not the experimenter.

There is no doubt that the studies reviewed above are an important contribution to memory research inasmuch as real-world memories - rather than laboratory-generated memories - were used, improving the ecological validity of the domain. For instance, it is already known that the correlation between clinical memory tests in patients with their every-day memory problems is rather low (Kapur & Pearson, 1983). Hence, efforts made in order to study more ecological memories should be applauded. On the other hand, a usual caveat of improving ecological validity is the loss of control.

In order to overcome the shortcomings of the autobiographical memory experiments just reviewed, chess was used as a task environment in the present study. The advantages of using chess as a research setting were discussed earlier in the thesis (see chapter 1) and in many articles (e.g., Gobet & Simon, 2000).

For this study, the use of Chess Base was fundamental. Two high-level chess players (one international grandmaster—GM—and one international master—IM) agreed to take part of this experiment as part of a series of experiments (see chapters 6 to 8). Once the participation of the players was agreed, I searched for their games on the data base. Chess Base provides numerous games of international players, with the name of the tournament, year, name of the opponent, and, of course, the moves of the game. This facility allowed me to generate stimuli from selected years using games that the two participants had played. Consequently, no previous interview was needed in order to generate the autobiographical stimuli. Moreover, the age of the memories was easily manipulated by choosing games played in different years.

This study is aimed at finding the location of autobiographical memory processes in the brain, as well as attempting to find differential activation of memories of different ages. In so doing, the high ecological validity that characterises this field was maintained, and more control over the variables studied was obtained.

9.2. Methods

9.2.1. Participants

Two chess players took part in this experiment. One grandmaster of 2550 ELO and 21 years of age and an international master of 2500 ELO and 22 years of age. Both of them were right-handed, and signed an informed consent and a safety form. Ethical regulations of the School of Psychology University ethical committee were followed in the experiment.

9.2.2. Procedure

Once the participants agreed to participate in the experiment, a set of games that they played in official tournaments (available in Chess Base) were chosen. With these games 67 stimuli were generated for the grandmaster and 66 for the international master (hereafter these position will be called 'own'). The stimuli consisted of chess positions with 26 +/-1 pieces on the board. The age of the games was manipulated in three groups: games played in the current year (2002), games played in 1999 and 2000, and games played in 1997 and 1996. Also, the result of the games (games won and games lost) and the colour with which they played (black or white) were manipulated. Twenty-four games played by grandmasters were also selected (henceforth, these positions will be called 'others'), and one stimulus of 26 +/-1 pieces was generated for every game. Finally, a control stimulus ('control') was generated and was presented 24 times. Figure 9.1 depicts an example of each condition.

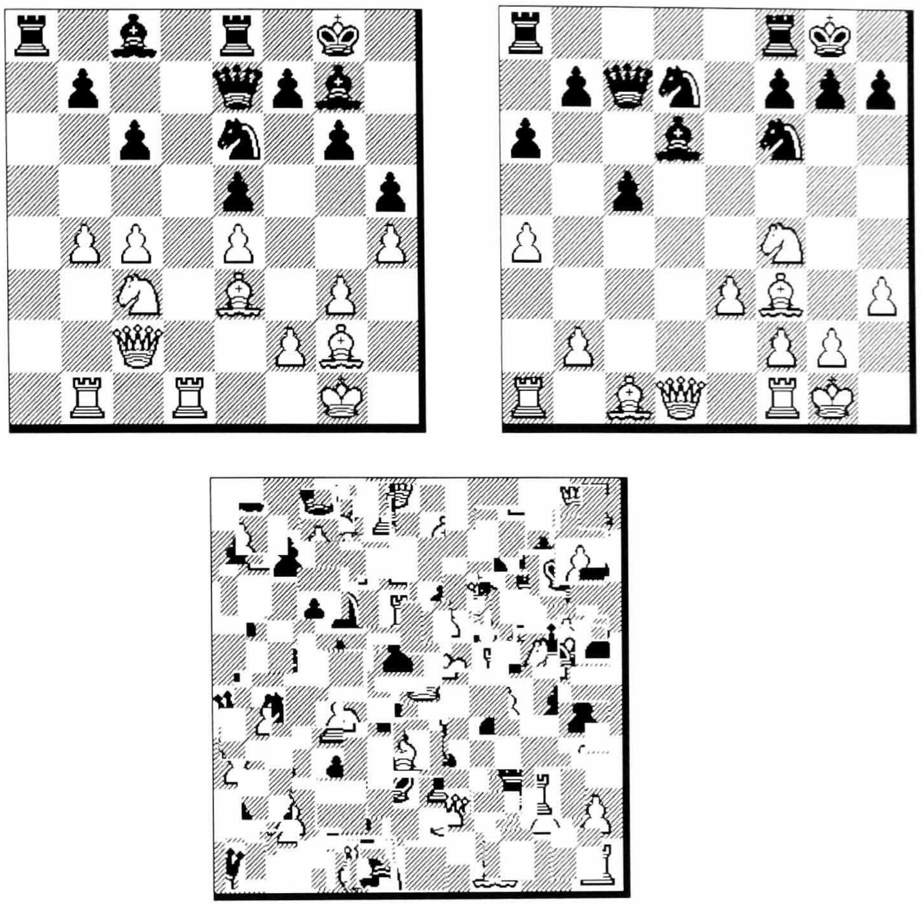


Figure 9.1. Stimuli used in the experiment. The first and second are examples of stimuli generated from games of the participants or other players' games. The third is the control stimulus. It is evident that the only difference between the first type and second type of stimuli is the fact that one belongs to the participants' own games and the other does not.

9.2.3. Design

During the scanning session, the participants saw chess positions which were on screen for 5 seconds, after viewing a fixation cross that was presented for 13 seconds. Immediately before the scanning session, they were informed that at some time after the scanning session they would have to fill in a form with the games that they were able to remember, indicating opponent, year, tournament, result and next move. Additionally, after the recall test they would have a recognition test in which they would have to determine two things: if the position presented was seen in the scanner and whether or not it is an own position.

There were three phases in the study: presentation, recall test, and recognition test. The presentation phase took place during the scanning session, and the other two phases occurred 4 and 5 hours after the end of the scanning session. In the presentation session, GM was presented with 115 positions (67 own, 24 others, 24 control), and IM with 114 positions (66 own, 24 others, 24 control). Table 9.1 shows the number of own positions used in each variable for each player during the scanning session.

Table 9.1. Number of positions used in each variable. Left hand side = GM. Right hand side = IM.

Age	Colour	Result	Number	Age	Colour	Result	Number
New	White	Win	6	New	White	Win	6
		Loss	3			Loss	4
	Black	Win	6		Black	Win	6
		Loss	5			Loss	6
	Total		20		Total		22
Intermediate.	White	Win	6	Intermediate.	White	Win	6
		Loss	5			Loss	2
	Black	Win	6		Black	Win	6
		Loss	6			Loss	6
	Total		23		Total		20
Old	White	Win	6	Old	White	Win	6
		Loss	6			Loss	6
	Black	Win	6		Black	Win	6
		Loss	6			Loss	6
	Total		24		Total		24
Subtotal	White		32	SubTotal	White		30
	Black		35		Black		36
		Win	36			Win	36
		Loss	31			Loss	30
Total			67	Total			66

Note. New positions = 2002; Intermediate positions = 2000 and 1999; Old positions = 1997 and 1996.

The recall session took place 4 hours after the scanning session and the recognition phase was 1 hour after starting the recall session. No time limit was given to any of these sessions. In the recognition session all the positions (own and others) presented in the scanner were shown again; additionally, 24 new 'others' positions and a number of 'own' positions were presented. In total the grandmaster saw 225 positions (115 old and 110 new) and the international master saw 221 positions (114 old and 107 new).

9.2.4. Scanning procedure

The experiment was carried out at the University of Nottingham Magnetic Resonance Centre in a 3T scanner (see detailed specifications in Methods section in chapter 3). T2* weighted functional images were obtained during the experiment as well as a set of structural images straight after the end of the experiment. Twenty two coronal slices were obtained per volume; the TR (time between the acquisition of the first slice of one volume and the first slice of the following volume) was set at 3 seconds. The speed of slice acquisition was 136 ms per slice.

Standard procedures were followed in SPM 99, including realignment, normalisation and smoothing. In the latter case, a kernel of 12 x 12 x 12 mm was used.

9.2.5. Statistical analysis

This was a combination of blocked and event-related designs, having the characteristic of an event-related design inasmuch as only one trial is the unit of analysis. However, the events in an event-related design usually last less than 2 seconds. In this design the stimuli were presented for 5 seconds. Additionally, a spacing of 13 seconds was used in order for the hemodynamic response function to settle down, which is not usually the case in event-related designs. Furthermore, the trials were modelled as blocks with a box-car function convolved with the hemodynamic response function. The merit of this design is that it possesses the statistical power of the blocked designs and all the good features of event-related designs. The time limitations that usually plague trial based designs were solved by making the participants respond outside the scanner.

In all the contrasts a Bonferroni correction for multiple comparisons was performed and a threshold of $p = 0.05$ was used, except for the own > others contrast in which uncorrected values were used and the threshold was $p = 0.001$.

9.3. Results

9.3.1. Behavioural performance

9.3.1.1. Recall task

In the recall session the grandmaster gave at least one cue that allowed to identify the game in 83.58 % of the total games shown during the scanning session. The international master's performance was 69.69%. In both cases they gave correct cues in almost all the games items (opponent, tournament, year and result) excepting next move. In the latter the grandmaster performed outstandingly remembering 31 correct moves (after seeing the position for only 5 seconds 4 hours earlier!), the international master gave 8 correct moves.

9.3.1.2. Recognition task

In the recognition phase the grandmaster correctly recognised as previously seen or new 99.22% of the positions of his own games and 93.75% of the 'others' positions (mean 97.74%). The performance of the international master was similar:

96.06% own, 89.58% others (mean 94.28%). Additionally, in the recognition session, the players had to indicate whether the position presented was one of their own games or someone else's game. The grandmaster assigned ownership correctly to 97.17% of the positions. The international master performed at 89.14%.

9.3.2. Brain imaging results

The high accuracy of the players in both recognition and ownership did not allow me to perform any analysis comparing the brain activity at encoding of correct to incorrect positions.

9.3.2.1. Age of acquisition, result and colour

In both players no activations emerged neither when the contrasts among the different ages of the games (new, old, intermediate) were performed, nor the results contrast (win, lost), nor the colour (white, black). Therefore, all the games were grouped together.

9.3.2.2. Own > control and others > control contrasts

The first type of contrasts were aimed at finding brain areas responsible for the encoding of information that would be needed afterwards. The brain activity for the control condition was subtracted from that of own condition (own > control) and from that of others (others > control). Table 9.2 shows the Talairach coordinates of the brain areas activated in the own > control, others > control, and own > others contrasts for the grandmaster, and Table 9.3 displays the same information for the international master.

9.3.2.3. Own > others contrast

The most important contrast is own > others, for it gives the information of brain areas involved in autobiographical memory. Essentially, both conditions have the same visual information, and they also share the chess semantics. They only differ in that own positions may activate autobiographical memories of the participants, which may not happen with the 'others' positions. Table 9.2 also shows this information.

It is striking that most of the activations in the own > control contrast are bilateral and are the same in both players, with the only difference being the number of voxels activated (see figure 9.2). The activity is concentrated bilaterally in the following areas: middle occipital gyri, superior parietal lobes, posterior cingulate, medial temporal areas (parahippocampal gyri and fusiform gyri) and inferior frontal gyri .

In others > control, the majority of the activations are also bilaterally distributed in both players. In the grandmaster the middle occipital gyri and medial temporal areas (parahippocampal and fusiform gyri) contain most of the total activity. The international master had activations in the two regions mentioned above and also the superior parietal lobules and inferior frontal gyri. Figures 9.3 shows the brain activity displayed in structural images.

Table 9.2. Talairach coordinates of the grandmaster in all the contrasts of interest.

Contrast	Vox.	Hem.	Brain region	BA	t-value	Z-value	Talairach		
							x	y	z
Own > Control	346	L	Middle occipital gyrus	18	7.69	7.36	-36	-90	5
	726	R	Middle occipital gyrus	18	6.25	6.07	30	-90	16
		R	Post cingulate/Parahippocampal g.	37/30	6.4	6.21	21	-49	8
		R	Parahippocampal gyrus	19	8.29	>7.8	27	-47	-5
	20	L	Superior parietal lobule	19	5.18	5.07	-21	-79	45
	22	R	Superior parietal lobule	7	5.04	4.95	24	-70	53
	529	L	Fusiform gyrus	37	7.13	6.86	-30	-53	-10
		L	Posterior cingulate	30	6.25	6.07	-24	-61	9
		L	Cerebellum		5.38	5.26	-42	-74	-16
	238	R	Precentral gyrus	4	6.11	5.94	50	9	11
		R	Inferior frontal gyrus	46	5.45	5.33	56	30	10
		R	Inferior frontal gyrus	47	4.67	4.59	50	47	-2
	627	L	Inferior frontal gyrus	45	6.96	6.71	-36	27	15
		L	Inferior frontal gyrus	45	6.77	6.54	-39	19	21
	21	R	Inferior frontal gyrus	47	4.86	4.77	30	29	-1
	27	L	Inferior frontal gyrus	11	4.67	4.59	-30	32	-9
	101	L	Medial frontal gyrus	6	5.88	5.73	-24	-7	42
	45	R	Superior frontal gyrus	6	5.02	4.92	21	5	44
Others > Control	1142	R	Middle occipital gyrus	18	6.03	5.86	33	-84	10
		R	Parahippocampal gyrus	19	8.19	7.79	27	-47	-5
		R	Cerebellum		6.3	6.12	45	-54	-23
	932	L	Middle occipital gyrus	18	8.05	7.68	-36	-90	5
		L	Fusiform gyrus	37	7.06	6.8	-30	-53	-10
		L	Fusiform gyrus	19	5.91	5.76	-42	-76	-14
	14	L	Superior parietal lobule	7	4.71	4.63	-21	-58	55
	20	L	Posterior cingulate	30	5.02	4.92	-24	-58	8
	20	L	Precentral gyrus	6	4.67	4.59	-24	-7	42
	8	R	Precentral gyrus	4	4.55	4.47	50	7	13
	7	L	Insula	13	4.62	4.55	-33	7	16
	6	R	Inferior frontal gyrus	47	4.4	4.34	33	29	-4
	41	R	Superior frontal gyrus	6	4.97	4.88	21	5	44
Own > Others	37	L	Precuneus	31	3.63	3.59	-9	-48	36
	281	L	Superior temporal gyrus	22	3.77	3.73	-62	-52	16
		L	Superior temporal gyrus	39	3.76	3.72	-56	-57	25
		L	Inferior parietal lobule	40	3.73	3.68	-50	-50	44
	341	L	Inferior frontal gyrus	45	4.03	3.97	-56	27	10
		L	Middle frontal gyrus	8	3.82	3.77	-36	16	38
		L	Middle frontal gyrus	9	3.78	3.73	-45	33	29
	54	L	Superior frontal gyrus	9	4.05	4	-18	51	20
	25	L	Superior frontal gyrus	6	3.72	3.68	-12	15	60
	33	L	Superior frontal gyrus	8	3.54	3.5	-6	37	45

Note. In the first two contrasts Bonferroni correction for multiple comparisons was performed, establishing the threshold at $p<0.05$ ($t=3.12$). In own > others no correction was carried out, and the threshold was established at $p<0.001$. Talairach coordinates, Brodmann areas, t and z values, and number of voxels activated that belong to clusters of more than 5 voxels are displayed.

