Review of Psychology
1995, Vol. 2, No. 1-2, 13-21

UDK 159.9

Components of expertise: looking for SEEK in sorting

HANS GRUBER and ALBERT ZIEGLER

In Chase and Simon's (1973b) pattern recognition theory, quantitative differences in knowledge (size and number of chunks) were considered to determine skill differences between chess experts and novices. In addition, Holding's (1985) SEEK (Search, EvaluatE, and Know) model also included differences in search and evaluation. The present study dealt simultaneously with all three components of the SEEK model. Fifty-three chess players of five different levels of expertise sorted two sets of 30 chess positions according to their own criteria. Written descriptions of the sorting criteria used were analysed. The dynamic aspects arising were captured as well as evaluative statements, and chess knowledge. With increasing level of expertise, an increase in relevance of all three components was shown.

Two Models of Expertise

Chessmasters are often regarded as people who have a magic touch. This notion is most probably inspired by the spectacular performances èthat chessmasters have demonstrated over and over again: Masters play against fifty or more opponents simultaneously, they are able to play blindfold chess, they show a phenomenal memory for the moves of previous games, and they have exceptional combinative power. It seems, on the face of it, that chessmasters are extraordinarily gifted individuals endowed with supernatural aptitudes. It is not surprising that these skills have attracted the attention of psychologists who have sought to unearth the factors that underlie chess talent in their laboratories. When first viewed, the results of such investigations into the basis of chess skill were rather disappointing (e.g., Djakow, Petrowski, & Rudik, 1927). The world's best players were not above average in memory capacity, attention, or concentration.

The seeming independence of chess mastery from general measures, such as intelligence tests, caused a break in psychological chess research. De Groot's pioneering work on chessmasters (De Groot, 1946, 1956, 1965, 1966, 1978) may be considered to have laid the groundwork for a new stream of research: research on expertise. Here the focus is placed on domain-specific features, especially knowledge. De Groot (1965) sought to distinguish between chess players of different levels of skill. The world's best players were compared with good club players. De Groot was thus able to control the influence of knowledge on complex performances. Using the thinking-aloud technique (cf. Ericsson & Simon, 1993), De Groot asked his subjects to choose a move in a presented chess position, putting into words all thoughts that occurred to them. The results were surprising and of great importance for the advancement of psychological research on expertise. The observed skill groups did not differ in most respects (depth of search, number of considered first moves, "progressive deepening" strategy in search). Since all subjects took about the same time to decide on a move, none of the quantitative measures distinguished grandmasters from weaker players. The only striking difference was that the grandmasters invariably explored strong moves, whereas the other players almost never did. In most cases, the grandmasters immediately chose the best move. De Groot concluded that the differences between players of different skills are based on processes that occur within the first few seconds of viewing a new position. A task involving perceptual and short-term memory processes should reveal differences in skill. De Groot thus presented his subjects with chess positions for a few seconds and asked them to reconstruct the positions on another chess board. This memory task did indeed distinguish between chess players of different levels of skill. Chase and Simon (1973a, 1973b) extended these findings and proposed a

Hans Gruber, University of Munich, Institute for Educational Psychology, Leopoldstr. 13, D-80802 Munich, Germany; Albert Ziegler, University of Munich, Institute for Educational Psychology, Leopoldstr. 13, D-80802 Munich, Germany (Correspondence concerning this article should be sent to both addresses).

We are grateful for the valuable comments of John Beasley, Ken J. Gilhooly, Joachim Hoffmann, and John Rice.

pattern-recognition theory based on Miller's (1956) chunking concept. The experts' superiority in the recall of chess positions appears to result from the specific perceptual structures that the experts hold in memory. This can be explained by their ability to perceive familiar patterns of pieces and to structure the positions of these pieces very quickly into a couple of chunks.

To identify the number of chunks, Chase & Simon (1973a, 1973b) used the two-seconds criterion: Whenever, in the course of reconstructing the pieces, a player paused for more than two seconds, it was assumed that the previous chunk had been completed and a new one would now be retrieved. Most chunks detected in this way consisted of three or four chess pieces.

