The mind's eye in blindfold chess

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Abstract

Visual imagery plays an important role in problem solving, and research into blindfold chess has provided a wealth of empirical data on this question. We show how a recent theory of expert memory (the template theory, Gobet & Simon, 1996, 2000) accounts for most of these data. However, how the mind's eye filters out relevant from irrelevant information is still underspecified in the theory. We describe two experiments addressing this question, in which chess games are presented visually, move by move, on a board that contains irrelevant information (static positions, semi-static positions, and positions changing every move). The results show that irrelevant information affects chess masters only when it changes during the presentation of the target game. This suggests that novelty information is used by the mind's eye to select incoming visual information and separate "figure" and "ground." Mechanisms already present in the template theory can be used to account for this novelty effect.

The mind's eye in blindfold chess

Mental imagery, and in particular visual mental imagery, has been the subject of intensive research in psychology. This research is perhaps best known for the protracted debate of whether imagery is made possible by propositions or by analogue mental images. Recently, experimental and theoretical research has been seconded by brain-imaging techniques, which have helped develop hypotheses about the brain tissues involved in manipulating mental images (for a review, see Kosslyn, 1994).

In spite of this extensive research, little is known about the role of visual imagery in problem solving, and, in particular, in expert problem solving. While some elements of answer have been provided in domains such as physics (Larkin & Simon, 1987), mathematics (Paige & Simon, 1966) and engineering (Ferguson, 1992), many questions have yet to be answered. For example, to what extent do mental images favor the creation of efficient internal representations and allow new information to be integrated with prior knowledge? How do they enable selective search in problem-solving situations? What is the role of the "figure" and "ground" in mental images? How does expertise mediate mental images?

Few domains have been as instrumental as chess in providing preliminary answers to these questions. The focus of this research 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).

This study aims to understand the relationship between visual perception and imagery in chess. In particular, we are interested in the overlap of internal and external information within the mind's eye. We designed two experiments where chess players had to create and maintain images using relevant stimuli. At the same time, they perceived irrelevant stimuli. In order to perform the task, participants had to heed relevant stimuli continuously, and, in so doing, they could not avoid perceiving the irrelevant stimuli. We were also interested in the role played by the amount and novelty of irrelevant information presented. A final goal of this paper is to link empirical data on mental images in chess to a current theory of expertise, the template theory (TT, Gobet & Simon, 1996a, 2000). In particular, since the amount of information stored in long-term memory (LTM) is crucial in TT, we were interested in the role of previous knowledge and its interaction with the problem of overlapping information in the mind's eye.

After reviewing work on blindfold chess, we describe the template theory, and show how it can account for most of the available data on blindfold chess. However, one component of the theory, the mind's eye, is still underspecified. The two experiments of this paper are aimed at gathering information about this component.

Mental imagery in expert problem solving

The question of the nature of mental representations is probably as old as philosophy. For example, Aristotle suggested that imagery is the main medium of thought (Eysenck & Keane, 2000). In psychology, interest in mental imagery has been unabated since the classical studies on rotation and scanning of mental images by Cooper, Shepard, Kosslyn and others (see Kosslyn, 1994, for a detailed history). Beyond standard experimental studies of mental images, research has investigated their neurobiological substrate (e.g., Kosslyn, 1994), their relation with external representations (Newell & Simon, 1972), and their role in the use of multiple representations (Lane, Cheng & Gobet, 2001; Tabachneck-Schijf, Leonardo & Simon, 1997).

Little is known, however, about the links between expertise and mental images, in particular in problem-solving situations. While there is substantial anecdotal evidence that experts do use mental images in domains such as science (Miller, 1986), engineering (Ferguson, 1992), visual arts (Zeki, 1999), and sports (Jarvis, 1999), few empirical studies have been carried out to flesh out the mechanisms involved. This is an unfortunate situation, as the use or misuse of mental images may have important consequences in these domains, including for training and education.