Table 9.3. Talairach coordinates of the international master in all the contrasts of interest.

Contrast	Vox.	Hem.	Brain region	BA	t-value	Z-value	Talairach coordinates		
							x	y	z
Own > Control	1757	L	Middle occipital gyrus	19	10.37	>7.8	-30	-87	15
		L	Superior parietal lobule	7	9.37	>7.8	-24	-64	53
		L	Posterior cingulate	31	5.81	5.66	-15	-58	14
	1212	R	Middle occipital gyrus	19	9.48	>7.8	39	-78	12
		R	Superior parietal lobule	7	8.95	>7.8	27	-59	53
		R	Posterior cingulate	30	5.41	5.29	21	-54	22
	95	R	Inferior temporal gyrus	20	7.67	7.35	53	-53	-12
	416	L	Parahippocampal gyrus	35	7.2	6.92	-24	-39	-13
	66	L	Inferior temporal gyrus	37	6.15	5.97	-59	-53	-7
	121	R	Parahippocampal gyrus	35	5.86	5.71	27	-38	-3
		R	Fusiform gyrus	37	4.77	4.69	33	-42	-18
	834	L	Inferior frontal gyurs	44	9.04	>7.8	-42	7	27
		L	Inferior frontal gyurs	46	5.7	5.55	-48	41	6
		L	Inferior frontal gyurs	47	4.56	4.49	-39	40	-15
	470	R	Inferior frontal gyurs	44	8.32	>7.8	39	16	21
	124	L	Middle frontal gyrus	6	6.11	5.94	-21	2	50
		L	Middle frontal gyrus	6	5.98	5.82	-24	12	60
	30	R	Orbitofrontal gyrus	11	5.88	5.72	30	37	-20
	13	L	Cerebellum		4.74	4.66	-21	-46	-41
Others > Control	901	L	Middle occipital gyrus	18	8.93	>7.8	-30	-87	13
		L	Superior parietal lobule	7	7.66	7.34	-24	-67	53
	836	R	Middle occipital gyrus	19	7.51	7.2	39	-78	9
		R	Superior parietal lobule	7	7	6.74	27	-56	53
		R	Superior parietal lobule	7	5.94	5.78	33	-72	26
	39	R	Inferior temporal gyrus	20	5.95	5.79	53	-56	-12
	158	L	Fusiform gyrus	36	5.62	5.48	-27	-36	-16
	55	R	Parahippocampal gyrus	36	4.97	4.87	33	-33	-14
	164	R	Inferior frontal gyrus	45	6.36	6.17	39	19	21
	128	L	Inferior frontal gyrus	44	5.77	5.62	-48	7	25
Own > Others	518	L	Inferior parietal lobule	40	5	4.9	-42	-45	41
		L	Superior parietal lobule	7	3.96	3.91	-36	-43	63
	626	L	Superior frontal gyrus	6	4.72	4.64	-21	14	49
		L	Middle frontal gyrus	46	4.19	4.13	-42	39	15
		L	Middle frontal gyrus	6	4	3.95	-27	10	33
	61	L	Medial frontal gyrus	10	3.91	3.86	-18	58	-3
		L	Middle frontal gyrus	10	3.73	3.69	-30	55	-10
		L	Middle frontal gyrus	10	3.34	3.31	-39	43	-12
	24	R	Middle frontal gyrus	6	3.76	3.72	42	11	55
	8	L	Cerebellum		3.39	3.36	-6	-48	-28

Note. In the first two contrasts Bonferroni correction for multiple comparisons was performed, establishing the threshold at p<0.05 (t=3.12). In own > others no correction was carried out and the threshold was established at p<0.001. Talairach coordinates, Brodmann areas, t and z values, and number of voxels activated of clusters of more than 5 voxels are displayed.

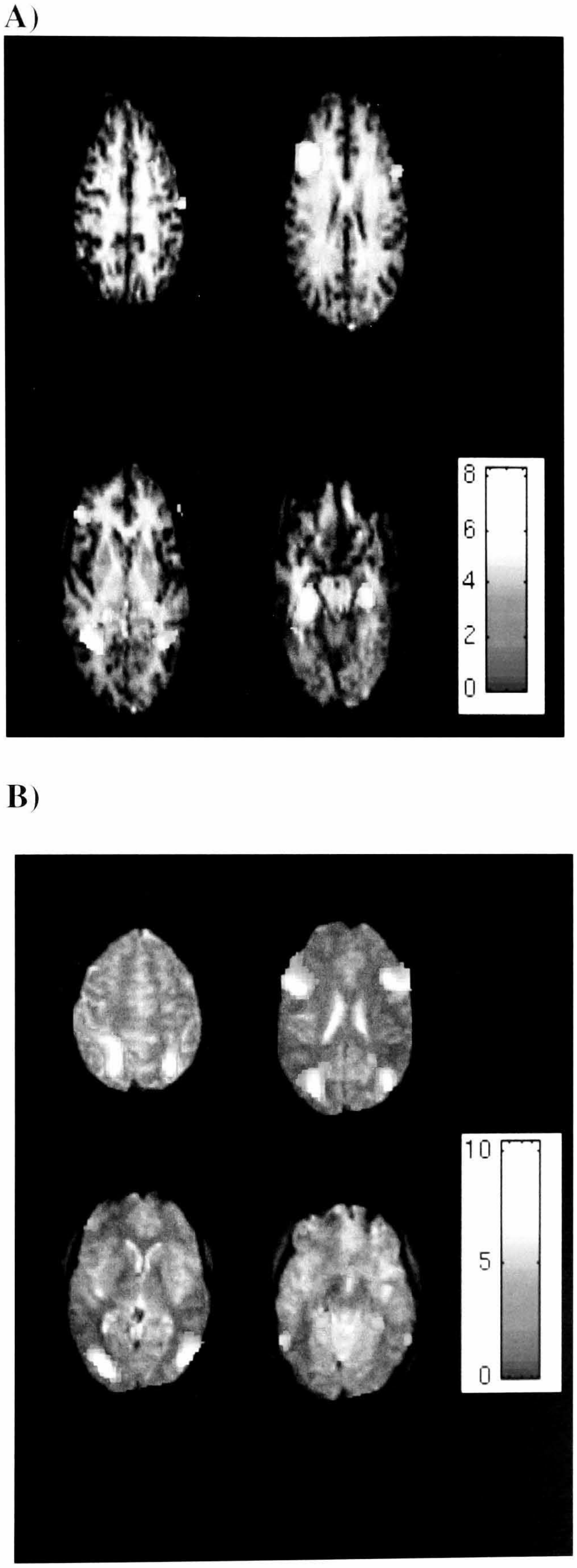
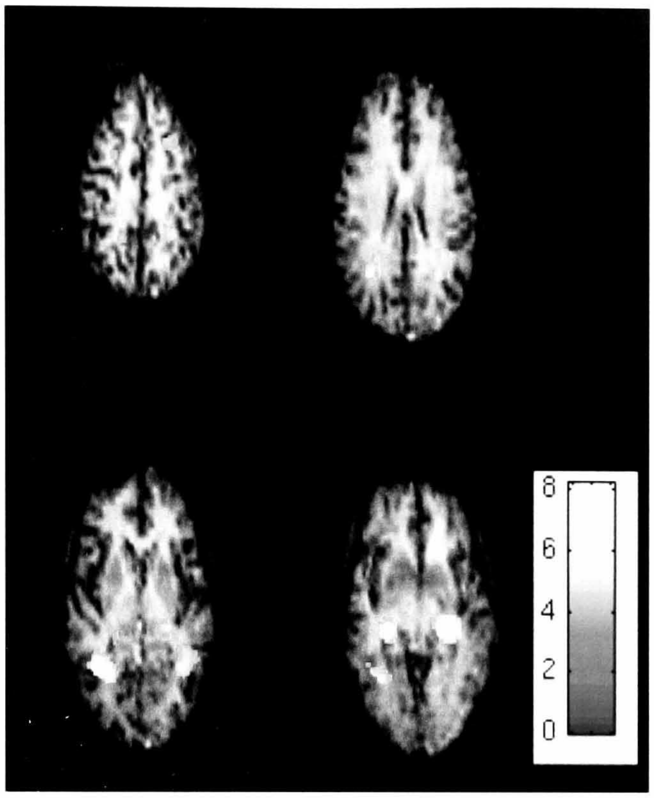


Figure 9.2. Contrast own > control. Brain areas activated displayed in structural images obtained after the realisation of the experiment. a) GM. b) IM.

A)



B)

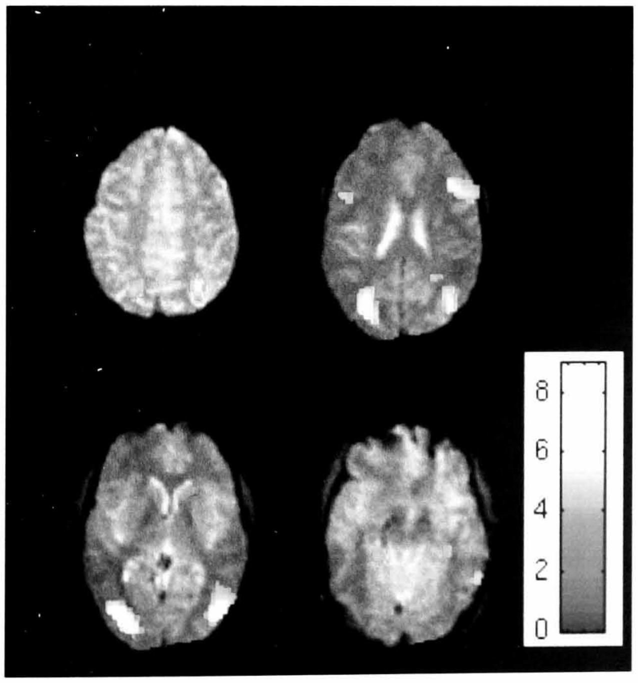


Figure 9.3. Contrast others > control. Brain areas activated displayed in structural images obtained after the realisation of the experiment. a) GM. b) IM.

The own > others contrast showed a strikingly similar pattern in both players and in both players this was left lateralised. This pattern included a posterior area in the supramarginal gyrus (in GM somewhat more dorsal to that of the IM, including posterior temporal and parietal areas in the former, and inferior parietal and superior parietal in the latter). Figure 9.4 displays the brain activations in a template 3D brain.

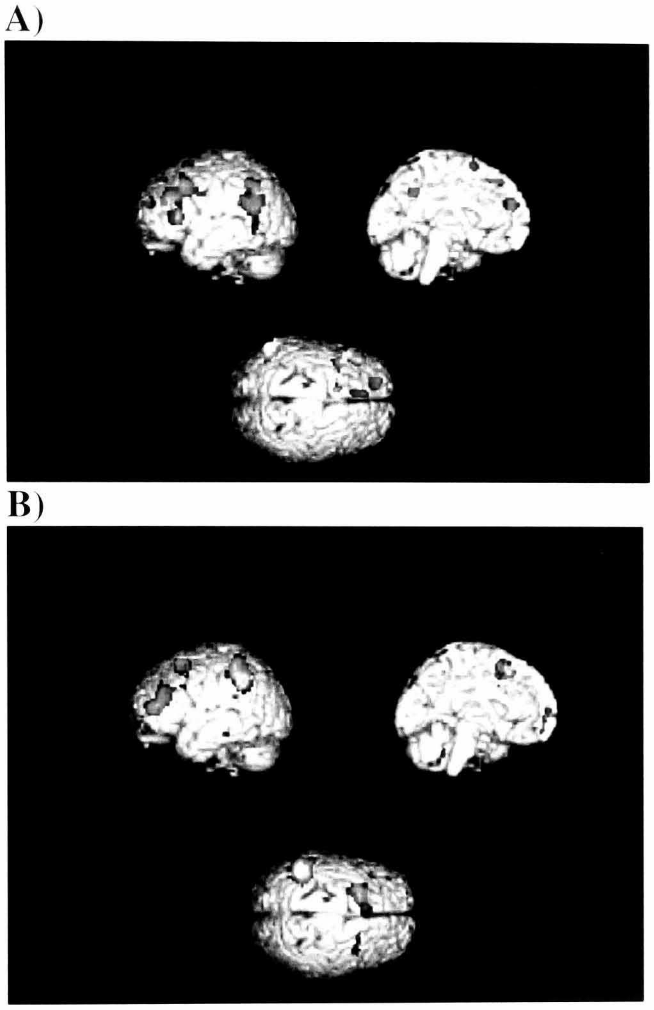


Figure 9.4. Contrast own > others. Brain areas activated displayed in structural images obtained after the realisation of the experiment. a) GM. b) IM.

The graph in figure 9.5 displays the distribution of the number of voxels activated throughout the brain both in GM and IM. The pattern is quite similar in both players. The contribution of frontal areas in the others > control contrast is quite low. This is in agreement with brain imaging studies that show decreased frontal activity in memory tasks after practice (e.g., Van Horn et al., 1998). This result is also in agreement with the finding of the first experiment in chapter 10 of this thesis in which chess players needed a very low contribution of the frontal cortices in a memory task.