To explain the experts' superior performance in the task of choosing moves, Chase and Simon started from the assumption that the chunks are combined with standard move proposals. Several chunks indicating the same move give some degree of certainty that the move is a good move. However, this chunking theory, with its emphasis on short-term memory processes, was called into question by some empirical counter-evidence (Charness, 1976; Frey & Adesman, 1976). Notably, recall performance was neither impaired by presentation of distractor tasks nor by increasing memory load when two positions had to be remembered simultaneously. These findings suggest that chess information is directly fixed in a long-term store.

On the basis of this evidence search processes and evaluation were considered to play a more important role in problem solving. Holding (1979, 1985, 1989, 1992a; Holding & Reynolds, 1982) returned to the idea that the search and evaluation components play a preeminent role in chess expertise. In his SEEK (Search, EvaluatE, and Know) model, Holding (1985) stated that choosing between alternative moves is the basic process in chess skill. The expert uses his knowledge to guide his search and to evaluate chess positions accurately. Contrary to perception-recognition-association theory, Holding's SEEK theory emphasizes the role of forward search and of evaluating the search tree's nodes; knowledge only supports the search and evaluation functions.

However, Holding introduced the three components of SEEK not as psychological concepts but as measurable parameters of chess skill (cf. Gruber, 1994). So far, differences between expert and novice chess players have typically been determined by chess-game-specific tasks, for example, by the capability of planning ahead. Such findings provide information about quantitative differences of playing performance between chess players of different levels of skill. Looked at more closely, such results are not really convincing: Is it not trivial to discover that more skilled chess players as a rule have more effective chess knowledge, can make more reliable evaluations of chess positions, and are able to plan ahead more effectively? Therefore, a central concern is research that helps us to establish the psychological dimensions of chess skill in order to identify the relevant psychological processes.

The approach on which the present study is based attempts to scrutinize directly the three components of the SEEK model in terms of psychological concepts. More specifically, we start from the assumption that the three components should be traceable in the expert's knowledge base. Evidence establishing the presence of search and evaluation within the knowledge base might enable us better to explain chess skill and why expert players excel. The standard task for the study of knowledge representation is the recall task. However, we consider the recall task as inappropriate for our purpose, because it sheds light mainly on the quantitative aspects of knowledge and disregards the qualitative ones. We would argue that the recall task is not a suitable instrument for study of the organization of knowledge (Gold & Opwis, 1992).

An alternative would appear to be sorting tasks in which the basic procedure is the subjects' sorting of cards into piles by their own criteria. So we were looking for SEEK in sorting. Categorization experiments have repeatedly been used in expertise research to good purpose (Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Rees, 1982; Reitman, 1991; Schiano, Cooper, Glaser, & Zhang, 1989; Schneider, Gruber, Gold, & Opwis, 1993; Williamson & McGuinness, 1990). They revealed qualitative differences in the categories of knowledge formed by subjects of differing levels of expertise.

Thus, for example, novices categorise physics problems by surface structure. This is in contrast to experts who group problems by the underlying physics laws applicable to them, that is, by deep structure. The similarity categories (sorting problems into groups based on similarities of solutions) provide information about the qualitative-structural aspects of the representations of a chess position.

Hypotheses

Knowledge

Complexity of sorting labels. Miller (1956) introduced the concept of chunking denoting the process of organizing single items into greater groups. According to Chase & Simon (1973a, 1973b), chunking processes are most important for explaining expertise in chess. Expert chess players possess a large store of well-organized chess patterns in their knowledge base, so that expert chess players' labels will presumably comprise more complex configurations.

Hypothesis 1a: The novices' similarity categories (labels categorizing the sorting into piles) include only single chess pieces or single groups of chess pieces ("Complexity 1"). In contrast, the experts' labels include configural representations, that is, several groups of pieces or even the complete board position ("Complexity 2"). Complexity is expected to increase with increasing skill level.

Degree of specification of knowledge. The chunking theory regards experts' and novices' knowledge as in principle the same, differing only in the size of the knowledge base and in the absolute number of chunks present in it. Nevertheless, qualitative differences in the knowledge base are assumed to be important factors that can explain chess expertise (Freyhof, Gruber, & Ziegler, 1992). Experts select, process, and store different parts of the presented information from novices. Novices and casual players have great difficulty in matching already formed position representations with the information presented by a new position. Good players, for example, appear not to perceive irrelevant information (e.g., visual similarity to chessgame external features) in their representations of chess positions. During the sorting task in our experiment, one element from the representation of a chess position is selected as being similar to an element from the representation of another chess position with which the first one is being compared (cf. Saariluoma, 1994). It is assumed that expert players use knowledge highly specific to chess, whereas weak players apply general heuristics which can be employed independently from the presented position. The analysis category involved is "position unrelated structure".

