LONG-TERM WORKING MEMORY:
COMMENT ON ERICSSON AND KINTSCH (1995)

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Abstract

Within the framework of their long-term working memory theory, Ericsson and Kintsch (1995) propose that experts build memory structures for the task domain (retrieval structures) that allow them to encode information rapidly into long-term memory. Ericsson and Kintsch use chess players' memory as one of their most compelling sources of empirical evidence. In this paper, I show that evidence from chess memory, far from supporting their theory, limits its generality. I conclude that the principle of generic retrieval structure applies only in domains where there is a conscious, deliberate intent by individuals to improve their memory, and that other mechanisms exist (possibly in conjunction with retrieval structures) that permit a rapid encoding into long-term memory under other circumstances.

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In a recent paper, Ericsson and Kintsch (1995) present compelling evidence that experts in various domains are able to encode information into long-term memory (LTM) faster than was proposed by traditional models of human memory. They mention empirical evidence about use of mnemonics (memory for menu orders, digit-span memory), mental multiplication, mental abacus calculation, chess, medical expertise, and text comprehension.

The core of their long-term working memory (LT-WM) theory, which is an elaboration of the skilled memory theory (Chase & Ericsson, 1982), is that "cognitive processes are viewed as a sequence of stable states representing end products of processing" and that "acquired memory skills allow these end products to be stored in long-term memory and kept directly accessible by means of retrieval cues in short-term memory [...]" (Ericsson & Kintsch, 1995, p. 211). Encoding occurs through a retrieval structure and/or through knowledge-based associations connecting items to other items or to LTM schemas, which allows for a integrated representation of the information in LTM (cf. their Figure 4).

A key element in the LT-WM theory is that experts develop, through practice and study, retrieval structures for the task domain. Retrieval structures are "a set of retrieval cues [that] are organized in a stable structure" (Ericsson and Kintsch, 1995, p. 216). The best empirical evidence for these structures is offered by the detailed study of SF and DD, two experts in the digit-span task (Chase & Ericsson, 1982; Staszewski, 1990). Analysis of reaction times and of verbal protocols, as well as experimental manipulations, gives strong support to the presence of retrieval structures within these tasks. As stated by the theory, in addition to retrieval structures, LTM associations to previously stored semantic memory facilitate the encoding of information by adding redundant cues, but these associations are not strictly necessary for experts to reach a high recall performance. For example, lists of digits manipulated to make semantic encoding difficult did not reliably impair DD's percentage of recall (Staszewski, 1990).

The main thrust of Ericsson and Kintsch's paper (1995, p. 217) is to propose that the basic tenets of the skilled memory theory (Chase & Ericsson, 1982), including the presence of retrieval structures, are generalizable across a wide variety of tasks, contrary to the more limited claim that the concept of retrieval structures is useful only in tasks where subjects show a deliberate and conscious attempt to improve their memory through strategies ("mnemonics") and where the scheme for subjective organization of the material to be recalled is known beforehand to them.

In this paper, I will show that this claim of generality is exaggerated. Although there is no doubt that most experts have a rapid (although less impressive than DD's) access to LTM, other mechanisms besides retrieval structures have to be postulated. To make my case, I will use the domain of chess memory, a model task in the study of expertise (Charness, 1992), which has the double advantage of having a long scientific tradition, going back to Binet (1893/1966), and of offering a large database of empirical data. Since Ericsson and Kintsch (1995) note that "research on planning and memory of chess positions offers some of the most compelling evidence for LT-WM" (p. 238), the choice of this domain is adequate to test their theoretical claims of generality.

1. LT-WM ACCOUNT OF CHESS EXPERT MEMORY

Ericsson and Kintsch (1995), building on previous research mentioned in Ericsson and Staszewski (1989), propose that skilled chess players use a general-purpose retrieval structure isomorphic to the 64 squares of the physical chess board. Positions are remembered by rapidly inserting the retrieval cues for the appropriate piece in the square it occupies in this position. According to the theory, any piece can be stored in any square of the retrieval structure equally rapidly. Thanks to this structure, which both relates pieces to each other and associates individual pieces to their respective locations, a position is represented as an integrated hierarchical structure, which allows a rapid encoding into LTM. To support their theory, Ericsson and Kintsch (1995, p. 237-8) review several pieces of evidence from chess memory research: results from recall experiments where the (random) chess positions lack meaningful configurations, results showing that skilled chess players can rapidly access the location of pieces within a chess position, and results showing that masters can mentally manipulate and update the contents of a position when playing blindfold chess. Note that most of the reported experiments use rather long presentation times (typically, 2 s per move or 2 s per piece), and that Ericsson and Kintsch are not explicit about what mechanisms apply with experiments showing recall with short presentation times, say less than 10 s for the entire position (typically 25 pieces), such as the standard De Groot (1946/1978) recall task. It is, however, clear from a previous publication (Ericsson & Staszewski, 1989) that the retrieval structure is also assumed to be used efficiently with short presentation times.