The difficulty of a problem is in large part determined by how it is internally represented (Newell & Simon, 1972). Mental images, while containing less detail than external pictures and diagrams, share the computational advantages offered by these (mainly, localization of information and inference operators; Larkin and Simon, 1987). A natural consequence of these assumptions is that experts should learn, among other things, to use an efficient mode of representation, including the operators necessary to take full advantage of it. Experimental support for the effective use of mental images by experts has been gathered from algebra word problems (Paige & Simon, 1966), computer programming (Petre & Blackwell, 1999), industrial design engineering (Verstijnen et al., 1998), architectural design (Chan, 1997), surgery (Hall, 2002), and sport (e.g., diving; Reed, 2002). However, the strongest experimental evidence comes from the literature on blindfold chess, which we will now review in detail.

Blindfold chess

In blindfold chess, a player carries out one or several games without seeing the board, typically against opponents who have a full view of it; the moves are communicated aloud using standard chess notation. As it seems to require remarkable cognitive capabilities, 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 color 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.

As suggested by this brief review, most evidence about blindfold chess has been anecdotal. It was not until about ten years ago that 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, but 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 color 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 worse than highly skilled chess players.

In a final set of experiments, Saariluoma and Kalakoski (1998) investigated 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.

Saariluoma (1991) and Saariluoma and Kalakoski (1997, 1998) explained their results utilizing a number of theoretical ideas: Chase and Simon's chunking theory, Ericsson and Kintsch's (1995) long-term working memory theory, Baddeley and Hitch (1974) theory of working memory, and Leibniz' (1704) and Kant's (1781) concept of apperception—that is, second-order perception. In the following two sections, we show that most of their results can be explained within a single framework.

The Chunking and Template Theories

While Chase and Simon's (1973) chunking theory is best known for its characterization of the patterns stored in chess players' long-term memory, it also describes at some length the role of the mind's eye, an internal store where visuo-spatial operations are carried out. Basing their account upon previous research (e.g., Simon & Barenfeld, 1969), Chase and Simon proposed that the mind's eye consists of a system storing perceptual and relational structures, both from external inputs and from memory stores. These structures can be subjected to visuo-spatial mental operations, and new information can be abstracted from them.

With practice and study, players acquire a large number of perceptual chunks, which are linked to useful information, such as possible moves or plans. Chunks can also be linked to a set of instructions allowing patterns to be recreated as an internal image in the mind's eye. The mind's-eye model acts as a production system (Newell & Simon, 1972): chunks are automatically activated by the constellations on the external board or on the internally imagined chessboard, and trigger potential moves or plans that will then be placed in short-term memory (STM) for further inspection through look-ahead search and/or used to update the imagined chessboard. The choice of a move, then, depends both on pattern recognition and on a selective search in the space of the legal possibilities.

In spite of its good explanatory power overall, Chase and Simon's chunking theory has two main weaknesses: it underestimates encoding speed into LTM, and it is mostly silent about the high-level knowledge structures that players use, such as schemata (Holding, 1985). As a consequence, it has recently been revised by Gobet and Simon (1996a; 2000) in their template theory (TT). As with the chunking theory, chess expertise is mainly due to the storing of chunks in LTM, which relate to familiar patterns of pieces. Patterns elicit chunks in LTM, which allow players to recognize automatically (parts of) the positions and give access to relevant information, such as information about strengths and weaknesses of the position, tactical possibilities, and potential moves. Pattern-recognition processes—which are assumed to be automatic and unconscious—are performed both from the internal image that chess players are constructing and from the stimulus they are perceiving (Gobet & Simon, 1998). Often-elicited chunks evolve into "templates," which are more complex data structures similar to the "schemata" commonly used in cognitive psychology (see Lane, Gobet & Cheng, 2000, for an overview). Templates contain both stable information (the core) and variable information (the slots), and it has been estimated that it takes about 250 ms to add information to the slots of a template (Gobet & Simon, 2000).