Hypothesis 1b: It is expected that novices and casual players will more often fall into the "position unrelated structure" analysis category than groups of club players.

Search

A meaningful feature of expertise is that experts not only perceive relevant information but also transform it so that it becomes useful for their own purposes. It is unlikely that an expert's representation of a chess position is a purely visual reproduction. A good player's representation presumably contains dynamic ideas about the future course of the game and is therefore largely influenced by search processes. Search processes deal with the dynamics of the game, with strategic planning, and with tactical manoeuvres. The analysis category referred to is "search (dynamic aspects)".

Hypothesis 2: Stronger players are expected to fall more often into this analysis category than weaker players. Search and dynamic aspects are relevant for all club players, but not for less skilled players such as casual players and novices. Thus it is expected that casual players and novices will not fall into the "search (dynamic aspects)" analysis category.

Evaluation

It is assumed that an expert's knowledge is more elaborated than a novice's. Evaluation occurring as an automatically activated part of perception is a highly characteristic feature of elaboration. The analysis category referred to is "evaluation".

Hypothesis 3: Masters are usually expected to fall into the "evaluation" analysis category; in this they differ most clearly from other groups.

METHOD

Participants

Comparing participants of several distinguished performance levels allows for more detailed analyses of the specific processing procedures (cf. Hatano, Amaiwa, & Shimizu, 1987). For empirical reasons it is important that the samples are sufficiently large, which is particularly difficult because of the scarcity of highly skilled players, namely chess masters. Our samples satisfied both requirements sufficiently; the sample of masters is one of the most expert ones ever studied in psychological research.

We not only compared experts with novices (as is the common practice), but we also set up five groups of participants comprising different levels of chess skill. (1) Novices ($n=10$) have at best an elementary knowledge of chess; they are able to distinguish between the different chess pieces and the pieces' different moves. (2) Casual players ($n=15$) play chess about once or twice a month. (3) Class C players[1] ($n=8$) are relatively poor experts (Elo rating[2] about 1650). They constitute

[1] The group labels used are not the German classification but an analogue of the one given by Holding (1985), p. 11.

[2] A reliable and empirically validated method is available to assess chess playing strength. Beside the international rating system (ELO system) there exist some older, largely compatible national rating systems. The ELO system is described in Elo (1978).

the largest group of organized players and differ from casual players principally in that they play regularly in tournaments. (4) Candidate masters (n=9) are semi-professional players with an Elo rating of about 2100. (5) International Masters and Grandmasters (n=11) hold titles that are awarded by the World Chess Federation (FIDE). The best player taking part in our study was a British International Grandmaster who was fourth on the world ranking list at the time. The average Elo rating in this group was about 2400. Control variables were assessed on the basis of a biographical questionnaire. The five groups did not differ significantly in respects of age (M=29.4 yrs; SD=10.1 yrs; $F(4,48)=2.06$, *ns*). The same holds for education. Nearly all the players had reached university level. Pairwise median tests yielded no significant differences, with the exception of the novices who had a higher level of education than class C players. Not even the length of chess experience was an appropriate group differentiation variable, disregarding the novices who by definition did not have such experience. The other four groups did not differ significantly ($F(3,33)=2.66$, *ns*). Even the casual players had on average played chess for over 10 years. The only biographical distinguishing variable was the intensity of actual chess playing, measured by the number of hours played per week in the last three months ($F(4,42)=34.88$, $p<.001$). Each pairwise group comparison was significant at the 5 per cent level, with the exceptions of the comparisons of novices against casual players and of class C players against candidate masters. Novices and casual players play less than 1 hour a week, class C players and candidate masters play between 1 and 10 hours a week, masters play more than 10 hours a week.

Of course, the three groups of club players differed significantly in respect of their actual ($F(2,20)=77.41$, $p<.001$) and their highest past chess rating ($F(2,19)=66.87, p<.001$).