Although the LT-WM theory is not specified at a detailed level (in particular, no parameters are given for the time necessary to encode retrieval cues in the retrieval structure), it makes some qualitative predictions that can be tested. I now review relevant empirical evidence from chess memory research, starting with some of the evidence discussed by Ericsson and Kintsch (1995), that does not appear to support their position. As will soon be clear, chess players' memory raises serious difficulties for the LT-WM theory.

2. EMPIRICAL DATA FROM CHESS RESEARCH AT VARIANCE WITH THE LT-WM THEORY

2.1 Random Positions

Ericsson and Kintsch (1995, p. 237) stress that "the ability to store random chess positions provides particularly strong evidence for the ability to encode individual chess pieces into the retrieval structure." This comment is surprising, because empirical evidence about random positions is devastating for the LT-WM theory: players of all skill levels have huge difficulties with this type of position.

First, even if masters maintain a modest superiority over weaker players with presentation times up to 10 s (Gobet & Simon, in press-a), their performance is poor (on average, 5.5 pieces out of 25; with game positions, masters typically replace 23-25 pieces out of 25). Second, and this is more damaging for the theory, masters perform poorly with long presentation times. With a visual presentation of the whole board for 60 s, they do not remember more than 70% correct (Gobet & Simon, 1995). With an auditory, piece-by-piece presentation of 50 s, at a rate of one piece every 2 s, they do not recall more than 60% (Saariluoma 1989). In addition, Saariluoma (1989), again using dictation of pieces, has shown that masters recall little from four random positions presented in sequence (around 10% per position), while they perform relatively well with game positions (around 60% correct per position).

Obviously, masters' recall performance is much below what is predicted from the presence of a retrieval structure allowing rapid encoding on all squares of the internal board. While Ericsson and Kintsch mention that access to schemas in LTM facilitates encoding, they also are quite explicit that the retrieval structure allows encoding <u>individual</u> pieces and, therefore, should be useful for recalling random positions. Furthermore, there are at least as many relations of attack, defense, color, and proximity in random positions as in game positions (Chase & Simon, 1973), which should allow experts to encode redundant cues, such as relations between pieces, into the retrieval structure, in particular with presentation times of 50 s or 60 s for the entire position. Note finally that the retrieval structure used with SF and DD in the digit-span task allows them to remember sequences of digits that are essentially random. That SF and DD are able to reliably and rapidly recode random items into meaningful chunks, while chess masters are not, seems to point to a key difference between the cognitive processes and the task environment of the digit-span and chess experts. Ericsson and Kintsch suggest that the poor performance with chess random positions is accounted for by the difficulty of encoding them into "new distinct structures" in LTM.[1] This explanation seems rather <u>ad hoc</u>, given their definition of the chess retrieval structure and their claim that recall of random positions strongly supports the hypothesis of retrieval structure.

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[1] Actually, it should be easier to encode them into new distinct structures in LTM, because random positions differ radically from the positions learnt by chess players through experience and, therefore, should suffer less mutual interference.

2.2 Mental Manipulation and Updating of the Board

Ericsson and Kintsch (1995) propose that the retrieval structure hypothesis offers an explanation for chess masters' ability to play blindfold games, without external perceptual support, at a level close to their normal skill. First, a factual correction is necessary. Contrary to Ericsson and Kintsch's (1995) claim that most masters are able to play blindfold chess at a level close their level in normal chess, blindfold chess games are characterized by many more blunders than normal games. No formal study has established this assertion, but there is a good agreement among chess experts that the quality of play in the two situations differs radically (see Holding, 1985; Karpov, 1995). This suggests stronger limits in players' ability to represent a position when blindfolded than implied by Ericsson and Kintsch (1995).

The difficulty of playing blindfold chess is illustrated by experimental evidence (Saariluoma, 1991). Saariluoma showed that masters, after having listened to a game dictated at a rate of one half-move (move for White <u>or</u> Black) every 2 s, could recall, after 30 half-moves, more than 90% of the position when the moves were taken from an actual game or when the moves where random, but legal. However, when the game consisted in (possibly) illegal moves, the recall dropped to only around 20%, which was barely better than weak players' recall. Within the framework of the chunking theory (Chase & Simon, 1973), Saariluoma's explanation (1981) was that random legal games drift only slowly into chaotic positions where few chunks can be recognized, while random illegal games move more rapidly into such positions. It is unclear what explanation the LT-WM theory offers for these results, in particular for the differential recall of random legal and random illegal games, because in both cases, playing a move produces changes on the board that can be equally well encoded into the retrieval structure. It is also unclear how the LT-WM theory could incorporate Saariluoma's explanation based on chunking without drastically reducing the role played by the retrieval structure in chess players' memory.