Aspects of TT have been implemented as computer programs. CHREST (Chunk Hierarchy and REtrieval STructures; De Groot & Gobet, 1996a; Gobet & Simon, 2000) accounts for empirical data on chess memory and perception, such as eye movements, the effect of distorting chess positions, and the role of presentation time on memory recall. CHUMP (CHUnking of Moves and Patterns; Gobet & Jansen, 1994) implements the idea that chunks elicit possible moves and sequences of moves. Finally, the relation of mental imagery to problem solving has been investigated in SEARCH (Gobet, 1997), an abstract model of chess playing, which combines assumptions about the role of chunks and templates with assumptions about move generation and properties of the mind's eye, including decay and interference mechanisms.

As in the chunking theory, the mind's eye in TT is considered as a visuo-spatial structure preserving the spatial layout of the perceived stimulus, where information can be added and updated (De Groot & Gobet, 1996; Gobet & Simon, 2000). The theory includes time parameters for carrying out various types of operations, such as moving a Bishop diagonally or a Rook horizontally. These mechanisms, which have been recently applied to modeling the way students learn multiple representations in physics (Lane, Cheng & Gobet, 2001), are closely related to the mechanisms proposed by Tabachnek-Schijf, Leonardo and Simon (1997) in their CaMeRa model, which simulates the behavior of an economist solving a supply-and-demand problem. CaMeRa, in turn, incorporates some of the ideas proposed by Kosslyn (1994) in his theory of mental imagery, which details how several areas of the visual system, including the visual buffer, take part in the generation, transformation, inspection, and maintenance of visual images.[1]

Search processes are carried out in the mind's eye: when an anticipated move is carried out, the changes are performed there (Chase & Simon, 1973; Gobet, 1997). The mind's eye is subject to decay and to interference, the latter both from information coming from the mind's eye and from external information. Several predictions of TT and SEARCH about the role of the mind's eye in problem solving are supported by the empirical data, including: the high-levels at which chess players organize their knowledge (De Groot, 1946/1978; De Groot & Gobet, 1996; Holding, 1985); the fact that players often revisit the same positions during search (De Groot, 1946/1978); and the increase of mean depth of search and of the rate of search as a function of skill (Charness, 1981; Gobet, 1998b, Saariluoma, 1990).

Applying the Template Theory to Blindfold Chess

A substantial part of Saariluoma's research into blindfold chess was carried out to identify the possible role of chunking mechanisms when playing without seeing the board. Given that these mechanisms have been vindicated by empirical data

[1] Incidentally, the presence of these and other computational models, which provide detailed mechanisms for processing information in the mind's eye, indicates that this concept does not suffer from the joint problem of the homunculus and infinite regress (the contents in the mind's eye has to be 'seen' by another mind's eye, the contents of which has to be seen by a third mind's eye, and so on).

(Saariluoma, 1991; Saariluoma & Kalakoski, 1997), it is not surprising that the template theory, which is based upon the chunking theory, accounts for data on blindfold chess reasonably well. We now discuss how the main empirical results can be explained by this theory. Note that these explanations have not been developed ad hoc for blindfold chess, but have been used to explain similar phenomena with plain-view chess (Gobet, 1998a).

Several mechanisms inherent in TT 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, in particular with masters. Second, templates can be linked to each other and can be linked to moves. For instance, 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 (see Figure 1).

Insert Figure 1 about here

We can now 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 center of TT. 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 few chunks can be recognized, and, therefore, allow for a relatively good recall.

The fact that players are sensitive to visuo-spatial interfering tasks early on, but not later on, 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 TT. Information about color 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, 1996b; Saariluoma, 1994). The effect of transposing the two halves of the board is explained by the difficulty to access 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 TT, 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 follow 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 memory 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 TT, 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 we have just 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, we presented a game blindfold with a background, which is totally irrelevant to the target game. This manipulation is interesting theoretically, because it raises the question of how perceptual processes can separate the (relevant) figure from the (irrelevant) ground before the information is used in the mind's eye.

Experiment 1

The purpose of this experiment was to understand the relationship between visual perception and imagery within the mind's eye. We used a method similar to that used by Saariluoma and Kalakoski (1997): 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, color and location), we were 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, we placed pieces not related to the target game throughout the board. Two games were presented simultaneously, and the ability to remember positions was measured three times: after 10 ply,[2] 30 ply, and 50 ply; memory for the entire game was tested at the end.

