Memory processes among bridge players of differing expertise

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An experiment was conducted to study the mnemonic and perceptual abilities of contract-bridge players of differing ability levels. Four subjects (expert, life master, average player, and novice) were administered three tasks designed to explore the possible differences in performance between the players. A tournament-simulation task required subjects to play 10 hands, after which a surprise test was given for the cards in each hand of the 10 deals. A memory task required that subjects reconstruct a briefly presented stimulus containing four bridge hands of either structured or unstructured arrangement. The perception task required that the subjects reconstruct stimuli similar to those used in the memory task after brief glances at the stimulus. The results confirm the findings of research on chess players in that performance in the structured components of each task varied uniformly according to level of expertise but that performance in the unstructured component of each task showed little difference in level of expertise. It was argued that bridge players with "supranormal" memory are able to use their prior experience to configure and chunk information in more efficient ways than players of less expertise.

We have all been amazed at one time or another by an apparently normal individual who seems to possess remarkable abilities for recall and recognition. While most of us try to explain such uncommon feats by simply stating that the individual has a "great memory," this does little to help us understand how this individual is any different than the rest of us with mere "normal" human-memory capacities.

One approach to the problem of individual differences in cognitive functioning that has paid dividends in terms of understanding the root of these differences is the study of chess and Go players (Reitman, 1976) of varying ability levels. De Groot (1965, 1966) and Jongman (1968) were among the first researchers to investigate the problem-solving abilities of chess players. They studied the ability of subjects to reproduce middle and end-game positions after an exposure of only 5

to 10 seconds. They found that the ability of a subject to remember a chess position after brief exposure depends on the subject's level of chess expertise and the authenticity of the position.

That is, if chess players are presented with an actual middle or end-game position, grandmasters and masters can reproduce the positions almost without error. Below this level of expertise, the weaker the player the more errors are made. However, with random game positions, grandmasters, masters, and ordinary players all perform at the level of the weakest players. These results provide evidence that the grandmasters and masters do not have some extra-ordinary perceptual capability. Rather, they are able to recode the chess-piece configurations into fewer, larger chunks that can be more easily remembered and then decoded to reproduce the original configuration.

Simon and Barenfeld (1969) proposed an information-processing theoretical explanation of what occurs in human problem-solving during the initial attack on a problem. They showed how problem-solving involves the use of prior experience stored in the long-term memory to recode a complex stimulus into a smaller number of larger, familiar chunks. Using chess playing as an example in the explanation of their theory, they combined two computer programs (PERCEIVER for search and EPAM for recoding) and were able to account for the ability of chess grandmasters and masters to reproduce chess boards after brief exposure. Simon and Gilmartin (1973) developed and implemented the Simon and Barenfeld proposal that combines PERCEIVER and EPAM into an information-processing computer pro-gram model. They called their version MAPP. The authors com-pared the performance of MAPP with the performance of master chess players and found them to be very similar. Most important, they were able to estimate the number of familiar patterns that strong chess players hold in long-term memory. They estimated that mas-ters and grandmasters have a stored repertoire of between 10,000 and 100,000 patterns.

Chase and Simon (1973) did a comprehensive study designed to isolate and study the "chunks" that are perceived by chess players. While de Groot and Jongman were able only to hypothesize that chess masters encode information about a game position in chunks, Chase and Simon identified the chunk and defined its properties. They used two techniques in their study: a perception task requiring players to reconstruct a position while it remained in plain view behind a parti-tion, and a memory task, similar to de Groot's task, requiring players to remember a position after a brief exposure. Their results can be

briefly summarized as follows: they confirmed the de Groot and Jongman studies with respect to memory for structured and unstructured chess boards; they were able to identify the boundaries of the perceptual chunks; they found that superior performance of master players was due to both their ability to encode the board positions into larger chunks containing familiar configurations of chess pieces and a tendency for them to remember slightly more chunks; and the number of chunks retained in short-term memory after brief exposure to chess positions is within the 7 ± 2 span predicted by Miller (1956).

Because of the similarities between chess and bridge, many of the same questions regarding problem-solving and memorial abilities are also worthy of study within the context of contract bridge. One additional point that makes bridge even more interesting to study is that the working memory serves an intrinsically important role in the play of each bridge hand. That is, most good bridge players will actively seek to remember the cards played on previous tricks of the hand and by whom they were played. Before one decides to lead a king, it is imperative that he or she remember whether or not the ace of that suit has already been played.