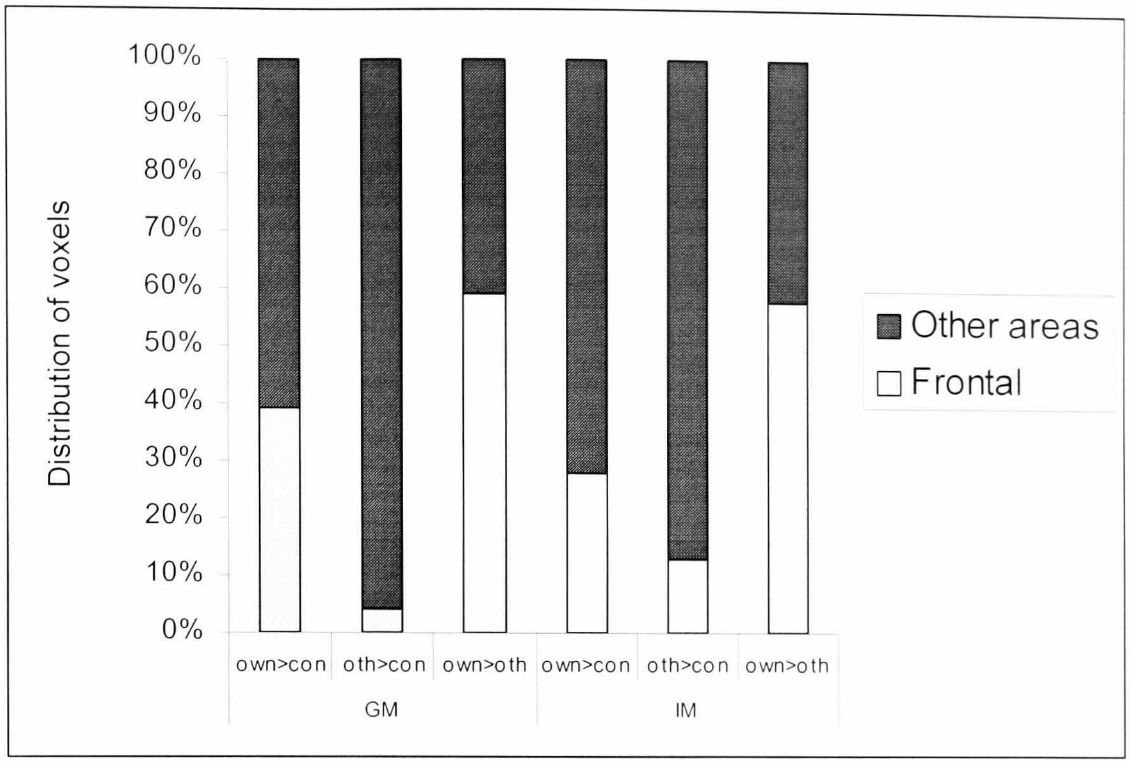


Figure 9.5. Distribution of voxels in frontal and non-frontal areas in all the contrasts in both players.

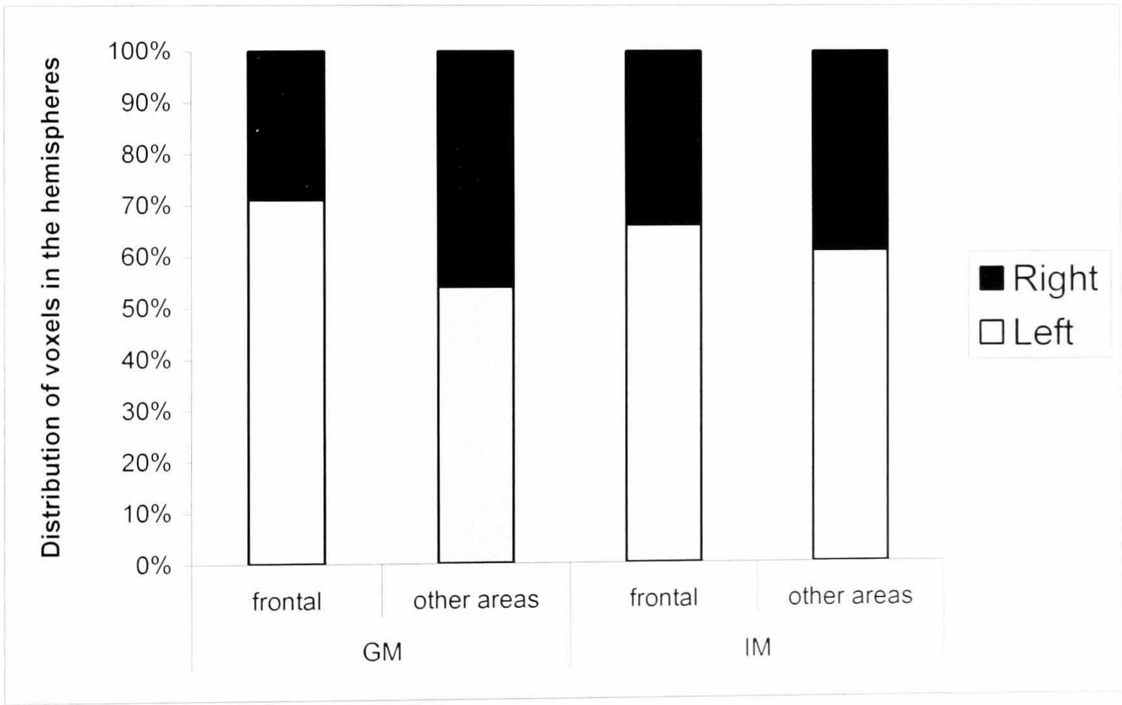


Figure 9.6. Distribution of voxels in terms of hemispheres in the contrast own > control.

In the own > control contrast the contribution of the frontal areas is higher in both players (higher in GM than in IM). Accordingly, in the own > others contrast, the contribution of the frontal lobe is about 60% in both players. Since the activation in this contrast is almost totally in the left-hemisphere, a plot (figure 9.6) with the distribution of the voxels activated according to hemispheres in the own > control contrast was performed.

As expected, there were more left frontal areas than right frontal areas activated in this contrast, explaining the left lateralised pattern in own > others. Figure 9.7 shows the same data in the others > control contrast. In this contrast the frontal areas distribution are not very relevant because the number of voxels activated was low. The figure shows that the proportion of voxels activated in non-frontal areas (which correspond to a high percentage of the total activation) is about equal in the others > control contrast. This shows that in own > control increase of number of voxels activated in frontal areas with a high bias to the left hemisphere explains most of the left-lateralised pattern.

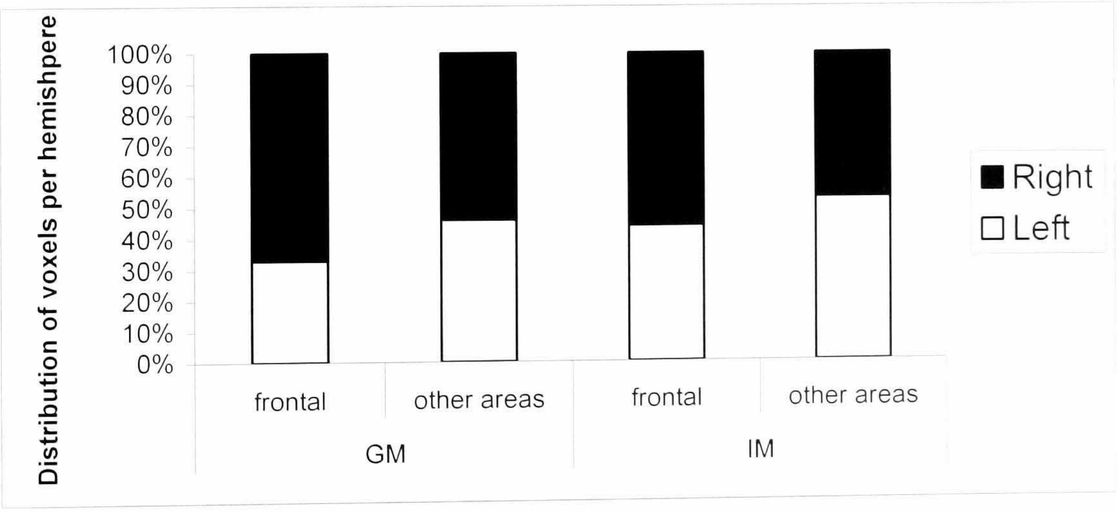


Figure 9.7. Distribution of voxels per hemisphere in the others > control task.

9.4. Discussion

The resemblance of the results of this study to those of Conway et al. (1999) is outstanding. Both studies showed two highly differentiated regions activated: one posterior region at or near the supramarginal gyrus (BA 39) and a pattern of a number of frontal areas with a totally left lateralised pattern. The autobiographical memory study of Maguire and Mummery (1999) also shares with these studies the almost completely lateralised pattern, the activation of the supramarginal gyrus and some left medial frontal areas. However, Fink et al. (1996) displays a completely different pattern in autobiographical memory: total right lateralisation. Indeed, Fink et al.'s study is an agreement with most of the studies carried out on episodic memory retrieval (see Cabeza, 2000 for a review).

Conway et al. (1999) suggested that the left frontal activations in their study correspond to the working-self execution of a generative search, and the supramarginal gyrus activation to the ESK activation. They explained the dissimilarity with the Fink et al. (1996) study by saying that in the latter there was no need for generative retrieval, hence, participants engaged in direct retrieval without the participation of the working-self (which is supposed to be situated in the left prefrontal cortex (Damasio, 1994)). They explained the posterior right network activation in Fink et al. as activation of the ESK. However, the lack of activation of right posterior areas in Conway et al. (1999) and the high activation of frontal areas in Fink et al. (1996) is not satisfactorily explained. The low right frontal activity and right posterior activity in Conway et al. (2001) are just non-existent in Conway et al. (1999).

Maguire and Mummery's (1999) theoretical proposal is critical in explaining these results. They argued that autobiographical memories could be either episodic (autobiographical event) or semantic (autobiographical fact); moreover, non-autobiographical memories could also be either episodic (public event) or semantic (general knowledge). Typically, autobiographical memories were considered only a type of episodic memories, while Maguire and Mummery suggest that personal relevance is a factor independent from the existence or not of a temporal context.

Cabeza and Nyberg (2000) review of brain imaging studies analysed the assumptions of the HERA model (Nyberg et al, 1996; Tulving et al., 1994). This model proposes that, first, semantic retrieval recruits left prefrontal areas; second, encoding information into episodic memory occurs in the left prefrontal cortex and, third, the right prefrontal cortex is differentially more involved than the left hemisphere in episodic memory retrieval. In their review Cabeza and Nyberg found support for the first and third hypotheses of the HERA model, but they found some studies with bilateral activation during episodic memory encoding.

Taking into account the Maguire and Mummery (1999) proposal and the Cabeza and Nyberg (2000) review, it is possible to explain the results of the present study and previous ones. In the contrast own > others of the present study, retrieval of autobiographical memories is expected. Following Maguire and Mummery (1999), the critical question is: did the chess players recollect autobiographical events or autobiographical facts? The masters were told that after the scanner they would be asked about the name of the opponent and the tournament, the year and the result of each game, as well as the next move of the game. Clearly most of those data are autobiographical facts (i.e., semantic autobiographical memories)—although retrieval of autobiographical events may be contiguous and cannot be ruled out. Therefore, the left frontal activation in this study is in accordance with the HERA model in the sense that semantic retrieval occurs in the left frontal cortex. As pointed out by Niki and Luo (2002) the truth judgement task used by

Maguire and Mummery (1999) could have diminished the richness in the recollection of episodic events.

Fink et al.'s (1996) study differs from the other three studies: Maguire and Mummery (1999), Conway (1999) and the present study in that the researchers explicitly asked the participants to imagine themselves in the situation. This could have biased participants to recall more episodic autobiographical memories than in the other three studies and, accordingly, to activate more right frontal areas, as expected by the HERA model. The activation of the left supramarginal gyrus found here is puzzling. On the one hand, the Cabeza and Nyberg (2000) review shows that the left supramarginal gyrus activity occurs in semantic and language studies, suggesting that the activation of this area is related to semantic retrieval; on the other hand, Maguire and Mummery (1999) found that this area is related to autobiography regardless of the existence of temporal context. Other theoretical approaches (e.g., Kosslyn, 1994) attribute a role of associative memory to this area.

In the others > control contrast in which autobiographical memory is not involved and episodic encoding is expected to be the most important process, a very low activation in the frontal lobes was found. This is in agreement with the first fMRI study of the following chapter in this thesis, in which chess players showed reduced activity of the frontal lobes, in contrast to the high activity displayed by the non-chess players. A similar finding was shown in Van Horn (1996) in a maze task in which a reduction in frontal lobe activity after creating the memory of the maze was apparent. The present study exhibited a parietal, occipital and temporal bilateral pattern with equally distributed activation of voxels in the right and left hemispheres, as the Cabeza and Nyberg (2002) analysis of episodic retrieval showed.

Regarding the age of memory results, in accordance with Conway et al. (1999), the present study has not found differences. Stark and Squire (2000) began studying the age of memories in brain imaging studies using memories of half an hour, one day and one week, and they did not find differences in the medial temporal lobe. Maguire et al. (2001) parametrically analysed autobiographical memories ranging from weeks to 20 years of age and failed to find differences in the medial temporal lobes, but found increased activity for recent memories in the right ventro-lateral prefrontal cortex. Niki and Luo (2002) found differences in the medial temporal lobe (recent memories produced more activation than remote memories) in memories of less than two years of age in comparison with more than 7 year old memories (although it was outside of their interest, they also found differences in a huge amount of brain areas both in recent > remote and remote > recent). The only reason that could have caused the lack of differences in the present study is that the window of one year in the recent chess game positions was probably large. However, Niki and Luo (2002) found differences with a similar time window. One explanation could be that chess players analyse their own games and consolidate the memories of the games more quickly than other memories. If this is the case, a methodological improvement could be to make the players play several games the day of the scanning session without allowing them to analyse them and to generate stimuli from those games for the 'new' condition.

To recapitulate, the use of chess to study autobiographical memory proved to be successful, insofar as it replicated the findings of a previous study. This experiment is also a methodological improvement inasmuch as no previous interview was required in order to generate the stimuli and the manipulation of the memory age was in the control of the experimenter and not in that of the participants. Finally, a combination of HERA model and the proposal of Maguire and Mummery (1999) was put forward, reconciling results of previous studies.

This study showed that chess could be used as a research setting in fMRI, with fruitful results. Once again, the versatility and power of chess as a task environment was demonstrated, supporting one of theses stated in chapter 1. The next chapter will focus on the comparison of chess players with non-chess players in memory tasks. The interest is both in expertise and in the neural basis of cognitive processes such as long-term memory storage and maintenance of information.

CHAPTER 10

Brain imaging (2)

Expertise and memory

Chapter 9 introduced a paradigm with chess experts by which it is possible to study autobiographical memory. The present chapter focuses on the relationship between patterns stored in long-term memory and in working memory.[1] Chess players and non-chess players participated in a scanning session in order to compare their brain activities in a recognition task with and without chess stimuli (see section 10.1). The second experiment (section 10.2)—a follow up of the first one—aimed at further understanding the principal aspects of the brain activations observed in experiment 1. The idea was to unconfound two variables: perceptual aspects of the stimuli (chess vs scenes) and structure of the stimuli (game vs random).

The brain imaging literature review of chess, expertise and practice discussed in chapter 2 (see sub-section 2.3.2.1) is fundamental for the experiments in this chapter. In section 10.1 and 10.2, I will centre my discussion on the rationale of the experiments based on that review.

10.1 Experiment 1. Working memory efficiency and long-term memory activation in experts

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[1] Working memory is a rather vague concept used with different meanings by different researchers. However, because it is beyond the scope of this thesis to discuss this problem, I still use this term, for it is popular. In the thesis, 'working memory' means 'on-line' memory, as opposed to 'archive memory' (see Izquierdo, 1999).

In the preliminary review of brain imaging studies in experts and practice effects (see section 2.8), two types of results were found: a) experts showed a reduction of activation in a particular area due to increase in efficiency, and b) experts used a brain area not used by non-experts. For instance, Pesenti et al (2001) found activation in brain areas in the expert not found in the non-experts, and Gauthier (1999, 2000) and Tarr and Gauthier (2000) found increased activity in a brain area in experts or trained subjects. On the other hand, Krings et al. (2000) and Kassubek et al. (2001) found a reduction in activation in different brain regions. Van Horn et al. (1998) found reduction in frontal areas and increased activity in posterior areas. Finally, Berman et al. (1995) did not find any difference.