Participants

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)[3] of 2,299 and an average national rating (SNG) of 2,193. Class A players had an average national rating of 1,885. (They

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[2]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.

[3] The Elo rating is an interval scale with a standard deviation of 200 points, which is used to delimit skill classes. Players with more than 2200 points are called 'masters', from 2000 to 2200 'Experts', from 1800 to 2000 'Class A players', from 1600 to 1800 'Class B players', etc. The international Chess Federation (FIDE) recognizes three titles: international grand master (usually players above 2500 Elo), international master (above 2400) and FIDE master (above 2300). There are also national ratings that resemble the Elo system. In the case of Argentina, it is called SNG (National Grading System).

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.

Material

Six grandmaster games were carefully chosen so that they were not played by elite grandmasters and did not follow 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.

Design and Procedure

We used a 2x3x3 design, 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.

The six games were presented on a computer screen "blindfold," that is, the players could see only the moves but not the current position. Three experimental conditions were used. In the control condition, the moves were played 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 carried out 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. The target piece was first presented for one second in its origin square and then for two seconds in its destination square. It was surrounded by a green square to discriminate it from irrelevant pieces.

The games were presented as follows. The first 10 ply of game 1 were played, followed by the first 10 ply of game 2. At this point, an empty board appeared on the screen, and participants had to reconstruct the last position in each game. Then, ply 11 to 20 of game 1 were played, 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 positions and a maximum of 10 minutes to reconstruct the moves of a 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 familiarize themselves with the procedure and the use of the mouse in the reconstruction of positions. The practice consisted in following the procedure explained above, for 6 practice games (2 per condition) until the reconstruction of ply 10 in all the games.

Results

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]. We 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.

Insert Figure 2 about here

We also analyzed the errors of omission (total number of pieces minus the number of pieces replaced) and of commission (pieces incorrectly replaced). 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, we report the results as percentages.

With respect to the percentage of errors of commission, we 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 [$\underline{F}(1,14) = 109.7$, MSE = 27,332; $\underline{p} < .001$], Depth [$\underline{F}(2,13) = 76.8$, MSE = 19,146; $\underline{p} < .001$], but not for Interference [$\underline{F}(2,13) < 1$, MSE = 55.34]. Again, Depth x Skill was the only significant interaction [$\underline{F}(2,13) = 24.1$, MSE = 6,010; $\underline{p} < .001$]. The same pattern of results was found for the percentage of errors of omission: Skill [$\underline{F}(1,14) = 12.5$, MSE = 1,842; $\underline{p} < .001$]; Depth [$\underline{F}(2,13) = 12.6$, MSE = 1,860; $\underline{p} < .001$]; Interference [$\underline{F}(2,13) < 1$, MSE = 13.36]; Interaction Depth x Skill [$\underline{F}(2,13) = 4.0$, MSE = 592.04; $\underline{p} < .02$].

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

Reconstruction of games

For this variable we utilized a 2 x 3 ANOVA model (Skill x Interference). 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. Again, we found 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].

Discussion

In this experiment, we repeatedly found the following pattern of results: (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 TT, as we have 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 recognize 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 TT. 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. The positions and the moves close to the starting position are well known both to masters and to Class A players; hence, we do not expect big differences in the corresponding recall performances. 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. We 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 us 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. We suggest two explanations. First, it is 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), we designed a second experiment where the interference positions changed during the task. We speculated that the novelty of the position would cause its automatic processing, therefore impairing performance for all skill levels. This assumption flows naturally from TT 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 on the presence of templates by an analysis of the types of errors made during reconstruction.

Experiment 2

The purpose of this experiment is to test our hypothesis that the lack of main effect of interference in the first experiment was due to the lack of novelty in the interference positions. We used two interference conditions, different from those used in experiment 1. 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, we found that a Class A player could not do the task at all. Therefore, we 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, we decided to eliminate some components of the experiment, leaving intact the elements that we considered essential for our research questions.

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).