Memory and problem-solving capabilities come together in bridge at the beginning of a hand when the player tries to deduce the cards held by the other players on the basis of the bidding and opening lead. For example, the declarer or defender can see only two hands in full view, his own and the dummy, and he must deduce, construct and remember the other hands on the basis of strength of bids, bidding conventions, and lead conventions. This process is called "card-reading" by Karpin (1973), and it often requires that several tricks of the hand be played before it is completed. Card-reading has two primary objectives: determining the distribution of the outstanding cards of each suit and drawing the correct inferences about the nature of an opponent's high-card holdings. Having the luxury of knowing all four hands enables the contract-bridge player to utilize his or her reasoning, logic, and experience under optimum conditions.

Bridge, even more than chess, involves the transfer of information from short-term memory (STM) to long-term memory, and the player who can process more information has a clear advantage. However, Miller (1956) has clearly established that human beings are limited-capacity information processors, and he argues that we can only retain 7 ± 2 chunks of information in our short-term memory at one time. We can, however, increase the amount of information processed by the STM by increasing the amount of information stored *within* each

chunk. Chase and Simon (1973) demonstrated that expert chess players operated in this fashion, and it is expected that excellent bridge players would show a similar increase in the amount of information stored within each chunk.

This study explored the problem-solving and mnemonic abilities of contract-bridge players by using many of the same variables and hypotheses studied by psychologists involved in chess research. There were three tasks, each designed to explore the possible differences in performance between bridge players of varying expertise (expert, life master, average player, and novice). A tournament-simulation task required subjects to play 10 actual hands and then reconstruct them after all had been played. The task was designed to study the card-reading techniques and memorial abilities of the players. A memory task similar to that used by de Groot (1965, 1966), Jongman (1968), and Chase and Simon (1973) required subjects to reconstruct structured and unstructured hands after a 20-sec exposure. This task was designed to discover whether the same relationship between level of expertise and "meaningfulness" of the position (de Groot, 1965, 1966; Jongman, 1968) found in chess players also holds true for bridge players. A perception task similar to that employed by Chase and Simon required subjects to replicate structured and unstructured hands. The subjects could view the display hands as long and as many times as they wanted, but when writing down the hand, they were unable to view the display hand. This task was designed to isolate, identify, and describe the perceptual chunks "used" by bridge players.

METHOD

Subjects

There were four subjects of varying bridge skill and experience (expert, life master, average player, and novice). Subjects were selected according to preestablished criteria for bridge level of expertise. An expert was determined by the following criteria: holding Registered Player Status (a player who receives remuneration for playing bridge), being yearly on the McKenny List of players who win the most masterpoints each year, and holding more than 2,000 lifetime masterpoints and having won at least one national championship. An average life master is one who has from 300 to 1,999 lifetime masterpoints, has won at least one regional championship, and has been playing tournament bridge for at least three years. An average player is one who has from 50 to 299 lifetime masterpoints, has won sectional, local, or side-game championships, and has been playing tournament bridge between 1½ and 3 years. A novice is a player who has between 0 and 49 lifetime masterpoints, has been playing bridge no longer than 1½ years, and may or may not have played tournament bridge.

Our expert subject (E) was a 36-year-old man who was a registered player, was on the McKenny List yearly, had won a national championship and had approximately 3,600 lifetime masterpoints. Our life-master subject (L) was a 29-year-old woman who had approximately 1,300 lifetime masterpoints, had won several regional championships, and had been playing tournament bridge for 8 years. Our average player (A) was a 27-year-old female who had approximately 65 lifetime masterpoints, had won several local and side-game championships, and had been playing tournament bridge for about 2 years (had played socially for 6 years). Our novice (N) was a 27-year-old woman who had been playing bridge for approximately 1½ years, had not played tournament bridge and therefore, had no lifetime masterpoints.

Tournament-simulation task

Apparatus

The materials used in this task consisted of 10 pre-dealt bridge hands with the cards in the East hand numbered 1–13 on the face. The suits were arranged in the following order: spades, hearts, clubs, and diamonds, and from highest to lowest ranking in each suit. The assistant playing the East hand was not a bridge player, and the cards in the East hands were numbered 1–13 so that the experimenter (LHB), who was playing the West hand, could hand signal the card to be played for each trick. The experimenter, a life master and tournament bridge player himself, provided the subject (South hand) with optimum and uniform defensive play on each hand. The hands were selected from written accounts of the 1956 World Bridge Championships. This dated and obscure source was chosen to insure that none of the hands would be recognized by the more expert players. The choice of hands was also constrained by the need to be challenging and to provide the declarer several interesting lines of play by which she or he could fulfill the contract.