These results may seem somehow contradictory. However, the pattern observed in Van Horn (1998) makes the two kinds of results complementary. The decrease in frontal lobes occur because of increased efficiency (i.e., participants require less effort to perform the task), whereas the increase in activation in posterior areas is due to the creation of a new memory. Since this memory does not exist in naïve participants, its location in the brain should be active only in the experts.

10.1.1. Overview of the experiment

CHREST (see section 2.1.2) has a long-term memory network of chunks and templates, the size of which is a function of the level of expertise (i.e., the higher the level the larger the network). In a memory task, CHREST automatically activates the chunks and/or templates stored in the network that match the ones that are present in the to-be-remembered stimulus. If this theory is correct, there should be an area in the brain which is activated in chess players but not in non-chess players while dealing with chess stimuli. To test this proposal in the present experiment, chess players and non-chess players performed a recognition task with chess stimuli - 'game' - and with non-chess stimuli - 'scene' - and the brain activity of 'scene' was subtracted from that of 'game' in order to identify the long-term memory network.

Another prediction of CHREST is that the access to the long-term network is almost automatic and that the templates and/or chunks accessed in long-term memory are free from interference and decay; hence, minimal working memory processes would be needed in order to maintain them. A condition— 'dot' —was designed in order to test this hypothesis. 'Dot' stimuli were the same type as 'game', but in this condition, instead of doing a memory task, the participants performed a very simple perceptual task. The subtraction of the dot condition from the game condition should show brain activity due to the memory components of the game condition, cancelling out the perceptual aspects of the stimuli. If CHREST is correct, and minimal working memory processes are needed in experts, then less activity in working memory areas is expected in chess players in comparison to non-chess players.

The introduction of random positions in chess psychology - and the poor performance of masters on memory tasks with this type of stimulus - led to the idea that chess expertise is domain-specific (see chapter 2, sub-section 2.3.1.2.3). To make comparisons with those studies using a new methodology, it would be advantageous to use 'random' positions in brain imaging studies. Therefore, a random condition was also included in the study. However, the predictions are not clear-cut in this case. On the one hand, one would expect more activity in long-term memory areas in the game condition because the 'game' stimuli activate the long-term memory network and the 'random' stimuli do not. However, it is possible that 'random' also activates the long-term network in a less specific way.

Taking everything together, I expected that chess players would show a different pattern of activations than non-chess players. In the game > dot contrast, which emphasises the memory components of the task, chess players would require less effort; therefore, they would show less activity than the non-chess players. In the game > scene contrast, which emphasises the chess specific components of the task, it is expected that chess players would activate an area in which the long-term chess patterns are stored. Regarding brain locations, it is known that cells in area IT (inferior temporal cortex) in monkeys react to familiar stimuli (e. g. Gross, 1992, Logothetis et al.,1995). Therefore, I would expect activations in this area in chess players in the chess stimuli tasks. I hypothesise also that there would be a reduction in chess players in their brain activity in frontal and parietal areas in comparison with non-chess players. There are many studies showing these areas involved in working memory processes (e.g., Fuster, 1998, 2000).

10.1.2. Methods

10.1.2.1. Participants

Twelve right-handed healthy volunteers with normal vision signed a consent form and participated in the experiment. Five of them were chess players and seven were non-playing university students (all of them knew the rules of chess but had never played seriously before). The mean age of the chess players was 24.6 (sd = 7.98) and that of the non-chess players was 24.14 (sd = 4.63). The chess players were recruited from Nottingham chess clubs and from the University of Nottingham chess club. Three of them have International rating (2200—master, 2190 and 2050—experts), and the other two were regular players of the university team. It is worth noting that originally seven chess players and nine non-players took part in the study; two of the chess players and two of the non-players were discarded because of failure to fulfil the motion criterion (see chapter 3, sub-section 3.1.3.3.2). Ethical approval was obtained from the School of Psychology, University of Nottingham ethics committee.

10.1.2.2 Procedure

All the blocks of all the conditions had the same structure (see figure 10.1). Each block started with a fixation cross which remained on screen for 12.5 seconds. Following the fixation cross, a sample stimulus was presented for 6.5 seconds. After a 2 second's, delay a series of 7 stimuli appeared sequentially. Each of the seven stimuli was presented for 3 seconds with an inter-stimulus interval of 1 second. The task consisted of deciding whether the stimuli presented in the series matched the sample stimulus or not. They had to react within the 3 seconds during which the stimuli were on the screen.

There were 4 conditions: game, random, scene and dot (see figure 10.2). In the three first conditions, the task was the one explained above, only the type of stimuli varied. Dot was a perceptual- motor control for game. In dot, the block structure was the same as that of the other conditions but the task was different. The sample stimulus consisted of a chess position with a black dot somewhere in the middle of the board. The stimuli in the series of 7 were also chess positions, some of them had a black dot and some others did not have the black dot. The task consisted of pressing the left button of the button box if there was a black dot and the right button if there was no black dot. In the game condition, the stimuli were the right half of a grey-scale chessboard (4 x 8 squares) with black and white chess pieces resembling a chess game position. The random condition was the same, but the pieces were randomly distributed throughout the board.

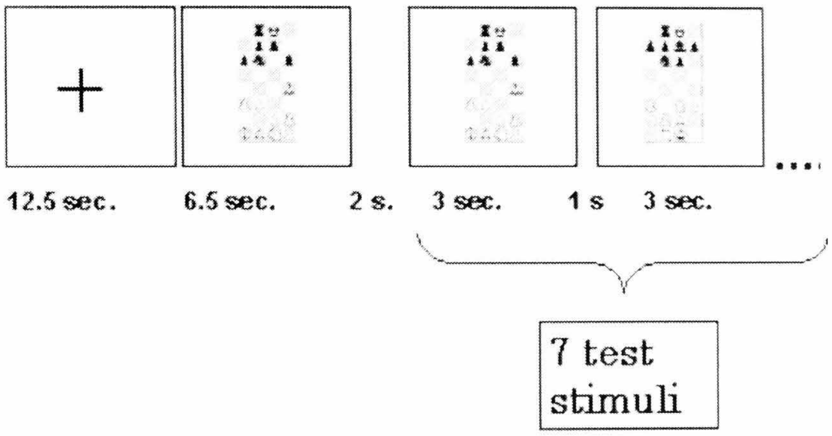

Figure 10.1. Block structure. Description in the text.

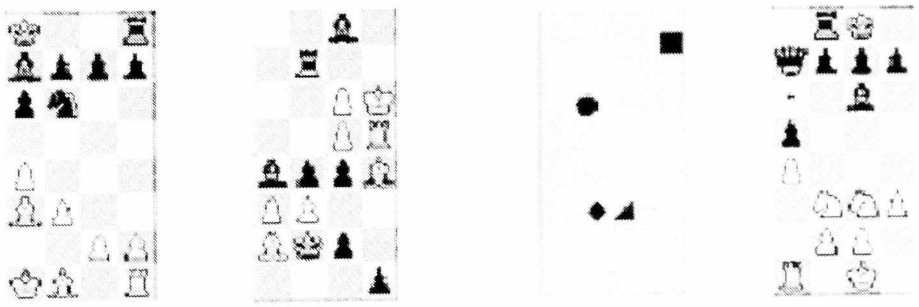

Figure 10.2. Stimuli used in the four conditions. From left to right: game, random, scene and dot.

All the positions in both conditions contained 16 pieces (8 +/- 1 white pieces and 8+/-1 black pieces). In the scene condition, the stimuli were a grey-scale background with ellipses and different types of black and white shapes (2 triangles, 2 squares, 2 rhombuses, and 2 circles).

10.1.2.3. Design

Forty four blocks (11 blocks of each condition) were pseudo-randomly presented (i.e., there were 11 sets of 4 blocks, in which each condition was presented once. The order of the conditions within the set was randomly assigned.). On average, 3 of the 7 stimuli matched the sample. The number of test stimuli matching the sample within each block varied from 2 to 4. Twelve stimuli of each condition were used, each of them took place as sample stimulus only once. The chess positions consisted of middle game positions with familiar configurations of pieces.

10.1.2.4. Statistical analysis

A box-car function convolved with a hemodynamic response function was used to model the data. I planned 3 contrasts in each group. Game > dot, game > scene and game > random. SPM maps of t values were obtained after Bonferroni correction of p values, showing $p < 0.05$. Only the clusters of more than 5 voxels were reported.

Game is the key condition, and the other three control for different aspects of the task. In the principal task, participants are supposed to perceive the stimulus; recognise it as a chess pattern; encode it; maintain a representation of it in memory during the delay and during the presentation of the test stimuli; match the test stimuli to this representation; decide whether they are the same or not; and finally press a button. In the dot condition, participants are required to carry out only the perceptual and motor aspects of the task explained above; therefore, the subtraction game > dot captures the memory components of the task. I assume that in chess players, while performing in the game condition, general memory processes and memory processes particular for such a familiar stimuli occur. In the scene condition, participants are required to carry out the same processes as in the game condition. However, the type of stimuli differs, which makes the subtraction suitable for identify both memory and perceptual components of the task that are specific of the chess positions. The random condition includes the same type of task and stimuli as game, but the meaningfulness and the typicality of the stimuli varied. The latter contrast afforded me the possibility of investigating the brain location of familiar patterns of chess pieces.

10.1.3. Results

10.1.3.1. Behavioural data

The task, as expected, was easy for all the volunteers. Therefore, none of the differences between chess players and non-chess players in the brain imaging results can be explained in terms of difference in performance. In table 1, the means and standard deviations in accuracy are presented. I carried out a 2 x 4 mixed ANOVA test with expertise (chess players and non-chess players) as a between subjects variable and condition (game, random, scene and dot) as within subjects variable. As expected, in terms of accuracy, there was not a significant main effect of expertise (F(1,1) = 2.46; ns, MSE = 0.001). However, there was a main effect of condition (F(1,3) = 7.98; $p<0.01$, MSE = 0.004). The interaction expertise x condition was not significant (F(1,3) = 1.44; ns, MSE = 0.0008) (see figure 10.3).

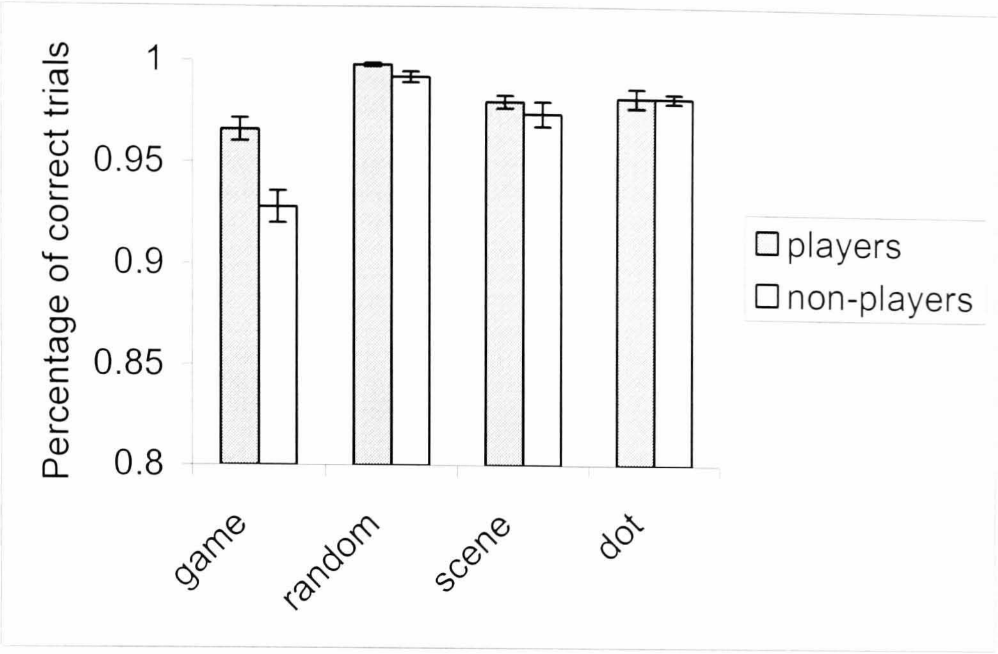

Figure 10.3. Percentage of correct responses in each condition for both groups. Error bars = standard error of the mean.

Post-hoc pairwise comparison analysis showed that the participants performed less accurately in game than in random: game > random = -0.048; p<0.01, but no other differences were found. The interaction expertise x condition was not significant (F(1,3) = 1.44; ns, MSE = 0.0008).

Surprisingly, in terms of response times non-chess players were faster than chess players in all the conditions. In figure 10.4 the means and standard error bars for response times are displayed. A 2 x 4 mixed ANOVA test was carried out with expertise (chess players and non-chess players) as a between subjects variable and condition (game, random, scene and dot) as within subjects variable. There was a main effect of expertise (F(1,1) = 10.3 ; p<0.01; MSE = 577,276) and condition (F(1,3) = 32.38; p<0.001; MSE = 169,866). The post-hoc Scheffe analysis revealed a significant difference in mean reaction time in the following comparisons: game vs scene = 165; p<0.01, game vs dot = 292; p<0.001, random vs dot = 170; p<0.01 and scene vs dot = 127; p<0.01. The interaction was not significant (F(1,3) = 2.34; ns; MSE = 12,296). However, figure 10.4 suggests a trend in which the gap between chess players and non-chess players is smaller in game than in any other condition.

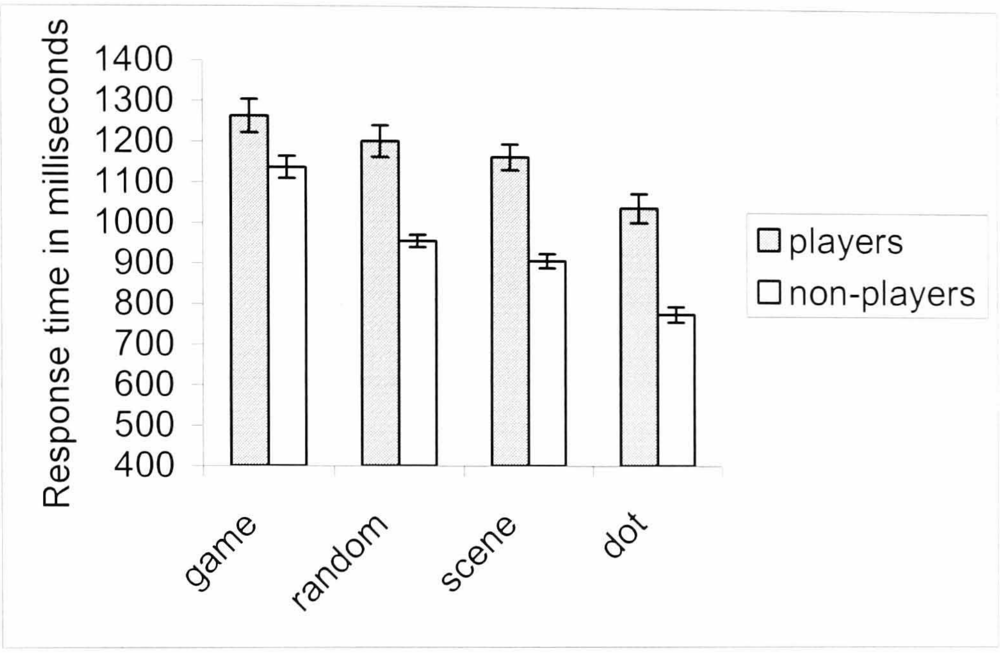

Figure 10.4. Reaction times in each condition for both groups.