Material

From a pool of grandmaster games with relatively uncommon openings, we selected 6 games for the stimuli to memorize, and 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, we used 50 different positions; in the semi-static condition, we used 5 different positions.

Design and Procedure

We used a 2x3x2 ANOVA design. 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, we did not ask the participants to reconstruct the position after 10 ply, and we did not ask them to reconstruct the games at the end. We took these decisions 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, we presented a different interference position at each ply. (In this condition, participants reported a sensation of motion.) In the semi-static condition, the interference positions lasted 10 ply. Hence we used 5 interference positions, taken after 10, 20, 30, 40 and 50 ply. 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.)

Results

Figure 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.

Insert Figure 3 about here

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%; $p <. 02$).

We further classified errors of commission 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 visualize the relative influence of errors of commission and omission, we plotted them together in Figure 4 , which shows the average percentages of errors after 30 and 50 ply, all players included.

The use of schemata for each game, as proposed by TT, 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, TT 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 4 shows that errors of omission and errors of the same game are the more frequent, thus supporting the presence of templates.

Insert Figure 4 about here

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 not any difference between each other; 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 we eliminated the reconstruction phase after 10 ply. 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 our second hypothesis — chess players use the board's percept as a perceptual help 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. We hypothesized that the novelty of the irrelevant pieces would make it hard to avoid their processing. However, although novelty did cause a decrement in performance, larger amounts of novelty did not cause larger impairment. We will take up this result in the general discussion. Finally, the analysis of errors provided direct support for the construct of templates.

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 TT, 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 goes further away from the initial position, it becomes harder to update. This is in line with TT'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 in the next move. As a consequence, according to TT, 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. We 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.

General Discussion

In the introduction of this article, we have shown how TT, a general theory of expertise, explains most of the data on blindfold chess available in the literature, without amendment or ad hoc assumptions. We 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 embedded 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 TT. 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.

We also acquired some evidence that changes in the background may affect performance, and 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 to select incoming visual information and separate "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.

Within the framework of TT, two mechanisms are possible to explain these results. First, novelty detection essentially happens at the perceptual level. Eye movements are directed, perhaps by cues in peripheral vision, to squares where novel information is provided (e.g., the move in the target game), and are inhibited from returning to squares where information is static. Second, novelty detection occurs at the stage of memory encoding: for example, when discrimination learning mechanisms are engaged (see also Tulving et al., 1994). In the second, but not in the first case, chess players can be said to perceive a stimulus at the same time as they hold a different image in memory. In this case, it is likely that the time necessary for processing the information after presentation of a new move (update in STM, update in the mind's eye) impairs image rehearsal, leading to a lessening in information. This is because there is potentially overlapping and competing information in the mind's eye: the position presented on the screen and the image corresponding to the actual game. The results of Experiment 2 supported the second mechanism.

A question that is not resolved by the data is whether we are dealing with selective attention (the attention is directed towards the last move in the target game) or whether we are dealing with selective inattention (the attention towards the interfering position is somehow inhibited). Laeng and Teodorescu (2002) have demonstrated that eye movements during mental imagery are instrumental in image generation. Supplementing the blindfold experiments with eye-movement studies may offer a means of answering whether attention, or inattention, is selective in blindfold chess.

The mechanisms we have proposed are consistent with Kosslyn's (1994) theory of imagery. In this theory, which we can only outline here, the visual buffer roughly plays the same as the mind's eye in TT. According to Kosslyn, it is located in the occipital lobe (primary visual area) and is topologically arranged. Associative memory, thought to be located in the superior, posterior temporal lobes and in the area at the junction of the temporal, parietal, and occipital lobes, is the place where outputs from the ventral system (encoding object properties) and from the dorsal system (encoding spatial properties) come together. Associative memory stores associations between perceptual representations as well as conceptual information. What we call "chunks" and "templates" seems to correspond to what Kosslyn calls "structural descriptions": rich associative and conceptual representations encoding both parts of scenes or objects and their spatial relations. Unlike the visual buffer, associative memory is not topographically organized. Kosslyn (1994) suggests that visual patterns might be stored in arrays in the ventral system (inferior temporal lobe); in order to generate a visual image, these arrays should activate cells in the visual buffer. Once accessed, these memory structures are free of interference; by contrast, information in the visual buffer fades quickly. As a consequence, processing a large amount of information in the visual buffer leads to interference and loss of performance.