2.3 Rapid Presentation Time

It is known since De Groot (De Groot, 1946; De Groot, 1978) that strong players can recall a game position almost perfectly with a presentation time of 5 s and still get high percentages of recall with presentation times as low as 2 s (for additional data on very short presentation times, see Gobet & Simon, 1995). If the retrieval structure explanation is correct, chess would differ from the other tasks reviewed by Ericsson and Kintsch (1995) in an important way. With all other domains of expertise discussed by Ericsson, the presentation time per unit of information (e.g., one digit or one menu item) is at least 1 s, and experts have therefore at least 1 s to encode each unit. In chess, where masters can recall perfectly a position with all the 32 pieces with a presentation time of 5 s, we have to assume that individual units of information (in the case of chess, pieces) are encoded into the retrieval structure very fast, in the order of about 160 ms (5 s divided by 32).[2] Ericsson and Kintsch do not discuss these differences in encoding times across domains or how such rapid encoding is possible in the case of chess.

Even harder to explain within the LT-WM framework are Ellis's (1973) results. Ellis presented for 150 ms miniature chess boards (4 x 4 squares), using only common patterns of white pieces (white pieces on the first 4 rows of a normal chess board, left or right side). Ellis found that his stronger subjects (good amateurs, but below expert level) had a high recall performance (on average, 6.7 pieces out of 8). As the presentation time is clearly too short to encode retrieval cues, some direct access to LTM is necessary. Such access is not specified by the LT-WM theory.

2.4 Number of Pieces Presented

The LT-WM theory predicts that, with a constant time of presentation, subjects should show a better percentage recall with positions containing few pieces than with positions containing many pieces, because more time can be spent per piece to store redundant retrieval cues. At variance with this prediction, Chase and Simon (1973) found that their subjects (with the exception of the beginner) recalled a higher percentage of pieces with middle game positions (on average, 25 pieces) than with endgame positions, which contained few pieces (on average, 13 pieces). Their strongest subject, a master, recalled about 8 pieces in endgame positions, which rules out the hypothesis of a ceiling effect. This result has been replicated by Saariluoma (1984, exp. 3). It is unclear how the LT-WM theory accounts for this result: few pieces need to be encoded into the retrieval structure, and these pieces in general share semantic relations, as they are taken from master games.

2.5 Piece Grouping during Presentation

Charness (1974), as well as Frey and Adesman (1976), has shown that pieces presented at a rapid rate (about 2 s per piece) are better retained when they are presented by chunks similar to the ones identified by Chase and Simon (1973a) than when they are presented by columns or randomly; this result is valid for both verbal and visual presentation. Saariluoma (1989) found a similar result between an ordered reading (White pieces are dictated first, starting from awns, and then from King to Knight in decreasing chess value) and a random-order reading. According to the LT-WM framework, the presence of a powerful retrieval structure should allow experts to independently store units of information regardless of the type of grouping (by chunks, by columns, or in scrambled order) during presentation. The results reported above

[2] This assumes a serial encoding within the retrieval structure. This seems in agreement with Ericsson and Kintsch, who state that experts use retrieval structures similar to that of DD and do not make any mention of parallel encoding.

show that chess experts do not have this ability and, therefore, directly contradict one important prediction of the LT-WM theory (Ericsson & Kintsch, p. 238).

2.6 Effect of Board Modification

The hypothesis of a 64-square retrieval structure predicts that modifying a chess position spatially should not impair recall, because each "square" in the retrieval structure offers the same potential for encoding retrieval cues. However, it has been shown recently that slight spatial modifications of positions have an impact on recall. Saariluoma (1994) distorted positions by swapping two of their quadrants by translation and found that the recall of the translated pieces was dramatically reduced in comparison with that of unmoved pieces. Gobet and Simon (in press-c) modified positions according to various mirror-image reflections (for example, White and Black, or left and right, are swapped). They found that recall was slightly, but reliably, affected by such distortions, particularly when positions were constructed using a reflection about the vertical axis (swapping of the left and right sides of the board). The mirror-image results are particularly difficult for the LT-WM theory to explain: since the semantic relations between pieces are not destroyed by the manipulation, the opportunities to add redundancies within the retrieval structure are still present in the modified positions.