Hand-reconstruction sheets consisting of the letters N S E & W in a diamond-shaped arrangement with the letters S H D C arranged under each were used. The subject was to write the correct cards under the appropriate suit letters for the appropriate hands.

Procedure

Subjects were initially given the following instructions: "This is a simulated matchpoint duplicate bridge game. You will be asked to play 10 interesting hands to the best of your ability. We will attempt to put up the best defense possible on each hand and you will be limited to a maximum time of 5 minutes per deal. My assistant is a non-bridge player and therefore will be following my hand signals as to what to play for each trick. Do you have any questions?"

From this point on the procedure was as follows: The duplicate board with Deal 1 contained within it was placed on the table. The experimenter laid out the dummy and provided the declarer (the subject) with any significant bidding that might influence the play of the hand. When the declarer and the assistant were ready, the experimenter made the best opening lead (which was the same on each hand for all subjects). Throughout the play of the hand the experimenter attempted to provide the best possible defense (minor variations in the line of play). The assistant was given hand signals as to which card

to play. When the declarer finished playing the hand the result was recorded. After the declarer was done with all 10 hands, he or she was then asked to reconstruct all 10 hands. This recall task came as a surprise to the subjects. The deal number, contract, and result (e.g., Deal 2, four hearts, contract made) were given to the subject to facilitate retrieval. The subject was instructed that he or she could designate any card below a 10 as an "X" but that A's, K's, Q's, J's, and 10s should be recorded. The subject could complete the reconstruction of deals in any order desired after being given the deal numbers, contracts and results. Upon task completion the subjects were asked the following questions about card-reading techniques: (1) Do you use card-reading techniques? (2) If you do, what is your specific card-reading style? (3) If not, do you know what card-reading is? (4) Have you attempted to card-read?

Memory task

Apparatus

The materials used in this task were as follows: a stop watch, hand-reconstruction sheets identical to the tournament simulation task, and 20 poster boards with a bridge deal fixed to each one. A new deck of cards was completely shuffled 20 times before dealing into 4 hands of 13 cards which were then glued to the pasteboard in a North, South, East, West Configuration. Ten of the deals, the Structured deals, were presented as they would be seen in a bridge column or book, the cards grouped according to hand, with each hand grouped by suit and with the cards arranged from highest to lowest rank within each suit. The poster thus had 4 hands, North, South, East and West, with four columns of cards in each (fewer in the case of void suits). The ten Unstructured deals were derived in a similar manner but were placed on the board in the same order in which they had been dealt. Each Unstructured deal was yoked to a Structured deal such that, for a given Structured deal, an Unstructured deal had the cards placed in the same number of columns in each hand with the same number of cards in each column. For example, if the North hand of a given Structured deal had 5 spades, 4 hearts, 3 diamonds, and 1 club, an Unstructured hand would have the first 5 cards dealt (irrespective of suit and rank) being placed in the first column, with the next 4 being placed in the second column, etc. See Figure 1 for an example of a Structured and Unstructured deal.

Procedure

Subjects were given the following instructions: "This second part of the study will also involve the reconstruction of hands. However, this time you will be presented bridge hands for a brief period of 20 seconds. When I say go, you will flip up the poster board in front of you and will be allowed to study it until I say stop. At that time you will put down the poster board and reconstruct the bridge hands as best you can. We are only interested in having you remember the distribution and high cards (A, K, Q, J, and 10) on each hand. Spot cards can be designated as Xs unless you want to represent them as numbers. Account for as much of all four bridge hands as possible. Are there any questions?"