Table 1

Group means, standard deviations of actual and best past Elo rating

Group	Actual rating		Best past rating	
	M	*SD*	*M*	*SD*
Clas C players	1642.3	113.6	1682.7	187.3
Candidate masters	2113.8	113.7	2168.0	67.3
Masters	2407.3	117.6	2445.1	97.7

Materials

One hundred and twenty chess diagrams were chosen from chess periodicals published from the 1960s to the 1980s. The diagrams showed positions after Black's twentieth move from games played by skilled players. This guaranteed that the chess positions were plausible for all participants, including the masters. No famous games were selected, nor were games which could be completed shortly after the diagrammed position: There were no positions which included a tactical combination. Sixty diagrams weighted according to the openings were chosen out of the pool of 120 diagrams. The diagrams were printed on post-card size sheets of paper. Then two sets of 30 diagrams were composed, each of which was numbered on the reverse side. The order of presentation was identical for all participants.

A pretest showed that the order of presentation of the two sets was irrelevant. However, subjects were more comfortable working with two sets containing 30 diagrams each than with three sets containing 20 diagrams each. It does not matter whether 20 or 30 diagrams have to be sorted, but motivation and engagement decrease rapidly if the same task has to be completed three times instead of twice.

Procedure

The sorting task required that participants sort into piles two sets of 30 chess diagrams by their own criteria. As neither number nor content of the similarity categories was prescribed, and no time limit was set, participants were able to elaborate deeply and to advance to their maximal processing depth (cf. Craik & Jacoby, 1975; Craik & Lockhart, 1972).

The participants were sent the test material by post together with written instructions. They were asked first to answer a biographical questionnaire placed in an envelope marked "A". On completing the questionnaire, participants were asked to continue with envelope "B" which contained 30 diagrams. The instruction specified that participants should sort the diagrams by their own criteria. Neither the number of piles nor the size of the piles was prescribed, but piles were not allowed to overlap. The participants then wrote down the numbers of the diagrams and the corresponding pile numbers. Then they had to describe verbally the principles of classification they had used in the sorting, thus supplying a kind of label for each similarity category. The same procedure was repeated with thirty more diagrams from envelope "C".

It was suggested to the participants that they spend about 20 minutes sorting the diagrams. Twenty minutes appeared suitable from pretests. All participants were able to sort within 20 minutes without difficulty. The pretests showed that if any, only the masters felt the limit to be restrictive. Therefore, any such error would lead only to an underestimation of the differences between the participant groups. Any error occurring as a result of this time restriction is therefore a conservative one.

Data Analysis

Prior to the experiment, we held discussions with chess experts not participating in the study, undertook intensive study of the literature, and developed several theory-driven categories of analysis that will be presented together with the hypotheses.

Three raters independently classified all the labels that participants gave to their groupings according to the analysis categories described above (cf. Appendix for examples of each analysis category). Labels could be attached to several analysis categories. The three ratings for each label were compared and differences discussed. Differences occurred only five times. In these cases an expert's opinion was taken in addition.

RESULTS AND DISCUSSION

In respect of size and number of piles, there were no significant differences between groups (a multivariate analysis of variance yielded neither significant main effects nor a significant interaction effect). Moreover, no significant differences between the two sets of 30 diagrams could be detected relative to the size and number of piles produced (e.g., the means of the number of piles for sets one and two were 5.49 and 5.34, respectively). Consequently, the sets were combined in further analyses.

For every participant, the percentage of piles that could be associated with the analysis categories was computed. Weighted fractions of each participant's terms were used in the subsequent computations (adding to more than 100% since one label can be attached to several categories).

Table 2 presents the group means of the percentage of piles that can be associated with each analysis category.

Results are presented in three steps, each addressing one of the components of the SEEK model (Holding, 1985). The first step looks at two different aspects of knowledge: the complexity of labelled configurations, and the degree of specification of knowledge involved. The second step captures the forward search aspects by discussing labels containing dynamic statements. In the third step, evaluative components of the labels are analysed.

Hypothesis 1a: Knowledge - Complexity of sorting labels. Novices produced sortings which mainly consisted of "Complexity 1" labels. In contrast, stronger players rarely used "Complexity 1" labels. However, pairwise group comparisons of "Complexity 1" using the one-tailed Mann-Whitney U-Test yielded significant differences only between masters and other groups. This resulted from the surprising fact that even novices and casual players sometimes generate "Complexity 2" labels.