2.7 Multiple board recall

As predicted by the LT-WM theory, interfering material affects the recall of chess positions only minimally (Charness, 1976; Frey and Adesman, 1976). In the same line of research, Cooke, Atlas, Lane, and Berger (1993), as well as Gobet and Simon (in press-b), showed that players could recall several boards presented briefly (5 or 8 s each), although the percentage of correct pieces per board decreased as a function of the number of boards attempted. In addition, subjects seemed to have real difficulties with four and five boards. These limits with large numbers of boards are real and seem difficult to overcome even with practice. For example, Gobet and Simon (in press-b) describe the development of a subject trying to increase his performance in the multiple board experiment by using a mnemonic technique to help him distinguish and store the boards. In the course of his 150-session practice, the subject attempted to recall as many as 10 boards a few times but showed a plateau at around 8 boards. This plateau can perhaps be explained by the shorter time, in comparison with DD's, allowed to Gobet and Simon's subject for encoding units of information.

2.8 Problem Solving

In his protocol analysis of the find-a-move task, De Groot (1946/1978) discovered the phenomenon of "progressive deepening," which relates to the question of rapid encoding into LTM. When thinking about which move to play in a position, players, whatever their levels, tend to visit the same nodes of the search tree several times. Interestingly, when they want to reinvestigate a node, players do not access its internal representation directly, but access it by generating (in the mind's eye) the moves leading to it, starting from the stimulus position. De Groot and Gobet (in press) suggest that this is due both to limits in STM and to players' attempting to transfer knowledge gained at some part of the tree search to a different part. Within the framework of the LT-WM theory, which proposes that encoding a position (node) into LT-WM is fast and accurate, it is unclear why chess players should use progressive deepening. It would be easier for them to access the node they are interested in directly, without going through all the intermediary states. This would be sufficient for transferring information to important nodes in the tree search.

3. RETRIEVAL STRUCTURES AND TEMPLATES

As discussed above, the empirical data on chess skilled memory contradict most of the predictions of the LT-WM theory, mainly because the proposed retrieval structure is too powerful. Since Ericsson and Kintsch (1995) claim that data from chess research provide some of the most compelling evidence for LT-WM, this suggests serious limitations in the generality of their theory.

While the LT-WM theory may account for some of the data by assuming that interference occurs between the retrieval cues (e.g., the multiple board experiment and the progressive deepening phenomenon) or by specifying explicit mechanisms to access information in LTM, such as chunk recognition, the data on the recall of random games and positions, of endgame positions, of positions presented with various piece groupings and of positions modified by translation or mirror-image are definitely at variance with the hypothesis of a 64-square retrieval structure. Therefore, although the interference and multiple board experiments suggest that the general message of Ericsson and Kintsch—LTM encoding is faster than was supposed in earlier theories—is valid, it appears that chess masters use mechanisms different from that postulated by Ericsson and Kintsch (1995).

Why does the LT-WM theory, which convincingly explains mnemonists' behavior, have so many difficulties with data from expert chess memory? It is not because chess is a idiosyncratic task removed from common human cognition: the main features of chess expertise (selective search, memory for meaningful material in the domain of expertise, importance of pattern recognition) are generalizable to quite a few other domains (Charness, 1992). Rather, these difficulties may come from generalizing inappropriately theoretical constructs that are specific to domains where explicit mnemonic strategies play an important role. More specifically, the LT-WM approach postulates a generic retrieval structure (cf. Figures 2 and 4 of Ericsson & Kintsch, 1995) that does not depend on the specifics of the material presented (assuming that this material belongs to the domain of expertise). This structure permits encoding of information through retrieval cues even in the absence of integration through schemata already stored in LTM.

A comparison of the LT-WM theory and the template theory (Gobet & Simon, in press-b) will clarify what are the main theoretical weaknesses, in semantically rich domains, of the type of general-purpose retrieval structures proposed by Ericsson and Kintsch. The template theory, like the chunking theory (Chase & Simon, 1973) of which it is a revision, proposes that expertise is due to: (a) a large database of chunks, indexed by a discrimination net; (b) a large semantic memory, including both schemas and productions; and (c) associations between the (perceptual) chunks and the semantic memory, as well as associations within semantic memory. In addition, the theory proposes that some chunks that recur often during practice and study evolve into more complex data structures (templates), which allow information to be rapidly encoded into slots. For example, in a given class of position, a slot may be created for a square that plays an important role and that can be occupied by different types of pieces or be empty at different times. Templates offer both core information that cannot be changed (as with the chunks of the chunking theory) and slots allowing rapid update of information. The theory proposes that different templates will be retrieved for different classes of positions and that, because of their construction based on the recurrence of certain patterns of pieces, templates are unlikely to be recognized in random positions, and, to a lesser extent, in endgames, where players are less likely than in middle games to meet a given pattern often. I have shown elsewhere (Gobet, 1995) that the template theory accounts for most empirical data from chess memory research.