Within the 20 deals the order of presentation of Structured and Unstructured deals was determined from a random number table with all subjects
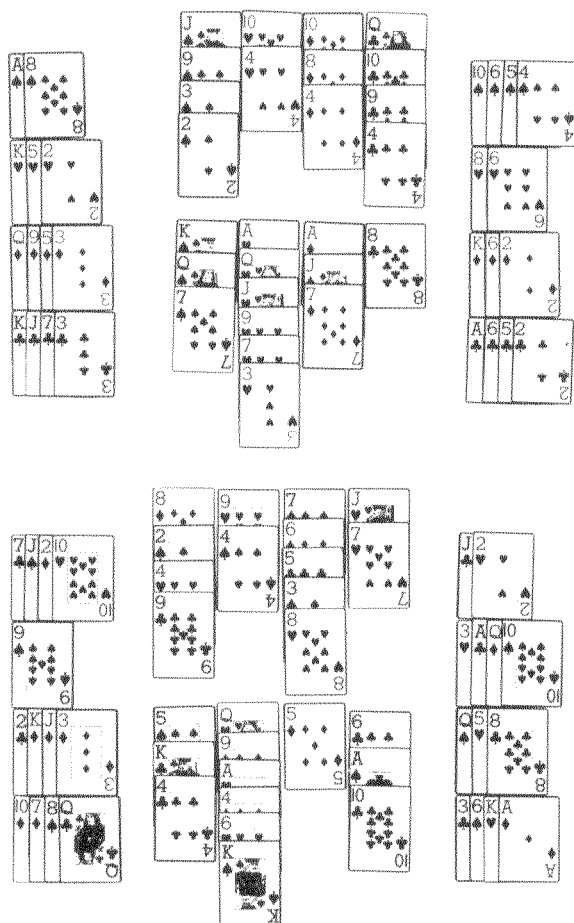
Figure 1. Example of a Structured (top) and Unstructured (bottom) deal used in the memory and perception tasks

receiving the same ordering of Structured and Unstructured deals. Upon completion of all 20 deals the subjects were asked about the technique they used to remember the deals.

Perception task

Apparatus

The following materials were used in this task: a stop watch, hand-reconstruction sheets, and 20 cardboard bridge deal presentation boards. These 20 deals were arrived at in the same manner as the memory task. Deals once again were presented in Structured and Unstructured formats with matching distributions.

Procedure

The subjects were given the following instructions: "This last task will involve the duplication of bridge hands. Once again you will be flipping the poster board up to view the deal and down when writing down the deal. However, this time you will be allowed to look at a bridge deal for as long as you want and as many times as you want. My assistant will be timing how long you look each time at the poster board. I will be recording what you write down after each look. Once again distribution and high-card points (A, K, Q, J, and 10) are most important. Spots can be designated as Xs or as themselves. Work as quickly and efficiently as possible. Are there any questions?"

Once again the Structured and Unstructured deals were presented in a random order. After completion of all the deals, subjects were questioned about the strategies they used in performing the duplication task.

RESULTS AND DISCUSSION

Tournament-simulation task

At the end of tournament simulation the subjects were given a surprise request to recall the hands from each deal and were given the deal number and the contract and results of the deal as a cue for recall. The data from this task are shown in Table 1. While E recalled 6

Table 1. Tournament-simulation task data

	Expert	Life master	Average player	Novice
Deals with perfect recall	6	3	0	0
Deals without recall	0	0	0	6
Hands without recall	0	0	6	24
Suits without recall	0	0	44	96
Card-reading	Yes, many years	Yes, many years	Just beginning	No, never
Number of deals played correctly	6	6	4	0
Spots recalled	41	53	8	5
Mean errors per deal[a]	1.1 (.55)	1.8 (.54)	13.6 (3.39)	31.6 (2.12)
Honor cards recalled correctly	197/200 98.5%	194/200 97.0%	131/200 65.5%	32/200 16.0%
Correct distributions	152/160 95.0%	148/160 92.5%	100/160 62.5%	19/160 11.8%
Suits given perfect recall	149/200 93.1%	141/200 88.1%	85/200 53.1%	16/200 10.0%

[a]Standard error is given in parentheses.

of the 10 deals perfectly and L recalled only 3 perfectly, the other indices of performance show these two subjects to be comparable and, as a group, to perform better than the two poorer players. The mean errors per deal, for example, are roughly equivalent for E and L, while increasing systematically for A and N where an error is defined as either omitting a correct card from a given hand and suit or recording a card in the incorrect suit and hand. Similar patterns are observed for the number of honor cards (10-A) correctly recalled in their respective suit, the number of times the subject recalled the correct number of cards in a given suit independent of memory for the particular cards (Correct Distribution), and the number of suits given perfect recall.

These data are not very analytical since they do not give us any indication of why the subjects differed in their memory performance. What they do tell us is that there are incredibly large differences in our subjects' memory for bridge hands as a function of their bridge-playing ability levels. This is true not just for the very important honor cards and for the correct distributions but even for the recall of those cards below the 10, i.e., the spots which the subjects recalled even though instructed that they could designate all spot cards as "X" during the recall.