To summarise, the behavioural data showed that both chess players and non-chess players performed the task accurately, and they did not differ in terms of performance. In the game condition both groups performed slightly but significantly less accurately and this could also be seen in reaction time. In the latter dependent variable, chess players were slower than the non-chess players in the four conditions. However, the gap was reduced in the game condition. The dot condition was performed faster than any other, followed by the scene condition, which was solved faster than the random condition. The latter was also performed more quickly than game.

10.1.3.2. Imaging data

Table 10.1 and figure 10.5 show the activations of chess players and non-chess players in the game > dot contrast. There is a striking difference in the number of voxels activated in the two groups. Chess players activated 576 voxels in total, whereas non-chess players activated 8,780 for the same contrast. The dot condition consisted of the same stimuli as the game condition but no memory was required for the task. Therefore, this contrast shows the activations due to the memory component of the game condition. Activations in the chess players group were found in BA37 (left occipital and bilateral temporal fusiform gyri), BA19 (bilateral superior occipital gyri), BA7 (bilateral precunei and right superior parietal lobule). In the frontal lobes the activations were in BA46 (left middle frontal gyrus), BA45 (right middle frontal gyrus) and BA9 (inferior frontal gyrus).

Table 10.2 and figure 10.6 show the activations of both groups in the game > scene contrast. Again, non-chess players displayed a greater amount of activation (3391 vs 839 voxels), though the difference is smaller than that of the previous contrast. This result is somewhat unexpected, since this contrast shows the chess components of the game condition. The scene condition was designed to be the same memory task as game, except for the different type of stimuli.

The activations of chess players were in BA7 (bilateral precunei), a cluster including right posterior cingulated (BA30/31) and left lingual gyrus (BA18), BA39 (posterior middle temporal gyrus), BA37 (right temporal fusiform gyrus, right inferior temporal gyrus and left parahippocampal gyrus) and BA36 (right parahippocampal gyrus).

Table 10.1. Foci of activation in Game > Dot and Dot > Game contrasts.

Contrasts & expertise	Vox.	Hem.	Brain region	BA	t-value	Talairach coordinates		
						x	y	z
Game > Dot								
Chess players								
	28	L	Occipital fusiform gyrus	37	5.88	-33	-44	-10
	36	R	Superior occipital gyrus	19	5.56	39	-74	26
	149	L	Superior occipital gyrus	19	5.91	-27	-74	28
		L	Precuneus	7	5.48	-21	-71	37
		L	Precuneus	7	5.3	-12	-73	45
	243	R	Superior parietal lobule	7	7.49	12	-64	56
		R	Precuneus	7	6.38	24	-68	42
	7	L	Temporal fusiform gyrus	37	5.24	-47	-59	-17
	6	R	Temporal fusiform gyrus	37	4.85	47	-53	-12
	107	L	Middle frontal gyrus	46	6.07	-47	30	21
	115	R	Middle frontal gyrus	45	6.76	53	22	26
		R	Inferior frontal gyrus	9	6.19	41	10	22
Non-chess players								
	4709	R	Precuneus	19	14.95	30	-71	34
		R	Superior parietal lobe	7	14.54	33	-50	49
		R	Precuneus	7	14.26	21	-65	47
	38	R	Postcentral gyrus	3	6.46	62	-13	28
	23	R	Middle temporal gyrus	21	5.27	50	-1	-18
		R	Inferior temporal gyrus	20	5.02	41	-10	-20
	2885	R	Middle frontal gyrus	9	14.28	47	22	26
		R	Medial frontal gyrus	6	12.73	6	25	43
		R	Inferior frontal gyrus	45	12.46	44	30	12
	738	L	Middle frontal gyrus	45	10.12	-50	30	26
		L	Inferior frontal gyrus	47	8.6	-30	26	-6
		L	Middle frontal gyrus	9	8.55	-53	13	32
	246	L	Superior frontal gyrus	6	9.43	-27	11	52
	141	L	Superior frontal gyrus	10	7.92	-30	61	2
		L	Middle frontal gyrus	10	6.76	-39	55	-3
		L	Middle frontal gyrus	10	6.71	-33	50	3
	20	R	Thalamus		5.15	6	-17	9
Dot > Game								
Chess players			no voxels showing contrast					
Non-chess players	175	L	Posterior cingulate gyrus	31	8.22	-8	-53	27
	42	R	Medial cingulate gyrus	24	5.53	1	-18	42
	234	R	Insula	13	8.12	41	-11	11
		R	Superior temporal gyrus	22	5.2	65	-20	6
		R	Superior temporal gyrus	22	4.98	50	0	-2
	22	R	Middle temporal gyrus	21	6.37	59	-55	5
		R	Middle temporal gyrus	21	5.64	62	-46	2
	454	L	Superior temporal gyrus	42	7.39	-59	-22	12
		L	Middle temporal gyrus	21	6.91	-50	-41	-5
		L	Superior temporal gyrus	22	4.9	-59	-5	8
	120	L	Middle temporal gyrus	39	6.88	-38	-68	25
		L	Superior temporal gyrus	39	6.34	-47	-60	19
	17	L	Superior temporal gyrus	22	5.42	-50	5	-5
	67	R	Medial frontal gyrus	11	7.94	2	34	-16
	244	L	Superior frontal gyrus	9	8.26	-11	54	33
		L	Medial frontal gyrus	10	6.31	-2	58	8
		L	Superior frontal gyrus	10	5.97	-1	62	18

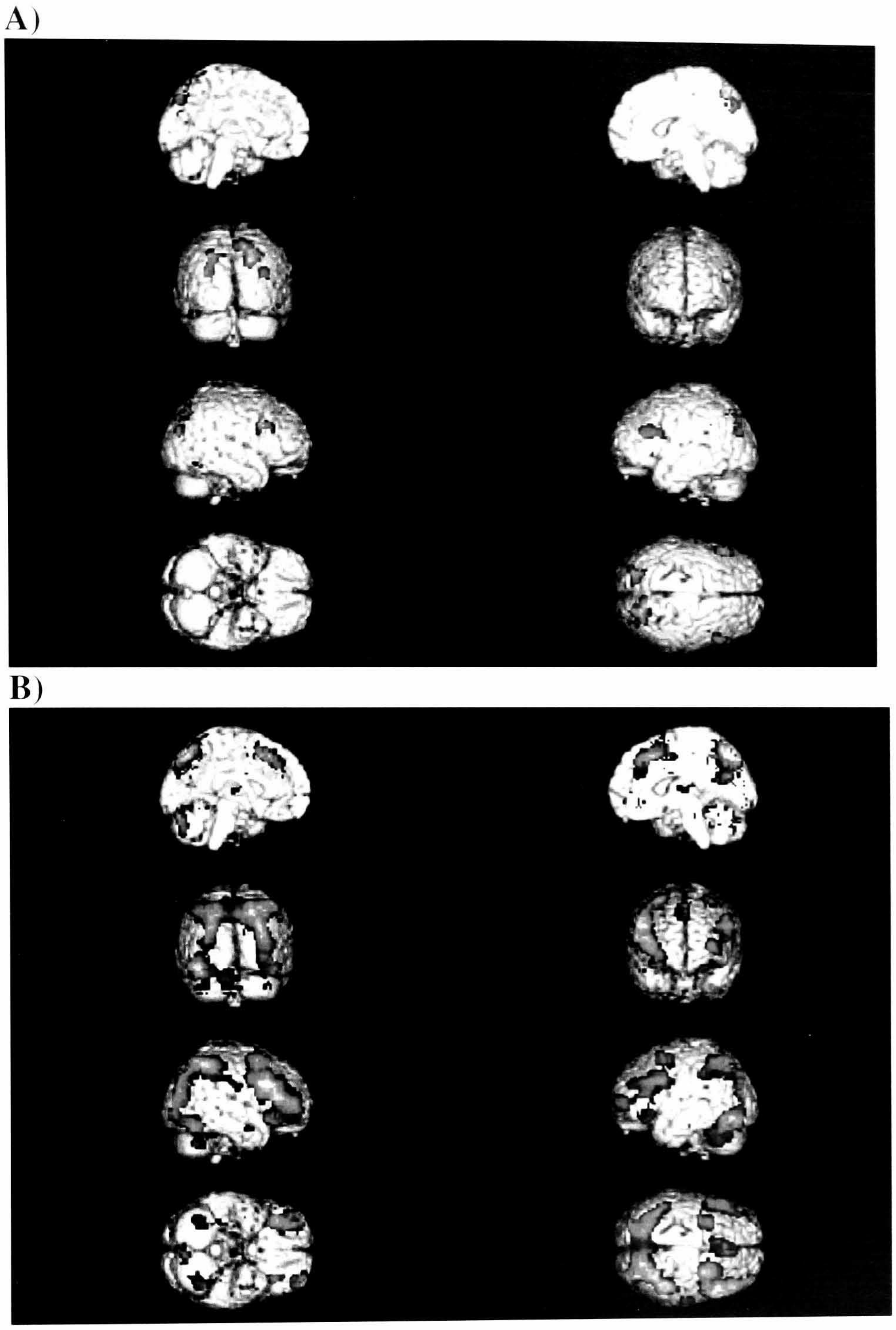

Figure 10.5. Activations in the Game > Dot contrast. The voxels shown are significant at $p<0.05$ after Bonferroni correction. a) Chess players, b) Non-chess players. Left column (top to bottom): left hemisphere medial view, whole brain back view, right hemisphere lateral view, and whole brain bottom view. Right column (top to bottom): right hemisphere medial view, whole brain front view, left hemisphere lateral view, and whole brain top view.

Table 10.3 shows the areas corresponding to the contrast game > random. This contrast is interesting only in the chess players group, since no differences were predicted in the non-chess players group. However, BA20 (right inferior temporal gyrus) and a set of mostly right hemisphere frontal areas were active in the non-chess players. Chess players showed a small cluster of 16 voxels in the left parahippocampal gyrus (BA37).

Table 10.2. Foci of activation in Game > Scene and Scene > Game contrasts.

Contrasts & expertise	Vox.	Hem.	Brain region	BA	t-value	Talairach coordinates		
						x	y	z
Game > scene								
Chess players								
	313	R	Precuneus	7	7.4	8	-61	55
		R	Precuneus	7	6.06	6	-44	52
		L	Precuneus	7	5.66	-6	-53	52
	349	R	Posterior cingulate	31	6.88	15	-48	19
		R	Posterior cingulate	30	5.99	9	-49	11
		L	Lingual gyrus	18	6.09	-12	-52	5
	7	R	Temporal fusiform gyrus	37	5.14	47	-50	-13
	7	R	Inferior temporal gyrus	37	4.79	50	-47	-5
	113	R	Middle temporal gyrus	39	7.8	44	-75	23
	50	R	Parahippocampal gyrus	36	6.92	27	-38	-6
	174	L	Parahippocampal gyrus	37	10.44	-29	-44	-8
Non-chess								
	35	R	Inferior occipital gyrus	18	7.03	30	-87	-3
	346	L	Occipital fusiform gyrus	19	9.36	-24	-79	-14
		L	Cerebellum		8.67	-39	-68	-17
	1445	R	Middle temporal gyrus	39	8.05	36	-75	23
		L	Middle occipital gyrus	19	8.28	-30	-80	21
		R	Precuneus	7	9.37	18	-64	50
	12	R	Precuneus	7	5.54	15	-66	25
	13	L	Paracentral lobule	5	4.87	-18	-24	45
	6	R	Superior frontal gyrus	6	4.7	12	12	66
	672	R	Middle frontal gyrus	8	8.61	41	24	24
		R	Inferior frontal gyrus	9	7.35	50	10	30
		R	Middle frontal gyrus	46	7.29	53	36	15
	484	R	Middle frontal gyrus	6	7.55	24	2	44
		R	Middle frontal gyrus	6	7.44	27	5	52
		R	Middle frontal gyrus	6	6.96	30	14	54
	73	R	Postcentral gyrus	2	7.17	62	-13	25
	22	L	Superior frontal gyrus	8	5.76	-30	11	52
	41	L	Inferior frontal gyrus	47	6.27	-30	26	-9
	226	L	Inferior frontal gyrus	45	6.26	-41	30	12
		L	Middle frontal gyrus	9	5.8	-53	13	32
		L	Inferior frontal gyrus	45	5.25	-50	27	21
	16	R	Thalamus (medial dorsal		5.16	9	-20	6
	9	R	Midbrain		5.03	6	-33	-18
		L	Midbrain		4.61	0	-30	-14
Scene > game								
Chess players			No voxels showing contrast					
Non-chess								
	25	R	Insula	13	5.36	44	-8	9