Table 2

Group means of the percentage of piles falling into five analysis categories

	Analysis category				
Group	Compl	Comp2	Unrel.	Search	Eval.*
Novices	60.8	34.2	92.9	0.0	9.1
Casuals	48.1	52.2	78.1	13.0	15.7
Class C	56.8	42.4	31.2	19.5	20.7
Candidates	30.2	71.5	11.1	41.0	41.3
Masters	12.4	81.5	0.0	59.0	63.1

* Full names of the analysis categories: Complexity 1, Complexity 2, Position unrelated structure, Search (dynamic aspects), Evaluation.

However, these labels differ in content from those supplied by master players. An analysis of content showed that novices and casual players almost always refer to visual features while masters do not; masters prefer to use elaborate features. The fact that the frequency distribution of the "Complexity 2" labels is not linear, derives from the differences between masters and candidate masters on the one hand, and class C players on the other. The latter appear to have experienced a degree of qualitative expertisation (cf. Lesgold, 1984) without, however, being able to visualise board positions in the way masters do. In their labels, class C players refer less to visual aspects and more to elaborate ones, but do not appear to be able to relate such evaluations to board positions.

On the whole, the similarity criteria in the sortings supplied by the stronger players are distinguished by a more coherent sense of a positions chess content, and give a glimpse of the complexity of their knowledge units. This suggests that factors other than the vast number of chunks have to be taken into account in explaining the outstanding memory performance of expert chess players. One of the shortcomings of the chunking theory is the chunk-by-chunk model, that is, the assumption that the single chunks are unrelated to each other. We would argue that, in looking at chess positions, masters do not as a rule perceive the information presented in terms of single pieces or groups of pieces but as coherent overall patterns. In this sense, feats of chess memory by master players are not generated by "magical seven" separate chunks that are unrelated to each other but rather by coherent meaningful units (Egan & Schwartz, 1979; Lesgold, 1984; Williamson & McGuinness, 1990). So an important aspect to be considered is the internal structure of the knowledge base, which is highly organized in experts. This is confirmed by other evidence concerning unusual specific memory ability in respect of information presented shortly, for example, large lists of numbers (Ericsson, 1985; Ericsson & Polson, 1988; Kliegl, Smith, & Baltes, 1986; Staszewski, 1990).

Hypothesis 1b: Knowledge - Degree of specification of knowledge. The results show clearly that participants' labels within the analysis category "position unrelated structure" occur almost exclusively in novices' and casual players' sortings. Pairwise group comparisons using the one-tailed Mann-Whitney U-Test showed that each group of club players differed significantly from novices and from casual players. Novices did not differ significantly from casual players, nor did any group of club players differ significantly from another group of club players. Novices and casual players very often use a structure independent of chess specific contents. They relied on general memorizing strategies, and the information they used in sorting was not related to the information imparted by the actual chess positions (an interesting example presented by a novice is the one given above: "The position of the pieces was solitary, looking like a % symbol."). For club players, however, this type of information is irrelevant, and they seldom used it. Even weaker club players are able to integrate the chess positions shown in the diagrams into their knowledge base about chess positions, which is sufficient to enable a chess-specific organization of new information. Experts are thus able to show high-level "situated cognition" (Brown, Collins, & Duguid, 1989; Lave, 1988). The notion of larger, more flexible, and situation-specific knowledge units that masters possess (cf. Gold, Gruber, Opwis, & Schneider, 1990) suggests that the mental model approach (Johnson-Laird, 1983) might provide an appropriate representation and information processing model for experts.

Hypothesis 2: Search. The importance of the analysis category "search (dynamic aspects)" increases with skill level: There are clear differences between the highest and lowest skill levels. Differences exist within the middle range, too, but these are not as clear-cut as expected. Pairwise group comparisons using the one-tailed Mann-Whitney U-Test yielded significant differences between all groups other than pairs of neighbouring skill level. It is a plausible assumption that search involves a dynamic conception of the chess game, and is indicative of deeper processing. In other words, to predict the course of the game over the next few moves requires consideration of all the items of information displayed on the board. This makes it necessary to generate information that goes beyond perceiving and memorizing the given position. Search is an attempt to weight the information presented, emphasizing some parts and neglecting others. This suggests that an expert's perception of a chess position is an active process in the sense of changing the initial mental model of this position, which has been built up by the visual presentation. Weighting parts of the information allows for situationally adequate cognition. Thus, experts and novices perceive chess positions differently because of different search activities.