Memory task

While the tournament simulation task gives no clues as to the mechanisms underlying the differences in memory abilities as a function of bridge skill, the memory and perception tasks both were designed so that inferences could be made about the mechanism contributing to these differences in performance. The data from the memory task are shown in Table 2 with mean errors (defined as in the tournament task) per trial depicted in Figure 2.

The data from the Structured hands are similar to those from the tournament simulation task in showing generally better performance for E and L with systematically poorer performance for A and N. The E and L subjects were able to recall at least something from each of the 40 hands presented in this task while A was incapable of recall from 10 hands and N had no recall from 17 hands. Likewise, E had no recall from a given suit in a given hand on only 11 of 160 opportunities while N failed to recall on 93 of the 160 potential suits.

While the two superior players both had more honor cards correctly recalled and more correct distributions recalled than the two weaker players, A and N seemed to split on their emphasis on these two important types of information. Subject A performed better on correct distribution than she did on number of honor cards correctly

Table 2. Memory task data

Subject	Deals with perfect recall	Hands without recall	Suits without recall	Spots recalled	Mean errors per trial	Honor cards recalled correctly	Correct distribution	Suits given perfect recall	Pieces of information per deal (POI)
Structured deals									
Expert	2	0	11	14	4.4 (1.68)	169/200 84.5%	140/160 87.5%	127/160 79.3%	30.9 (1.95)
Life master	2	0	9	9	4.9 (2.03)	166/200 83.0%	146/160 91.3%	124/160 77.5%	31.2 (1.96)
Average	0	10	54	0	25.1 (1.30)	32/200 16.0%	81/160 50.6%	25/160 15.6%	11.3 (1.23)
Novice	0	17	93	0	26.3 (0.63)	63/200 31.5%	35/160 21.8%	8/160 5.0%	9.8 (.72)
Unstructured deals									
Expert	0	24	112	0	28.6 (.91)	34/200 17.0%	32/160 20%	17/160 10.6%	6.6 (.91)
Life master	0	17	107	0	28.0 (1.0)	62/200 31.0%	22/160 13.7%	16/160 10.0%	8.4 (.88)
Average	0	21	109	0	31.3 (.52)	13/200 6.5%	35/160 21.8%	9/160 5.6%	4.8 (.52)
Novice	0	25	124	0	31.5 (.50)	38/200 19.0%	10/160 6.25%	7/160 4.3%	4.8 (.47)

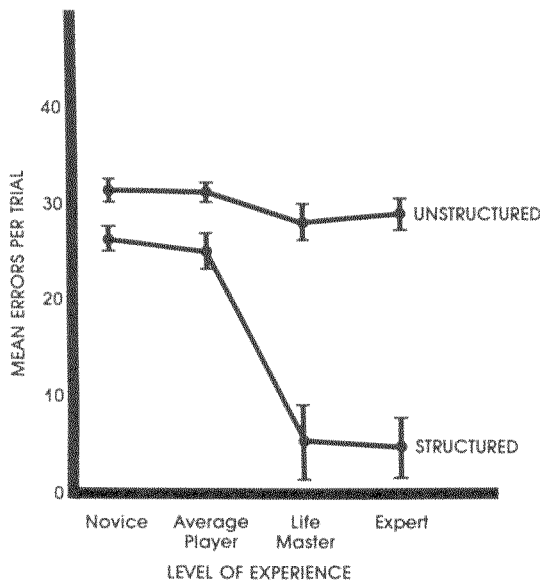*Note.* Standard error is given in parentheses.

Figure 2. Mean errors per trial (deal) on the memory task; the brackets define the 95% confidence intervals

recalled. This pattern of data was opposite that of N, who did better on recall of honor cards than she did on recall of correct distribution. This different pattern in the types of information that were better remembered by A and N is probably explained by the logical progression of the importance of honor cards and correct distribution that occurs as players increase in ability. When an individual first begins playing bridge there is a certain amount of transfer from other card games, e.g., poker, which dictates the supreme importance of the honor cards. One thing that must be discovered before an individual can begin to truly master the game of bridge is that the distribution of cards according to suits can be more important than which honor cards are held in a hand.