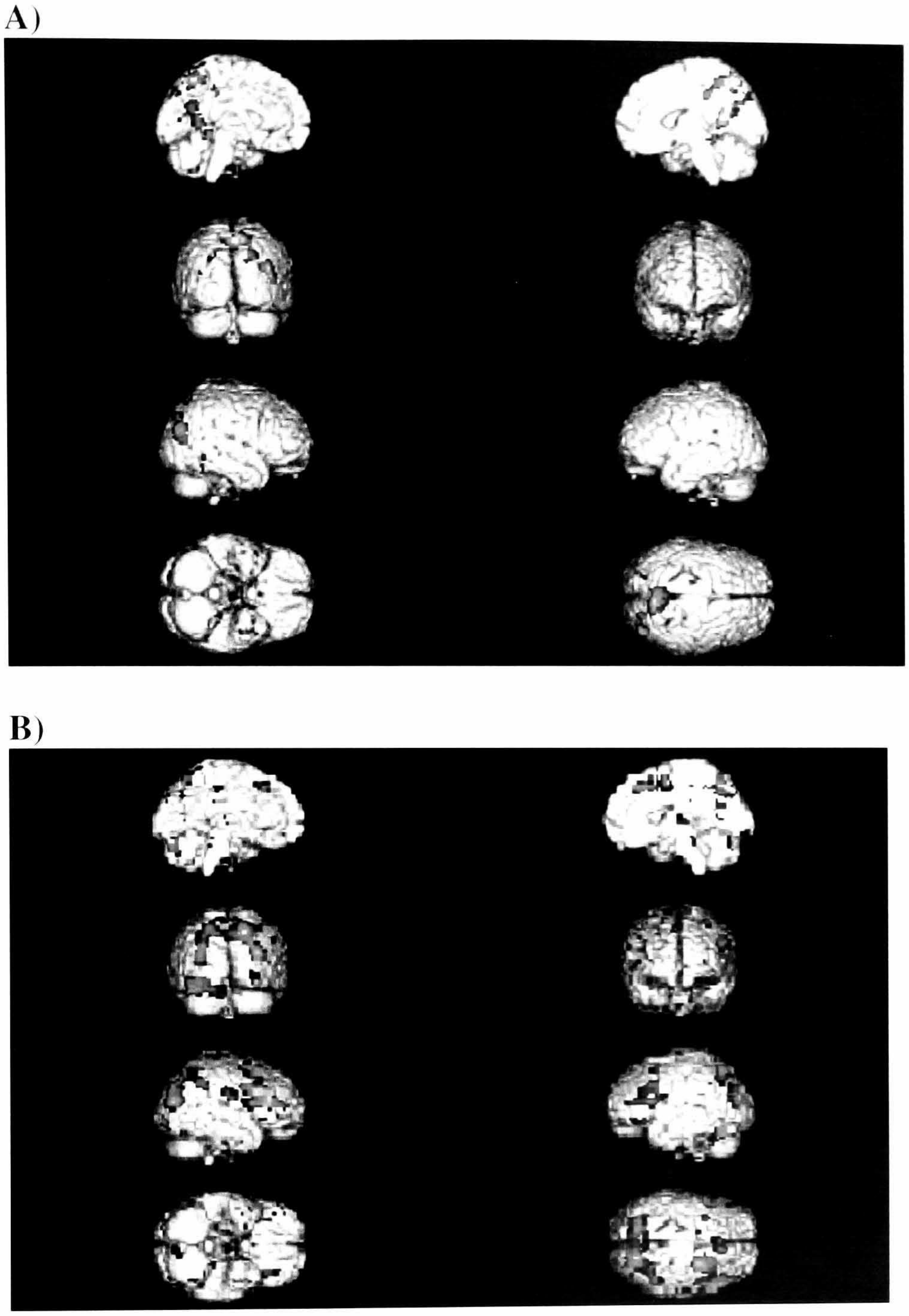

Figure 10.6. Activations in the game > scene contrast. The voxels showed are significant at p<0.05 after Bonferroni correction. A) Chess players, B) Non-chess players. Left column (top to bottom): left hemisphere medial view, whole brain back view, right hemisphere lateral view, and whole brain bottom view. Right column (top to bottom): right hemisphere medial view, whole brain front view, left hemisphere lateral view, and whole brain top view.

Table 10.3. Foci of activation in Game > Random and Random > Game contrasts.

Contrasts & expertise	Vox.	Hem.	Brain region	BA	t	Talairach coordinates		
						x	y	z
Game > Random								
Chess players								
	16	L	Parahippocampal gyrus	37	5.31	-29	-44	-7
Non-chess players								
	152	R	Inferior temporal gyrus	20	7.43	44	-9	-15
		R	Inferior temporal gyrus	20	6.34	39	-1	-25
	102	R	Middle frontal gyrus	9	5.84	44	22	26
		R	Inferior frontal gyrus	8	5.48	47	7	33
	57	R	Medial frontal gyrus	11	5.8	33	35	-2
	120	R	Superior frontal gyrus	8	5.41	33	17	52
		R	Middle frontal gyrus	6	5.04	27	2	50
		R	Middle frontal gyrus	6	4.93	27	17	41
	41	R	Inferior frontal gyrus	45	5.4	53	21	15
	25	R	Postcentral gyrus	2	5.14	62	-19	31
	29	L	Inferior frontal gyrus	47	5.53	-33	23	-6
	7	L	Middle frontal gyrus	9	4.93	-53	16	32
	13	L	Insula		5.16	-27	12	32
Random > game								
Chess players			no voxels showing contrast					
Non-chess players								
	24	R	Insula		5.4	41	-14	9

10.1.4. Discussion

10.1.4.1. Game > dot contrast

The game > dot contrast gave very clear results. In order to perform the same task chess players recruited less neurons than non-chess players. This is consistent with previous studies in which a reduction of activation was observed in experts or trained participants. For instance, Van Horn et al. (1998) showed a decrease in activation in the frontal lobes in subjects who learned a maze in comparison with the same participants when they were naïve. Krings et al (2000) showed that piano players recruited less motor areas than the non-piano players in a motor sequence task. Jansma (2001) also showed decreased activity in frontal areas in a practised task in comparison with a novel task.

The network of areas recruited by chess players in the present experiment includes frontal areas BA46 (left middle frontal gyrus), and a cluster containing BA45 and BA9 (right middle and inferior frontal gyri). In a recent review of the scanning literature, BA9 was shown to be bilaterally involved in all types of working memory and in sustained attention in the right, and BA46 was also bilaterally recruited by all kinds of working memory tasks, with emphasis on spatial working memory (see Cabeza & Nyberg, 2000 for a review of 275 fMRI and PET studies). The pattern of activation seen in posterior areas is also very clear. A dorsal pattern including a cluster in the right hemisphere in BA7 (superior parietal lobule and precuneus) and another in BA19 (superior occipital gyrus) emerged. The same was found in the left hemisphere. BA19 has been involved bilaterally in perception of faces, objects and space; imagery of space and motion; spatial working memory; problem solving tasks; and spatial episodic memory encoding (Cabeza & Nyberg, 2000).

Brodmann area 7 (especially the precuneus) has been shown to be involved in several tasks: visual imagery (Andreasen, et al., 1995), episodic memory retrieval (Henson et al., 1999; Krause et al., 1999), mental rotation (Richter, 2000), storage site for visual patterns (Roland and Gulyas, 1995) reactivation of engrams (Kapur et al., 1995), successful retrieval (Wiser et al., 2000), matching targets to templates (Herath et al., 2001), shifting attention (Cohen et al., 1996), and pursuit and generation of saccadic eye movements (Berman et al., 1999). Hikosaka et al. (2000) found an increase in precunei at an intermediate level of practice of a motor sequence task followed by a decrease in this area in an advanced level of practice. In the maze learning task used by Van Horn et al. (1999) the participants did not have a memory of the path they were meant to learn. When this memory was generated, the activation of the precunei emerged.

Finally, a small number of voxels within BA37 was also active bilaterally: left occipital (28 voxels) and temporal (7 voxels) fusiform gyrus, and right temporal fusiform gyrus (6 voxels). The fusiform gyrus is activated by the presentation of faces (Kanwisher, 1998), and its activation increases by expertise (Gauthier 2000, Tarr & Gauthier, 2000).

In this contrast, it was anticipated that activations would be found due to general memory processes. The activations triggered by the mere presentation of the chess positions in game were subtracted by the control task. I assume that participants engaged in additional perceptual processes to encode the sample stimulus (activation in visual area BA19 and dorsal (BA7) and ventral (BA37) pathways). As well as this, in order to match the sample to the incoming stimuli, subjects had to maintain the sample during the delay and during the set of test stimuli, which needs the activation of the visuo-spatial areas engaged in the perceptual processes of the image in combination with the activation in the frontal lobes.

10.1.4.2 Game > scene contrast

In the game > scene contrast, the chess players showed a pattern of brain activity that includes four main areas: a) BA7 (bilateral precunei);
b) Right posterior cingulate [BA30/31] (the cluster includes left lingual gyrus (BA18)); c) BA39 (right posterior middle temporal gyrus); d) A set of areas in the temporal lobe: BA 37 (right temporal fusiform gyrus, right inferior temporal

fusiform gyrus, left parahippocampal gyrus), and BA36 (left parahippocampal gyrus).

Two of those four areas were also activated in the non-chess players: BA7 (bilateral precunei) and BA39 (right posterior middle temporal gyrus). Moreover, the remaining two areas were almost exclusively activated by chess players: right posterior cingulate (B30/B31) and the temporal areas B36/B37 (left parahippocampal gyrus and right parahippocampal gyrus are the most important areas in this group).

The right posterior cingulate was an area activated almost exclusively in chess players. This area was not active in the game > dot contrast. Therefore, it is not an area involved in general memory processes. Maguire et al (1999) showed activation in the posterior cingulate when participants attempted to link what they were hearing with the prior knowledge that they brought to bear on a text comprehension task. Maguire et al. suggested that the role of the posterior cingulate in this comprehension-memory process is the linking of incoming information with a repository of activated knowledge to form a coherent representation of discourse. The posterior cingulate cortex was also activated in topographical learning tasks (e.g. Aguirre et al., 1996), which necessitate the integration of incoming information to form a coherent representation of a route. Maguire et al (1999) suggested that the posterior cingulate cortex is involved in the incorporation online of information into an accumulating structure of which background or prior knowledge is a fundamental component.

How can we relate the Maguire et al (1999) study to the present study? At first sight, it seems that the tasks are completely dissimilar, and no transfer of information between these two studies is possible. However, I propose that chess players indeed used their prior knowledge when performing the task. A counter-argument is that the use of prior knowledge is not necessary in order to perform the task. In fact, no prior knowledge whatsoever is required and the chess players' prior knowledge did not help them in their performance (they performed more slowly in all the conditions, and were less accurate in the condition in which their prior knowledge might have been involved). This is true, but CHREST (De Groot & Gobet, 1996; Gobet & Simon, 2000), showed that the mere perception of a stimulus specific to the domain of expertise automatically activates long-term memory storages of familiar patterns. Therefore, I suggest that the activation in right posterior cingulate in game > scene contrast is related with the link between incoming information (the series of 7 test stimuli) with prior knowledge (i.e. the storage of familiar chess patterns in the temporal lobe) activated by the sample.

Additional evidence comes from a study of Wiser et al. (2000), who compared a group of participants who had learnt a set of faces one week before the experiment (and they refreshed it one day before the experiment) with another group who was presented with the set of faces one minute before the study. Posterior cingulate were bilaterally activated in the contrast between the two groups. This supports the idea that the posterior cingulate plays a role when prior knowledge is involved.

Finally, I suggest that the activations in the bilateral parahippocampal gyri (more prominent on the left hemisphere) reflect the existence of a long-term memory storage of familiar chess patterns. There are several studies showing that the inferior temporal lobe is related to the activation of visual long-term memories (e.g. Desimone, et. al, 1984; Tanaka, 1993). In the present study, the parahippocampal gyri were activated in the game > scene contrast only by chess players, and it was not activated by the same group in the game > dot contrast, showing that it is not due to a general memory processing. This is an area activated by the mere presentation of the chess positions. As pointed out in the previous paragraph, CHREST (De Groot & Gobet, 1996; Gobet & Simon, 2000) assumes an automatic activation of long-term memory storages. The activation in more posterior areas of the inferior temporal lobe (e.g. fusiform gyrus) has also been seen on the game > dot contrast. As I proposed earlier, this might be due to increasing perceptual processes of the chess positions in game. Interestingly, non-chess players displayed activation in an even more posterior part of the fusiform gyrus (occipital fusiform gyrus). It might be the case that in experts – as shown by Gauthier et al (2000) and Tarr & Gauthier (2000) – the increase in perceptual demands uses more anterior areas of the fusiform gyrus than those of the non-chess players.

10.1.4.3. Game > random contrast

The small cluster activated in chess players in the contrast game > random supports the proposed role of the parahippocampal gyrus in storage of familiar patterns. On the other hand, it also indicates the relevance of the visual aspects of the display of chess positions. If non-visual information were important, many more differences in this contrast would have appeared. However, behavioural experiments clearly showed a difference in memory performance in game positions compared to random positions (e.g. Chase & Simon, 1973, Gobet & Simon, 2000). This issue was the key aspect of the second experiment

10.1.5. Conclusion

To summarise, this study uncovered a network of areas used by experts related to different aspects of expertise. There is a long-term memory storage of chess visual patterns in anterior parts of the inferior temporal lobe (e.g. parahippocampal gyrus, BA36). Interestingly, the pattern of activations is bilateral but with emphasis on the left hemisphere. The right posterior cingulate cortex is thought to be involved in the link between incoming information with prior knowledge (in this case, long-term memory storages of chess patterns). Schlaug et al. (1995) found an increased corpus callosum size in musicians. This is expected if a rapid link between the right posterior cingulate and the left temporal lobe is used, as seems to be the case in chess players. Areas related to working memory processes, i.e., frontal lobes in combination with areas involved in the sensory processing of the same modality (see Fuster, 1998, 2000) were necessary for experts to perform this task. However, non-experts used the frontal areas to a greater degree.

It was shown that both the reduction of activation due to increased efficiency of experts, and the increasing of activation due to the experience in the field, have indeed happened in this study as well. The reduction of activation occurs in areas not related to permanent storages. That means that the working memory network that activates frontal areas and long-term memory areas diminishes its activation only in the frontal lobes, but not in the inferior temporal lobes. The increase of activation occurs in areas related to permanent storages (i.e. inferior temporal lobes) and areas that deal with the link between the long-term memory store and incoming information (right posterior cingulate).

10.2. Experiment 2. Role of semantic information in brain activity

In the previous experiment a clear pattern of activation was found in the contrast that assessed the chess specific components of the task (game > scene). However, the contrast that considered the differences due to the chess game pattern (i.e., chess > random) showed only sixteen voxels activated in the left parahippocampal gyrus. If this finding were robust, it would mean that the perceptual aspects of the game stimuli account for most of the brain activity in long-term memory areas. In the second experiment this issue is investigated more deeply. Two factors were manipulated—structural and perceptual. The structural factor consisted of two levels, game positions and random positions; the perceptual factor had also two levels, chess board with chess pieces and grey-scale scene board with shapes.

Chess-game > chess-random and scene-game > scene-random contrasts assess brain activity due to the structural component. This is the case because in both the chess-game and the scene-game conditions, the stimuli displayed a chess game position; and in both the chess-random and the scene-random, the stimuli displayed a random position. The subtraction of the latter conditions from the former conditions would show the brain activity due to the typical chess patterns (i.e., typical chess structure). On the other hand, the chess-game > scene-game and the chess-random > scene-random contrasts show brain activity due to the perceptual component of the chess game position. That is the case because both the chess-game and chess-random conditions use a chessboard with chess pieces and both the scene-game and scene-random conditions use a grey-scale background with black and white shapes. Thus, the subtraction of the latter conditions from the former conditions would show brain activity due to the perceptual aspects of the chess stimuli.

10.2.1. Methods

10.2.1.1 Participants

Sixteen right-handed healthy volunteers with normal vision signed a consent form and participated in the experiment. Two of them were chess players (one grandmaster of ELO 2550, age 18, and one international master of ELO 2450, age 20) and twelve were university students who knew how to play chess but had never engaged in the game seriously (mean age = 21.42, sd = 1.39). It is worth noting that originally 19 non-players were scanned and five were discarded because of failure to fulfil the criterion of motion explained in chapter 3). Ethical regulations of the School of Psychology, University of Nottingham ethics committee were followed in the experiment.