Applied to our experiments, Kosslyn's theory predicts that, at the beginning of a game, all players are able to access a structural description of the initial position. When the initial moves are dictated, players can access other structural descriptions linked to the current one, without the need to generate a visual image in the visual buffer.

However, when no structural descriptions 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 the object properties encoding subsystem. As far as we now, Kosslyn's (1994) attention-shifting system, which disengages, moves, and engages attention, does not seem to be specified to the point to make clear-cut predictions about the role of novelty in our experiments.

Beyond its theoretical relevance, this study has implications for applied research. In education, there is currently a renewed interest in the potential benefit of multiple representations, both internal and external (Ainsworth, 1999). In many technical and scientific domains, being able to combine multiple representations is one of the required skills. However, using multiple representations may be time and resource consuming (Gobet & Wood, 1999). For example, diagrammatic and other external representations need to be translated into mental images in order to be fully integrated into other types of knowledge. Learning (how to generate) such images and how to link them to other information has a cost, that must be weighted against the benefits of using them. In particular, as suggested in our study, depth of anticipation, as well as changes of information in the background environment, may lead to a decrease in performance, perhaps to the point where mental images cannot be relied upon any more.

There is still much to learn about how expertise mediates mental images. In this paper, we have used an existent computational model to account for previous data on blindfold chess, and have described two experiments aimed at understanding the role of background in the manipulation of mental images. We found that irrelevant information affects masters' performance only when it changes during the presentation of the target game. We have argued that background novelty has important repercussions for theories of expertise and imagery, in that it plays a key role in what is attended to and/or learned.

Most research on experts' mental images has been carried out with blindfold chess, and this article is no exception. We urge researchers to replicate studies pursued with blindfold chess in other domains of expertise—both 'classic' domains (such as physics, medicine, or sports) and new domains—in order to test the validity of the theoretical ideas discussed in this paper.

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Figure Captions

Figure 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 our example, the move 1… c7-c5).

Figure 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).

Figure 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).

Figure 4. Experiment 2: Detail of errors of omission and commission.

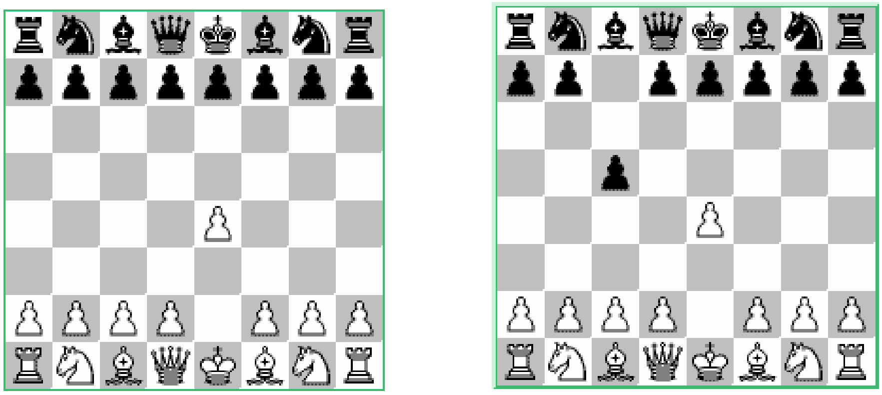
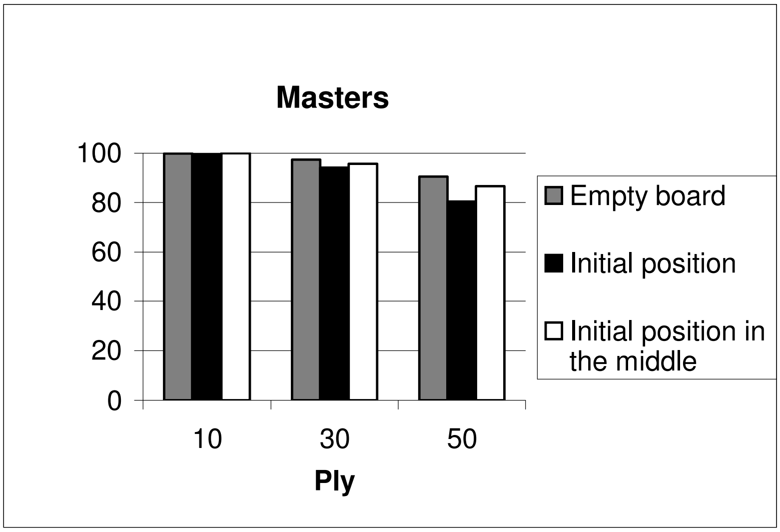