Hypothesis 3: Evaluation. Of the analysis categories used, "evaluation" is the category that is predominant among master players. Skills associated with evaluation emerge rather late in the evolution from novice to expert, but their importance then increases dramatically. The increase in the number of "evaluation" labels parallels the increase in the number of "search" labels. More than sixty per cent of the masters' category labels contained evaluations. This finding suggests deeper processing of chess information by the masters compared with all other players. Evaluation is combined with understanding the functional values of chess pieces and configurations. This supports the assumption that masters' knowledge chunks are of a different nature from novices'. For example, an expert's knowledge base seems to be organized in domain-specific hierarchies, in contrast to a novice's.

The depiction of the chess master given by the sorting task can be specified as follows: Chessmasters not only perceive stimuli, but process stimuli in order to produce new information, which can be used in a functional domain-specific manner. When combining chess pieces into meaningful clusters, they not only link the information with their knowledge but create new knowledge categories. Their thought processes are not dominated by a snapshot view of the chess board. Instead, masters concentrate on the sense of the anticipated moves, that is, on things that are not yet present on the board (cf. Hoffmann, 1990). Experts evaluate events on the board with regard to the quality of possible continuations of the game. Masters thus change their mental model of a chess position according to the results of evaluation processes, whereas novices usually pay attention only to visual features.

General Discussion.

From Novice to Expert. In recent years, a shift of paradigm has marked research on chess expertise. Theories that concentrated exclusively on the knowledge component appeared too narrow in scope. Holding (1992b) has furnished empirical evidence documenting an expert's superiority not only in knowledge but also in search behaviour and the ability to make additional evaluations. These are major components of Holding's (1985) SEEK model. The present study has been "looking for SEEK in sorting". A sorting task was used that yielded direct access to a chess player's knowledge representations of chess positions. Testing chess players of five different skill levels (from novice to International Grandmaster) made it possible to formulate a "developmental profile" of skill acquisition. Figure 1 shows the results of the search and the evaluation categories presented in Table 2 from this point of view as well as the position unrelated structure. Sorting the bars in Figure 1 by expertise groups allows a study of the characteristics of each skill level, thus providing a "developmental" view.

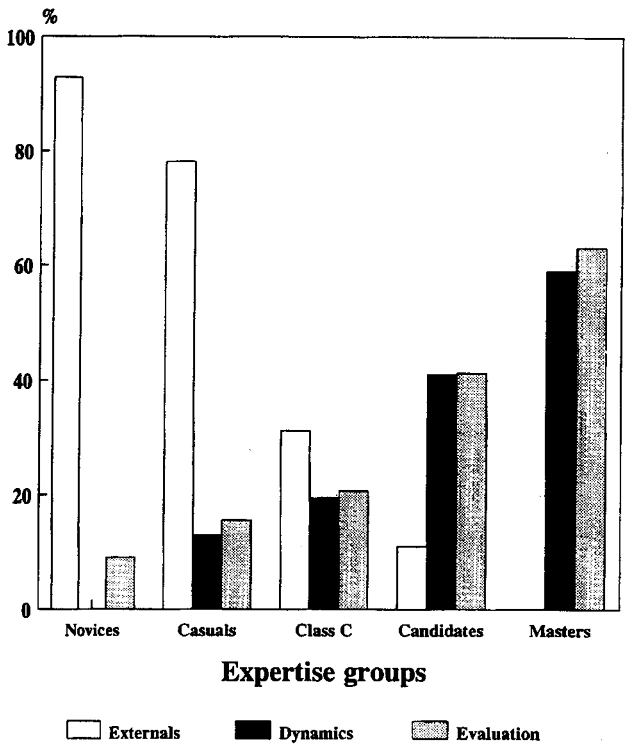

Figure 1. Expertise group profiles: Group means of the percentage of piles falling into "Position unrelated structure (externals)", "Search (dynamics)", and "Evaluation" categories, respectively.

Of course, such developmental profiles, which are yielded by cross-sectional studies cannot take the place of longitudinal studies. With caution, they can be interpreted as quasi-longitudinal. Master players have successfully traversed all the other skill levels (novice, casual player, class C player, candidate master). But this does not allow the inference that the patterns of knowledge that candidate masters, for example, currently possess exactly parallel those acquired by today's masters at the time that they themselves were candidate masters. If one considers how players grow towards master level, such concepts as exceptional talent should be kept in mind. Possibly, a master's development has contained different quality components from that of other players. Once one has made this qualification, the cross-sectional analysis of the five stages of expertise specified in our study can be interpreted as development. A clear increase in significance of the three components of the SEEK model with increasing skill can be observed (cf. Figure 1).