10.2.1.2. Procedure

All the blocks of all the conditions had the same structure (see figure x). Each block started with a fixation cross, which appeared on the screen for 13 seconds. Following the fixation cross, a sample stimulus was presented for 5 seconds. After a 5 second's delay a target stimulus was presented for 3 seconds and the participants had to decide whether the test stimulus matched the sample stimulus or not. To indicate that choice, they pressed the right button for 'yes' and the left button for 'no'. They had to react within the 3 seconds during which the stimuli were on the screen.

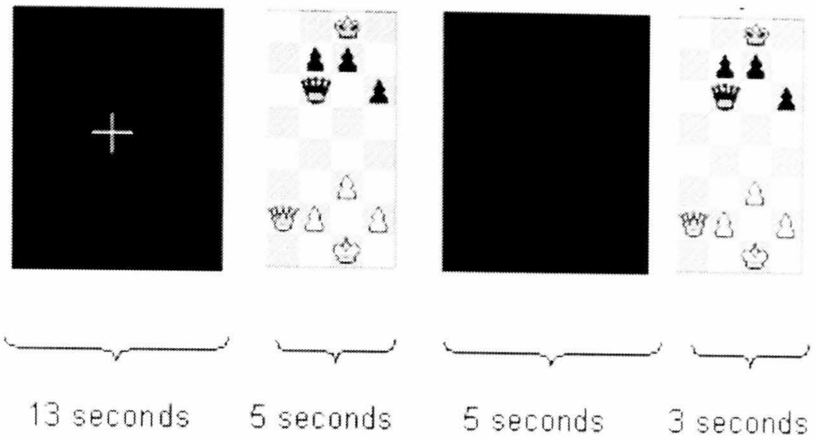

Figure 10.7. Block structure. Details in text.

There were 4 conditions: chess-game, chess-random, scene-game and scene-random (see figure 10.7). In the chess-game condition the stimuli were the right half of a grey-scale chessboard (4 x 8 squares) with black and white chess pieces resembling a chess game position. The chess-random condition was the same, but the pieces were randomly distributed throughout the board. All the positions in both conditions contained 10 pieces (5 white pieces and 5 black pieces). In the scene-game and the scene-random conditions the stimuli consisted of a grey-scale background containing an irregular rectangular design and different types of black and white shapes that matched chess pieces (a cross matched the king, a hexagon matched the queen, a square the rook, a rectangle triangle the bishop, a L-shape the knight and a rectangle the pawn). The positions were generated as follows. A chess game position was generated by me (2200 ELO player) with 5 white and 5 black pieces, always with 3 pawns, a king and the fifth piece was one of the queen, rook, bishop or knight. In the random positions the chess pieces that belong to each of the game positions were randomly distributed throughout the board. For the scene positions, first, different chess positions were generated, second, the chess pieces were replaced by the corresponding shapes. After this, the chessboard was replaced by the irregular-rectangular-design board. Fifty per cent of the times the target matched the sample; when it did not match the sample the test stimulus differed from the sample in that two pieces or shapes of the same colour had changed location. In the case of the game positions the change consisted on two legal moves, in the case of the random positions the change consisted of two illegal moves.

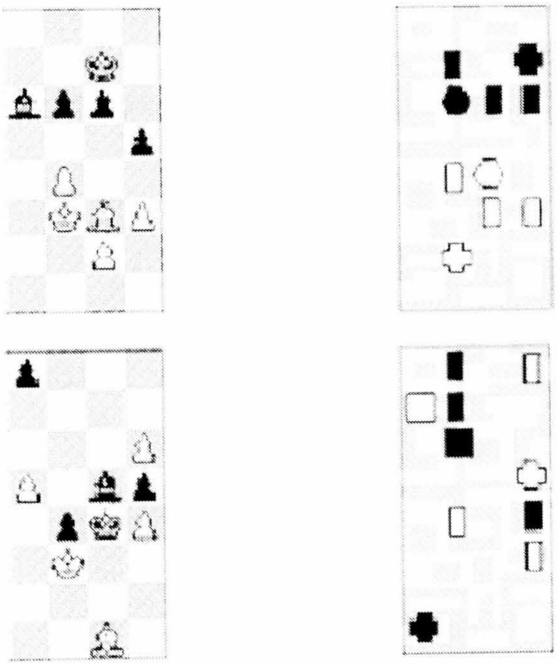

Figure 10.8. Stimuli used in experiment 2. Top left = chess-game, bottom left = chess-random, top right = scene-game, bottom right = scene-random.

It is worth noting that other manipulations were possible. An alternative could have been the use of shapes that do not match the chess pieces (like the ones used in the preceding fMRI experiment and in some experiments in chapters 7 and 8). Furthermore, both types of shapes could have been displayed on a normal chess board. However, it is quite problematic to use several conditions within the same experiment in fMRI studies. Taking this into account, I decided to manipulate the perceptual aspects of both the chessboard and the chess pieces in order to differentiate the perceptual aspects as much as possible, keeping the semantics (i.e., the identity of the pieces) constant.

10.2.1.3. Design

Seventy two blocks (18 blocks per condition) were pseudo-randomly presented (i.e., there were 18 sets of 4 blocks, in which each condition was presented once. The order of the conditions within the set was randomly assigned.). Fifty per cent of the test stimuli matched the sample. A different stimulus was used for each block with the respective transformed stimulus (two pieces or shapes changing location) in the case of non-matching trials.

10.2.1.4. Statistical analysis

Regarding the behavioural data, only descriptive statistics were carried out due to the low number of masters. In terms of the brain imaging data, the statistical model used was a box-car function convolved with a hemodynamic response function. Three planned contrasts were carried out in the group of non-players and individually in each chess master: Chess-game > chess-random, chess-game > scene-game, and chess-random > scene-random. SPM maps of t values were obtained after correction of p values, showing $p < 0.05$. Only the clusters of more than 5 voxels are reported.

10.2.2. Hypotheses

There are four possible outcomes in terms of brain activity on the chess players' contrasts. First, 'the structural hypothesis' in which differences between chess-game and chess-random would be important. This result would support the idea that the differences between game and scene in the first experiment were related to the lack of structure in the scene display. However, this outcome would be in contradiction with the small activity in chess > random in experiment 1, which showed only 16 voxels activated. Second, ‘the perceptual hypothesis’, which predicts differences between chess-game and scene-game and between chess-random and scene-random, suggesting that the differences in game > scene in experiment 1 were due to the perceptual aspects of the stimuli (chess pieces and chess board vs scene and shapes), regardless of the structure.

Third, 'the dual hypothesis' in which differences in all the contrasts alluded to above would be found and in different brain areas; hence, there would be a 'structural area' and a 'perceptual area'. Fourth, 'the semantic hypothesis', which predicts lack of differences in all the contrasts. In this case, the differences observed in game > scene in the first experiment are neither related to the perceptual aspects, nor to the structure of the stimulus, but to the semantics activated by the presentation of any kind of stimulus that represents a chessboard with chess pieces. The last pattern was what was found.

Regarding differences between chess players and non-chess players, since in the first experiment non-players showed a differential pattern of activations in game > scene and game > random, it is expected that the same would happen here, whereas in chess players if any difference in brain activity is found it would be rather small.

10.2.3. Results

10.2.3.1. Behavioural data

Figure 10.9 depicts the percentage of correct responses in chess masters and non-players. Overall, all the subjects performed quite well. The grandmaster performed above 90% in all of the conditions, the international master performed between 80% and 90%, except from scene-random. Non-players performed between 75% and 85%.

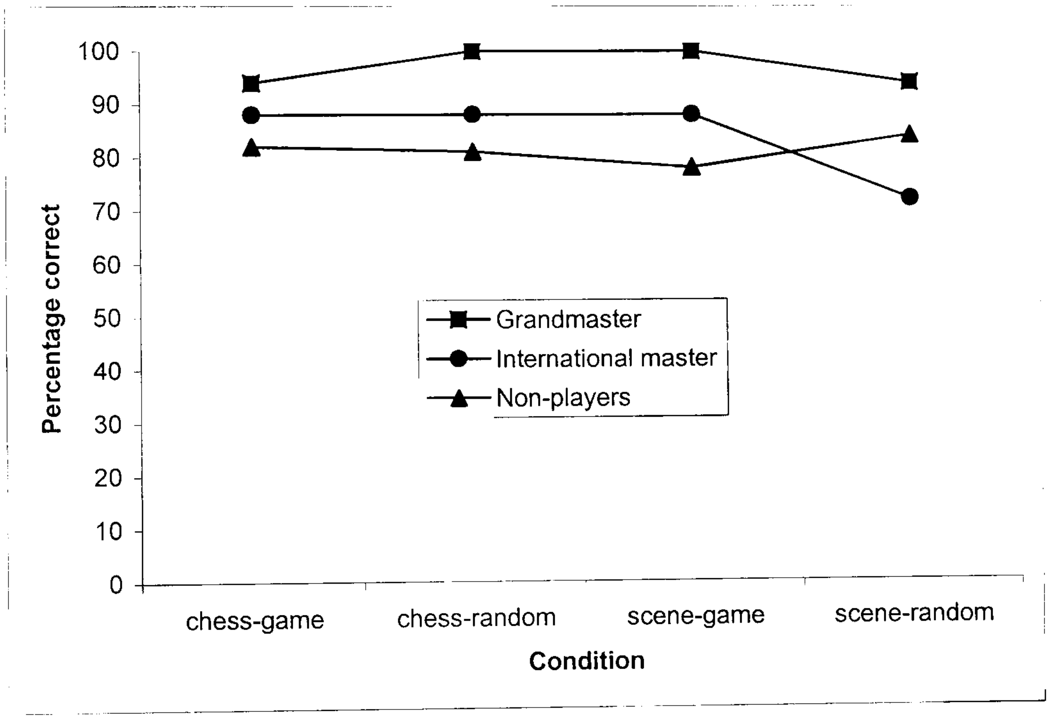

Figure 10.9. Percentage of correct trials in masters and non-players.

Figure 10.10 plots the response times of the masters and non-players. The grandmaster was much faster than all the other participants in all the conditions. Conversely, the international master was slower than the group of non-players. This result shows that response times in this task is not related to chess skill, at least up to international master level (2450 ELO in this sample) (speed of processing is further investigated in chapter 8). In comparison with experiment 1 of this chapter, this result illustrates the variability in response times within chess players, one of them being by far the fastest in this experiment, while the mean of chess players was slower than that of the non-players in the previous experiment.

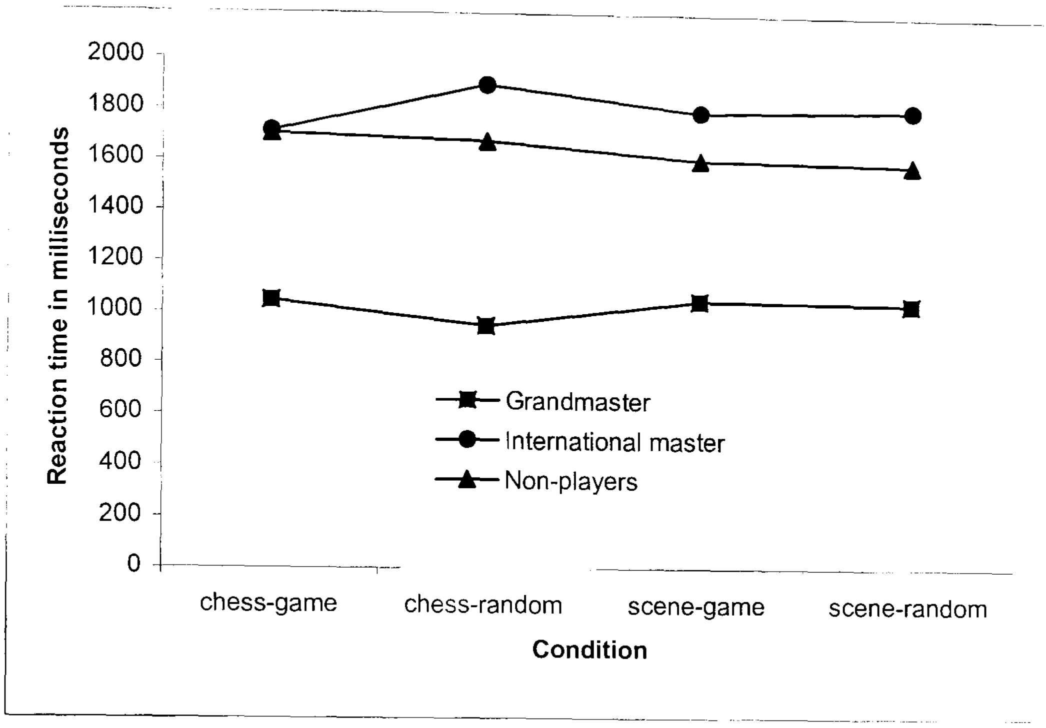

Figure 10.10. Percentage of correct trials in masters and non-players.

10.2.3.2. Brain imaging data

Table 10.4 shows the areas of activation in the three planned contrasts. Only the non-chess players' data are displayed because both the grandmaster and the international master showed no differences in any of the contrasts. This result supports the fourth hypothesis - the 'semantic hypothesis'.

The chess-game > chess-random contrast in the non-players' data showed a very small number of voxels activated. Unlike the same contrast in the first experiment, the pattern is left lateralised, though similar areas are active. The chess-game > scene-game contrast is consistent with game >

Table 10.4. Non-players. All contrasts.

Contrast	Vox.	Hem.	Brain region	BA	t-value	Z-value	Talairach		
							x	y	z
chess-game	8	L	Superior temporal gyrus	38	4.89	4.88	-47	17	-8
>	21	L	Inferior frontal gyrus	44	5.05	5.04	-56	15	13
chess-random	6	L	Middle frontal gyrus	46	4.72	4.72	-44	30	20
	6	L	Inferior frontal gyrus	47	4.69	4.69	-47	32	-2
chess-game	12	L	Cuneus	19	4.97	4.96	-3	-77	37
>	15	R	Precuneus	7	4.67	4.67	9	-68	34
scene-game	7	R	Inferior parietal lobule	40	4.68	4.67	62	-33	29
		R	Inferior parietal lobule	40	4.5	4.49	59	-40	24
	276	R	Posterior cingulate	29	5.73	5.72	3	-46	8
		L/R	Posterior cingulate	23	5.14	5.13	0	-22	29
		L/R	Posterior cingulate	29	5.13	5.12	0	-46	19
	1233	L/R	Anterior cingulate	32	6.29	6.28	0	33	26
		R	Superior frontal gyrus	8	6.1	6.09	6	35	53
		L	Superior frontal gyrus	8	5.74	5.73	-3	17	52
	35	L	Insula	13	5.11	5.1	-42	3	-5
		L	Superior temporal gyrus	22	5.01	5.01	-53	0	0
	68	L	Middle frontal gyrus	10	5.98	5.97	-24	62	8
		L	Superior frontal gyrus	10	5.19	5.19	-24	52	0
	59	R	Middle frontal gyrus	6	4.88	4.87	27	20	54
		R	Middle frontal gyrus	6	4.83	4.82	24	5	49
		R	Middle frontal gyrus	6	4.76	4.76	36	0	58
	6	L	Middle frontal gyrus	46	4.71	4.7	-48	33	20
	64	L	Inferior frontal gyrus	45	5.42	5.41	-53	21	7
	167	R	Cerebellum		6.19	6.18	30	-59	-12
		R	Cerebellum		5.18	5.18	36	-45	-20
		R	Cerebellum		4.59	4.59	45	-63	-27
	30	L	Cerebellum		5.57	5.56	-42	-51	-28
	117	R	Thalamus		5.52	5.51	6	-23	4
		R	Amigdala		5.44	5.43	18	-9	-10
		R	Brainstem		4.84	4.83	12	-21	-4
chess-random > scene-random	6	L	Posterior cingulate	31	4.91	4.91	-24	-66	17

scene in the first experiment. A large frontal area was active in the present study, and to a lesser extent, a group of posterior parieto-occipital areas (see figure 10.11). Interestingly, when there is no game structure the differences between chess and scene (i.e., chess-random > scene-random) almost disappeared.