Figure 1


Masters
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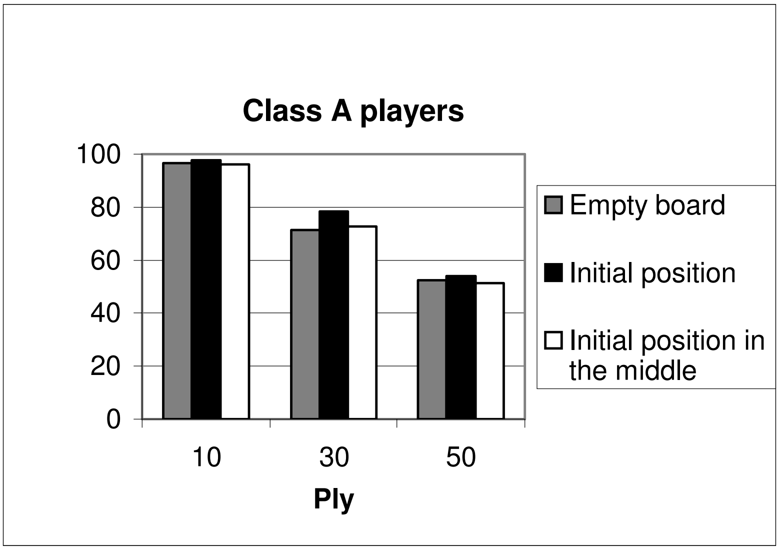
Ply
Empty board
Initial position
Initial position in the middle


Class A players
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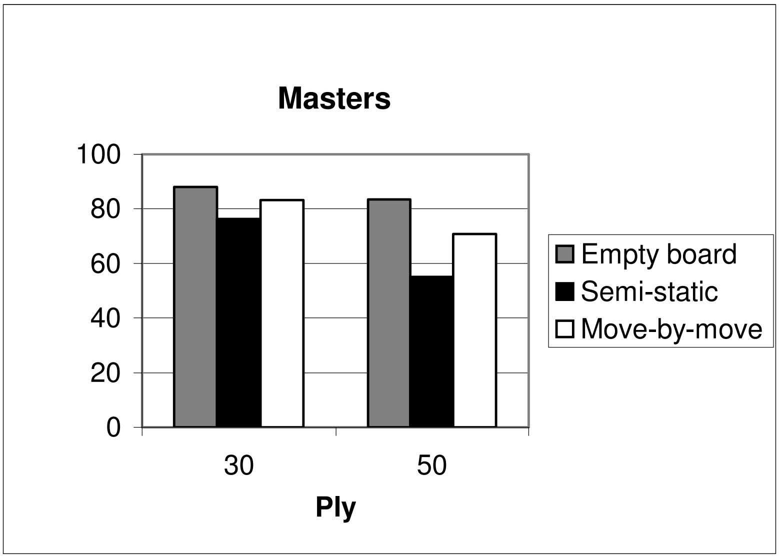
Ply
Empty board
Initial position
Initial position in the middle