(1) The percentage of knowledge categories classified as "position unrelated structure" decreases with increasing skill levels. Almost all the sortings made by novices have a "position unrelated structure", which is rarely present in a club player's sortings.

(2) A dynamic view of the positions presented, expressed as search for move sequences, is observed more frequently for skilled players than for less skilled players.

(3) The significance of evaluations increases with skill level. Masters use evaluations significantly more often than other players as base criteria for the sorting task.

These results support the SEEK model. Expertise in chess appears to be due to an interactive collaboration of the components of knowledge, search, and evaluation. In this sense, we think that in "looking for SEEK in sorting" we have had some success.

REFERENCES

BROWN, J. S., COLLINS, A., & DUGUID, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18,* 32-42.

CHARNESS, N. (1976). Memory for chess positions: Resistance to interference. *Journal of Experimental Psychology, 2,* 641-653.

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

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

CHI, M. T. H., FELTOVICH, P. J., & GLASER, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121-152.

CHI, M. T. H., GLASER, R., & REES, E. (1982). Expertise in problem solving. In R. J. Sternberg

(Ed.), *Advances in the psychology of human intelligence* (Vol. 1, pp. 7-75). Hillsdale, NJ: Erlbaum.

CRAIK, F. I. M., & JACOBY, L. L. (1975). A process view of short-term retention. In F. Restle (Ed.), *Cognitive theory* (Vol. 1, pp. 173-192). Potomac: Erlbaum.

CRAIK, F. I. M., & LOCKHART, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671-684.

De GROOT, A. D. (1946). *Het denken van den schaker* [Thought and choice in chess]. Amsterdam: Noord Hollandsche.

De GROOT, A. D. (1956). Über das Denken der Schachspieler. [Thought and choice in chess]. *Rivista di Psicologia, 50,* 73-104.

De GROOT, A. D. (1965). *Thought and choice in chess.* The Hague: Mouton.

De GROOT, A. D. (1966). Perception and memory versus thought: Some old ideas and recent findings. In B. Kleinmuntz (Ed.), *Problem solving: Research, method and theory* (pp. 19-50). New York: Wiley.

De GROOT, A. D. (1978). *Thought and choice in chess* (2nd Ed.). The Hague: Mouton.

DJAKOW, I. N., PETROWSKI, N. W., & RUDIK, P. A. (1927). *Psychologie des Schachspiels.* [Chess psychology]. Berlin: de Gruyter.

EGAN, D. E., & SCHWARTZ, E. J. (1979). Chunking in recall of symbolic drawings. *Memory & Cognition, 7,* 149-158.

ELO, A. E. (1978). *The rating of chessplayers, past and present.* New York: Arco.

ERICSSON, K. A. (1985). Memory skill. *Canadian Journal of Psychology, 39,* 188-231.

ERICSSON, K. A., & Polson, P. G. (1988). An experimental analysis of the mechanisms of a memory skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 305-316.

ERICSSON, K. A., & SIMON, H. A. (1993). *Protocol analysis* (rev. ed.). Cambridge, MA: MIT Press/ Bradford.

FREY, P. W., & ADESMAN, P. (1976). Recall memory for visually presented chess positions. *Memory & Cognition, 4,* 541-547.

FREYHOF, H., GRUBER, H., & ZIEGLER, A. (1992). Expertise and hierarchical knowledge representation in chess. *Psychological Research, 54,* 32-37.

GOLD, A., GRUBER, H., OPWIS, K., & SCHNEIDER, W. (1990, September). *Zum Einfluss von Vorwissen, metakognitivem Wissen und strategischem Verhalten auf die Gedächtnisleistung: Vergleichende Analysen bei Schachexperten und -novizen.* [The influence of knowledge, metaknowledge, and strategic behavior on memory performance: A comparison between chess experts and chess novices]. Paper presented at the 37th congress of the "Deutsche Gesellschaft für Psychologie", Kiel/Germany.

GOLD, A., & OPWIS, K. (1992). Methoden zur empirischen Analyse von Chunks beim Reproduzieren von Schachstellungen [Methods for the empirical analysis of chunks in recalling chess positions]. *Sprache & Kognition, 11,* 1-13.