The lack of activation in any of the contrasts in both chess players could be interpreted in terms of the 'semantic hypothesis'; alternatively, it is possible that there was a problem with the scanner or that the paradigm was not sensitive enough to find differences. In order to rule out these possibilities I proceeded to an analysis subtracting the brain activation during the fixation cross from that of the periods of the presentation of the target and the delay (the period of the test stimulus was not used in order to exclude activation due to the motor response). Table 10.5 and figures 10.12 and 10.13 depict the brain areas activated in this contrast. These results show that the lack of differences cannot be explained by a scanner problem or by a low sensitivity of the paradigm. Therefore, the 'semantic hypothesis' will be discussed in the next session.

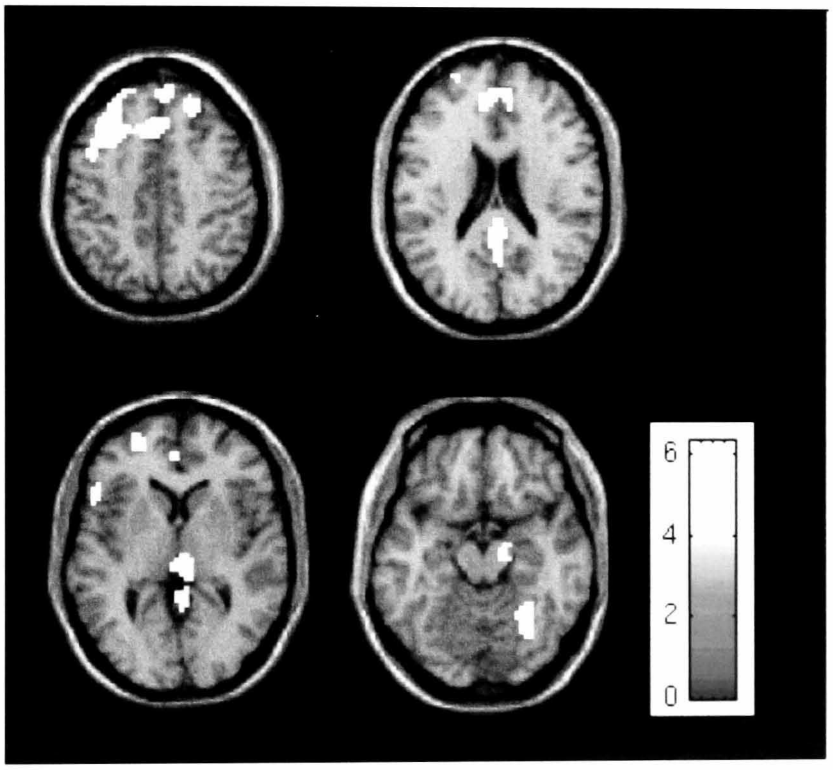

Figure 10.11. Non-players, chess-game > scene-game contrast. Four axial images from top to bottom of the brain, displaying brain activation.

The brain areas activated in this analysis are beyond the scope of this study, since all the conditions were grouped together. Suffice it to say that the pattern of brain activity displayed is consistent with the first experiment regarding the activation of working memory areas. However, no activation was found in the temporal lobe.

Table 10.5. Brain areas activated in the grandmaster and international master, target +delay > fixation cross.

Contrast	Vox.	Hem.	Brain region	BA	t-value	Z-value	Talairach		
							x	y	z
grandmaster	116	L	Middle frontal gyrus	6	3.93	>7.8	-36	0	50
target+ delay	705	L	Inferior parietal lobule	40	3.89	>7.8	-30	-56	42
>		L	Middle occipital gyrus	19	2.81	>7.8	-27	-87	7
fixation cross		L	Precuneus	7	2.35	>7.8	-9	-79	43
	982	R	Superior parietal lobule	7	3.51	>7.8	30	-62	50
		R	Middle occipital gyrus	19	3.26	>7.8	30	-72	15
		R	Middle occipital gyrus	19	2.92	>7.8	30	-90	16
	208	R	Cerebellum		2.97	>7.8	27	-68	-19
		R	Cerebellum		2.49	>7.8	24	-80	-19
		R	Cerebellum		1.96	7.26	45	-60	-27
	229	R	Inferior frontal gyrus	44	2.95	>7.8	36	7	25
	92	L	Inferior frontal gyrus	9	2.42	>7.8	-39	10	24
		L	Inferior frontal gyrus	9	1.47	6.06	-50	7	30
	36	R	Anterior cingulate	32	2.29	>7.8	6	14	41
	75	R	Middle frontal gyrus	6	2.01	7.4	33	-3	50
	23	L	Inferior parietal lobule	40	1.78	6.83	-48	-35	49
		L	Postcentral gyrus	40	1.34	5.75	-53	-29	51
	14	R	Middle frontal gyrus	46	1.53	6.2	45	30	15
	6	R	Brainstem		1.28	5.59	6	-27	-6
	11	R	Cerebellum		1.22	5.46	24	-48	-23
	6	L	Thalamus		1.2	5.41	-18	-20	15
international master	1844	R	Middle occipital gyrus	18	6.52	>7.8	27	-93	7
target+ delay		R	Middle occipital gyrus	18	5.85	>7.8	27	-90	16
>		R	Precuneus	7	4.74	>7.8	24	-70	48
fixation cross	527	L	Middle occipital gyrus	18	5.11	>7.8	-24	-96	5
		L	Cuneus	19	4.12	>7.8	-15	-86	35
		L	Inferior occipital gyrus	18	2.46	>7.8	-42	-87	-1
	214	L	Cerebellum		3.84	>7.8	-21	-83	-26
		L	Cerebellum		2.55	>7.8	-33	-77	-21
		L	Occipital fusiform gyrus	18	1.93	7.19	-21	-91	-13
	288	R	Medial frontal lobe	6	2.91	>7.8	3	5	47
		R	Medial frontal lobe	6	2.91	>7.8	3	0	53
		L	Medial frontal lobe	6	1.46	6.05	-21	0	50
	67	R	Middle frontal gyrus	6	2.02	7.41	53	5	44
		R	Precentral gyrus	4	1.94	7.22	48	-4	44
		R	Middle frontal gyrus	9	1.6	6.39	50	5	36
	56	R	Middle frontal gyrus	8	1.76	6.78	27	11	38
		R	Middle frontal gyrus	6	1.69	6.6	30	8	49
	25	L	Precentral gyrus	6	1.66	6.52	-48	-7	39
	7	R	Caudate nucleus		1.63	6.44	12	1	17
	7	L	Superior parietal lobule	7	1.46	6.05	-33	-58	55
	9	R	Thalamus		1.27	5.59	3	-17	4

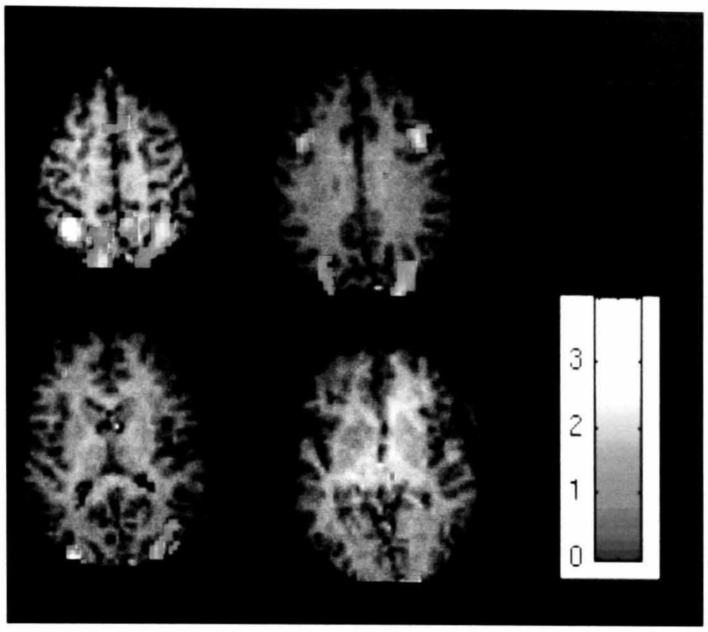

Figure 10.12. Target + delay > fixation cross contrast (grandmaster). Four axial slices from top to bottom of the brain displaying brain activity.

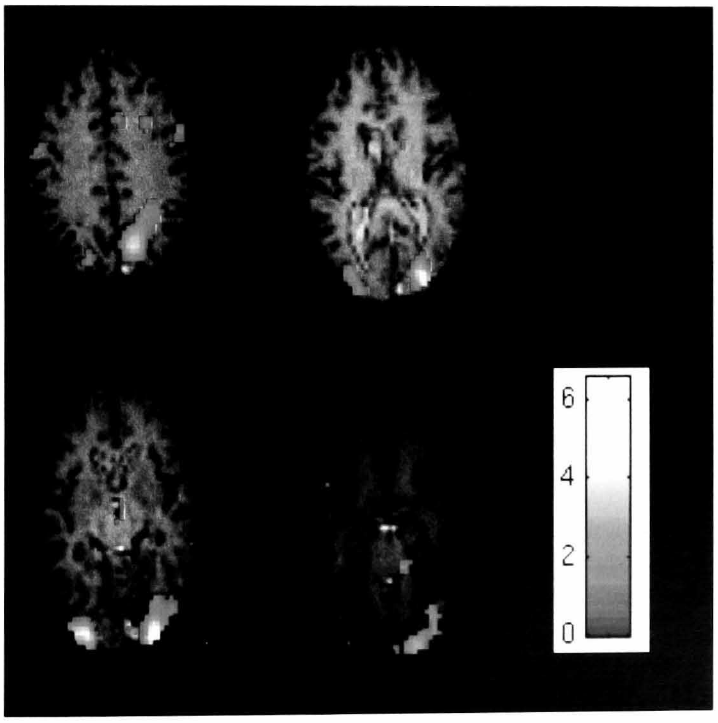

Figure 10.13. Target + delay > fixation cross contrast (international master). Four axial slices from top to bottom of the brain displaying brain activity.

10.2.4 Discussion

Three main results were uncovered in the present study. First, neither the grandmaster nor the international master show differences in brain activity in any of the contrasts. Second, this lack of effect is not an artifact of the apparatus or due to the lack of sensitivity of the paradigm. Third, non-chess players displayed the largest pattern of brain activity in the chess-game > scene-game contrast, but this pattern disappeared in the chess-random > scene-random contrast.

10.2.4.1. Semantic hypothesis

I suggested that a 'semantic hypothesis' predicted the lack of effect in all of the contrasts. This hypothesis is based in previous studies (for example, Chase & Simon, 1973; Saariluoma & Kalakoski, 1997) that showed that the presentation of a symbol instead of the actual chess piece allowed the chess players to access the identity of the piece, and the performance was not diminished in comparison with a condition with the presentation of the actual pieces. Therefore, it is proposed that the perceptual aspect of the piece is not the one encoded in long-term memory but the semantics of the chess pieces are. There are different types of chess sets, and it would be overloading and inefficient to encode in long-term memory the perceptual aspects of the pieces; instead, an abstract way of encoding would be more efficient.

In order to support this proposal, a direct test could be carried out using the scene condition of experiment 1 (in which it is not possible to establish a match of the shapes with the chess pieces) and the scenes of experiment 2 (in which a match is possible) with the same number of shapes. Brain activity in the parahippocampal gyri should be found in the contrast game > experiment 1-scene, but not in the contrast game > experiment 2-scene.

10.2.4.2. 'On line' chunking in non-chess players?

In the contrast chess-game > scene-game the non-chess players displayed a large pattern of brain activity. This is consistent with the contrast game > scene in the first experiment. Therefore, non-chess players process a chess position in a different manner from a scene with shapes (at least, when performing a memory task). If what they process differently is the perceptual aspect of the stimulus, then the difference should have been the same in the chess-random > scene-random contrast. However, in this contrast there were only 6 voxels activated.

All the non-chess players in both experiments reported that they knew the rules of chess. One possibility is that when they perceive chess pieces in a chessboard they try to do 'on-line' what the chess players have been doing in their chess career: chunking. They may try to group together clusters of pieces; on the other hand, they might not do the same with shapes. It is worth noting that when presented with a sheet depicting the matching between shapes and chess pieces before the scanning session, the non-chess players did not pay attention to it. On the other hand, chess players took their time with this sheet, and when asked—after the scanning session— if they had matched the shapes to the chess pieces they answered affirmatively.

The idea of chunking in non-experts participants was recently investigated by Bor et al. (2003), who explored the chunking theory in a sequential memory task. Participants had to remember a sequence of movements on a blank grid. In a condition where the movements were either in the same column, or in the same row, or in the same diagonal, participants displayed activity in frontal areas in comparison with a condition in which the movements did not follow a regular pattern. Bor et al. (2003) interpreted these findings in terms of chunking, that is, participants in the regular condition were able to perform a chunking of sequences, which was not possible in the non-regular condition.

An argument against the 'on-line' chunking hypothesis in the present experiment could be that in the contrast chess-game > chess-random the differences were negligible. However, this argument applies to chess players who treat chess positions in a different way from the random positions, but not from the non-chess players who perform almost equally with chess game positions and random positions in reconstruction tasks (see Chase & Simon, 1973; Gobet, 1998). Hence, it is proposed that non-chess players try to perform chunking when presented with a chessboard with chess pieces regardless of the structure of the position.

10.2.5. Conclusion

The brain activity of high-level chess players (grandmaster and international master) performing a delayed response task is homogeneous in several conditions varying the structure (game vs random) and the perceptual aspect (chess vs scene) of the stimulus. It is suggested that this uniformity is due to the fact that all the conditions gave a cue that automatically activated the semantics of the display of chess pieces on a chessboard.

It was also proposed that non-chess players —knowledgeable of the chess rules—engaged themselves on 'on-line' chunking when presented with a chessboard with chess pieces regardless of the structure of the display. However, these proposals should be taken cautiously and more experiments should be carried out in order to rule out alternative explanations.

Having presented all the empirical studies, next chapter will address the theoretical implications of the thesis. The results obtained will be used in order to estimate the values for some parameters of a general theory of expertise, taking the template/CHREST theory as a starting point.

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