While the template theory shares many points with the LT-WM theory, in particular the assumption that experts are able to encode material into LTM rapidly and that this ability is limited to their domain of expertise, there are two basic differences: (a) Templates are specific to a class of stimuli and can be used only in cases where they have been accessed through perceptual cues, while retrieval structures are generic within the domain of expertise; (b) Template slots are created only for certain aspects of the stimuli (in chess, certain squares or pieces, depending of the class of positions), while the LT-WM theory assumes that the retrieval cues of the retrieval structures apply equally to all stimuli (the 64 "squares" of the chess retrieval structure are usable for any type of position). These two differences explain why one theory accounts successfully for most of the results reviewed here, and why the other fails. In particular, three sets of results follow directly from the template theory: first, the necessity of accessing chunks and templates in LTM through recognition explains that recall is more difficult with random positions, distorted positions, positions presented with non-natural grouping of pieces, and with endgame positions (there are fewer opportunities to create chunks for the latter positions, as they occur less often); second, rapid access by recognition through the discrimination net accounts for the high performance with short presentation times; and third, strong players can recall several boards presented rapidly because they can use one template per position if the positions are typical enough.[3]

Ericsson and Kintsch (1995) explicitly propose that digit-span, menu order, mental abacus, mental multiplication, and chess experts use a generic retrieval structure. The application of their theory to medical experts is short and rather unspecific on this point. Finally, their treatment of text comprehension does not mention the presence of a general-purpose retrieval structure. Rather, retrieval structures specific to the text being read are generated case by case, based on the several levels of discourse (surface features, propositions, macropropositions, semantic relations, rhetorical relations; Ericsson & Kintsch, 1995, p. 230). Although it is beyond the scope of this paper to review the evidence supporting retrieval structures in these domains, a few theoretical comments may be to the point.

It seems to me that what Ericsson and Kintsch refer to as "retrieval structures" consist of (at least) two different sets of entities. First, there are the generic retrieval structures used in the digit-span task, the restaurant menu task, and, for that matter, in most mnemonics such as the method of loci. In these tasks, experts use arbitrary structures, developed with the deliberate goal of improving their memory. Tasks like abacus mental calculation and mental calculation may also fit into this category, with the qualification that the retrieval structures are not arbitrary but are shaped by the demands of the tasks (e.g., the necessity of computing intermediary products) and with the complication that the encoding into LTM does not seem to allow a retrieval as easy as in the previous tasks (cf. the moderate to poor incidental recall), perhaps because there is a deliberate intention to encode cues that are useful only for a limited amount of time.

Second, there are the specific retrieval structures (templates), which can be used only when cues in the environment signal their appropriateness, and whose usefulness cannot be anticipated beforehand. Tasks like chess, medical diagnosis, and text comprehension seem to fit into this category. The difference between the two categories is by no means trivial: within the template framework, retrieval structures are included in LTM schemas, while Figure 4 of Ericsson and Kintsch makes it clear that their retrieval structures are separate from LTM schemas.

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[3] The template theory assumes that visual STM is limited to about four items (cf. Zhang & Simon, 1985), which accounts for masters' difficulty in remembering more than four boards.

The concept of a retrieval structure, in the strict sense of a generic structure, does offer a theoretically plausible explanation in domains where memory for order is important, where there is a conscious effort to both construct and use a memory structure under strategic control, and where the input is encoded serially. It does not fit with the empirical data in the domain of chess, and, according to my reading of Ericsson and Kintsch's paper, it does not fit with their descriptions of medical expertise and text comprehension. Establishing what categories of experts use such generic retrieval structures is an empirical question, although cursive examination of the task environments in which experts operate indicate that encoding often does not occur into an abstract, generic structure but helps integrate information into semantic networks already present in LTM.

Within the EPAM framework (Feigenbaum & Simon, 1984), two computer models have recently have been developed, which illustrate the classification I have proposed. The first model simulates DD's expert memory in the digit-span (Richman, Staszewski & Simon, 1995), the second simulates chess expert memory (Gobet, Richman, & Simon, in preparation). While the basic mechanisms of these models are the same, the requirements of the task environment and the strategies used by the experts in the respective domains lead to memory structures (generic retrieval structures or templates) that offer quite different psychological properties.

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