GRUBER, H. (1994). *Expertise. Modelle und empirische Untersuchungen* [Expertise. Models and empirical studies]. Opladen: Westdeutscher Verlag.

HATANO, G., AMAIWA, S., & SHIMIZU, K. (1987). Formation of a mental abacus for computation and its use as a memory device for digits: A developmental study. *Developmental Psychology, 23,* 832-838.

HOFFMANN, J. (1990). *Über die Integration von Wissen in die Verhaltenssteuerung* [On the integration of knowledge in the control of behaviour]. *Schweizerische Zeitschrift für Psychologie, 49,* 250-265.

HOLDING, D. H. (1979). The evaluation of chess positions. *Simulation & Games, 10,* 207-221.

HOLDING, D. H. (1985). *The psychology of chess skill.* Hillsdale, NJ: Erlbaum.

HOLDING, D. H. (1989). Evaluation factors in human tree search. *American Journal of Psychology, 102,* 103-108.

HOLDING, D. H. (1992a). Search process versus pattern structure in chess skill. In B. Burns (Ed.), *Percepts, concepts and categories: The representation and processing of information* (pp. 649-676). Amsterdam: North-Holland.

HOLDING, D. H. (1992b). Theories of chess skill. *Psychological Research, 54,* 10-16.

HOLDING, D. H., & Reynolds, R. I. (1982). Recall or evaluation of chess positions as determinants of chess skill. *Memory & Cognition, 10,* 237-242.

JOHNSON-LAIRD, P. N. (1983). *Mental models. Towards a cognitive science of language, inference, and consciousness.* Cambridge, MA: Harvard University Press.

KLIEGL, R., SMITH, J., & BALTES, P. B. (1986). Testing-the-limits, expertise, and memory in adulthood and old age. In F. Klix & H. Hagendorf (Eds.), *Human memory and cognitive capabilities:*

Mechanisms and performances (pp. 395-407). Amsterdam: North Holland.

LAVE, J. (1988). *Cognition in practice. Mind, mathematics and culture in everyday life.* Cambridge: Cambridge University Press.

LESGOLD, A. M. (1984). Acquiring expertise. In J. R. Anderson & M. Kosslyn (Eds.), *Tutorials in learning and memory* (pp. 31-60). San Francisco: Freeman.

MILLER, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63,* 81-96.

REITMAN, J. (1991). Techniques for representing expert knowledge. In K. A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp. 240-285). New York: Cambridge University Press.

SAARILUOMA, P. (1994). Apperception in chess players' long range planning. *European Journal of Cognitive Psychology, 6,* 1-22.

SCHIANO, D. J., COOPER, L. A., GLASER, R., & ZHANG, H. C. (1989). Highs are to lows as experts are to novices: Individual differences in the representation and solution of standardized figural analogies. *Human Performance, 2,* 225-248.

SCHNEIDER, W., GRUBER, H., GOLD, A., OPWIS, K. (1993). Chess expertise and memory for chess positions in children and adults. *Journal of Experimental Child Psychology, 56,* 328-349.

STASZEWSLI, J. J. (1990). Exceptional memory: The influence of practice and knowledge on the development of elaborative encoding strategies. In W. Schneider & F. E. Weinert (Eds.), *Interactions among aptitudes, strategies, and knowledge in cognitive performance* (pp. 252-285). New York: Springer.

WILLIAMSON, J., & McGUINNESS, C. (1990). The role of schemata in the comprehension of maps. In K. J. Gilhooly, M. T. G. Keane, R. H. Logie & G. Erdos (Eds.), *Lines of thinking: Reflections on the psychology of thought* (Vol. 2, pp. 29-40). Chichester: Wiley.

Accepted October 1995

APPENDIX

Examples of each analysis category

Category "Complexity 1"

Single pieces or single groups of pieces. Example: "White centered pawn on e4."

Category "Complexity 2"

Combinations of several groups of pieces, or the complete board position. Example: "Positions in which white can draw."

Category "Position unrelated structure"

Example: "The position of the pieces was solitary, looking like a % symbol."

Category "Search (dynamic aspects)"

Example: "The positions will probably change into tactical ones very soon."

Category "Evaluation"

Example: "Drawn positions with chances for both sides."