Figure 2


Masters
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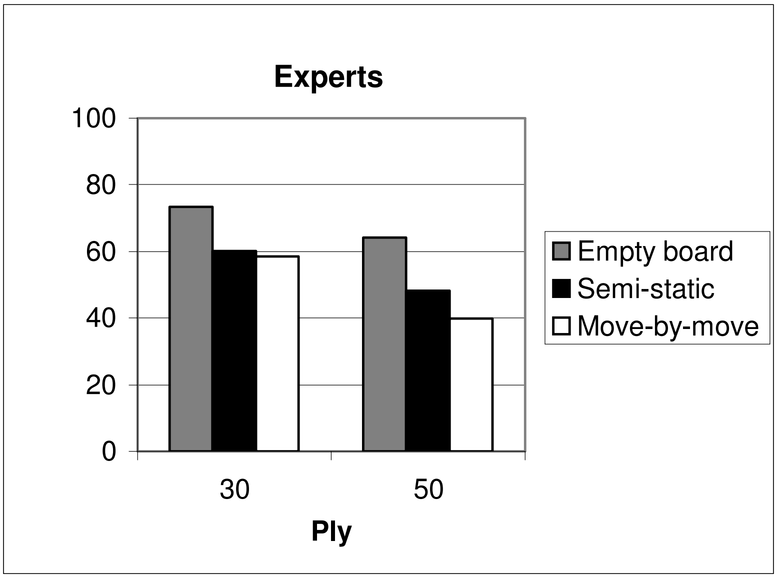
Semi-static
Move-by-move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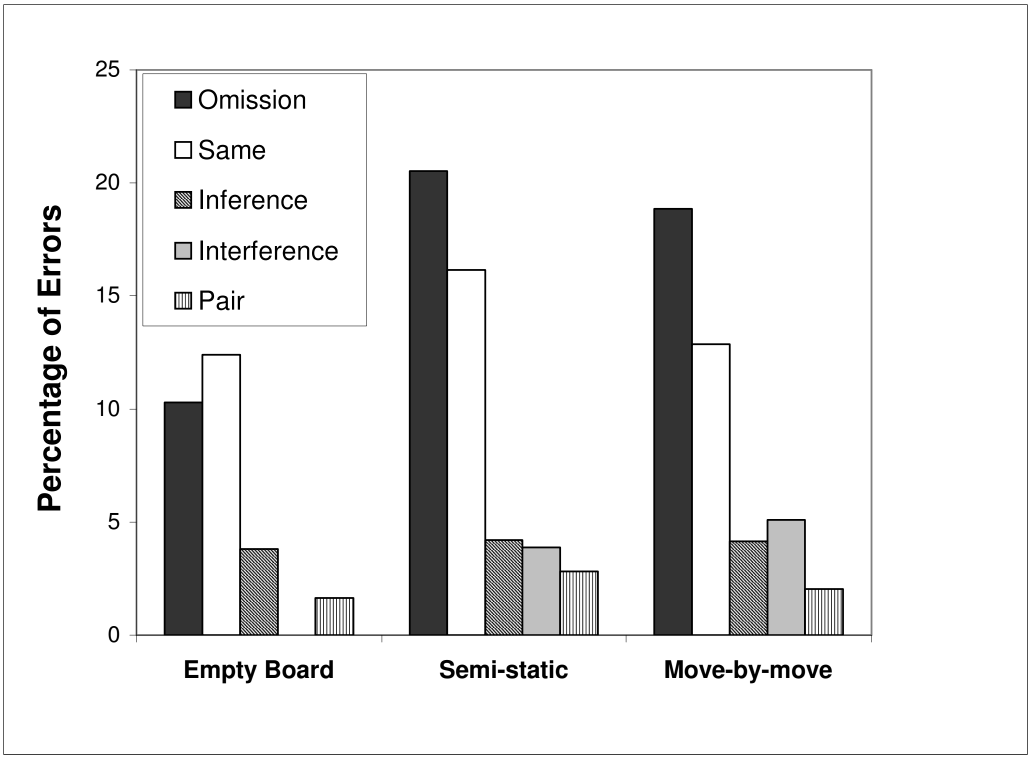
Semi-static
Move-by-move

Figure 3



Percentage of Errors
25
20
15
10
5
0
Omission
Same
Inference
Interference
Pair
Empty Board
Semi-static
Move-by-move

Figure 4