Another point of interest is the relative performances of the average and novice players on the tournament simulation and memory tasks. On the tournament simulation task, A performed considerably better than N; however on the memory task, their performances were quite similar. This discrepancy may be related to Frey and Adesman's (1976) chess research finding that knowledge of the moves that led to a given board aided better players in the recall of that board more than it did average players. Just as Frey and Adesman point out the

importance of the amount of "chess-specific information" acquired prior to recall, so it appears that the amount of bridge-specific information may also be important. Thus, the differences in performance on the two types of tasks may be attributed to the presence or absence of knowledge about the play that resulted from the deals to be recalled. The average player appears to have been able to use her more extensive knowledge of the play-by-play process in the game in such a way as to facilitate recall in the tournament simulation task, whereas no such knowledge was available to her in the memory task.

The data from the Unstructured hands are shown in the bottom half of Table 2. Obviously, eliminating the Structure from the hands made all subjects perform at about the same level, which was slightly worse than the worst subject on the Structured hands. Figure 2 shows the mean errors per trial with the 95% confidence limits for each data point defined by brackets. This measure shows quite clearly that the presence of structure aids the stronger players much more than it does A and N. In the absence of structure the strong players perform no better than the weaker players. Arranging suits according to rank (e.g. spades, hearts, diamonds, clubs) and order (e.g. descending order from ace to deuce) appears to function as a mnemonic aid that is useful to experienced players in helping them organize the hand and reduce the amount of information that has to be remembered. Additionally, this gives strong support to Chase and Simon's (1973) argument that the superior performance of expert players in tasks such as recall of chess positions and, in this case, recall of bridge hands, is the result of the activation of existing cognitive structures that are much more numerous and sophisticated in nature than those available to a novice. Whether the presence of structure allows the skilled players to acquire *more* chunks of information during the presentation interval or to form *larger* chunks of a constant number is unanswerable in any concrete manner from the present data. Chase and Simon used interresponse times to parse the subjects' recall into chunks, but we were unable to measure response times for the present experiment due to the absence of an appropriate apparatus.

The last column of Table 2 is a measure called pieces of information (POI) recalled per deal. This is the total number of correct distributions, i.e., correct recall about the length of a given suit and number of high card points (A-10) in that suit on each deal. Looking at the POI for the Unstructured hands, we can see that the range, 4.8 – 8.4 per deal, is well within the 7 ± 2 chunks estimated by Miller (1956) to be the limits of short-term memory. Of course, as mentioned above, we do not have the analytical power in this experiment to say definitely

whether the novice is remembering 4.8 chunks per trial with each chunk being one piece of information or is remembering 2.4 chunks with 2 pieces of information per chunk. In any case, the presence of structure greatly increases the pieces of information that are recalled on a trial but much more so for the expert and life master than for the average player and novice. Again, our inability to definitively parse recall into chunks prevents us from making strong assertions about whether structure aids the better players by resulting in larger chunks or in more chunks being formed in short-term memory. Chase and Simon's (1973) work leads us to believe that the improvement occurs because the better players form larger more hierarchically organized chunks in the structured situation than they do in the unstructured situation and than the weaker players do in both situations.

Perception task

The data from the perception task are shown in Table 3. The first thing that should be pointed out is that there appear to be systematic trends across most of the subjects for several measures. The data for the life master, however, are generally deviant from any of these systematic trends. Unlike her generally optimal performance under the other two tasks, she seemed to have adopted a rather maladaptive strategy in the perception task for both Structured and Unstructured hands. Looking at her data we can see that she seems to have tried to reconstruct the deal in as few looks as possible at the expense of the mean time for each look, and in fact, at debriefing, L stated that she was trying to be able to reconstruct a complete deal with only one glance. Her efficiency score, i.e., the number of cards reconstructed divided by the number of seconds to complete the reconstruction, reflects the imperfection of this strategy, it being the lowest for all subjects. We will thus discuss the trends in the data from the perception task without making further reference to the life master's data.

Looking first at the Structured hands, Table 3 shows that the mean number of looks required to reconstruct these hands was a function of level of expertise with E requiring the fewest looks and N requiring the most. The mean time for each look was also a function of ability level—again, with E taking the least amount of time for each look.

The mean number of cards per look and mean pieces of information per look include only information actually remembered from the glance at the deal and do not include the cards or POI that were deduced on each look, which are described below. While mean cards recalled per look shows that A recalled more than E (11.3 as opposed to 9.36 cards per look), this is primarily a result of the greater number

Table 3. Perception task data

Subject	Mean Number of looks	Mean time/ look	Mean time to reconstruct a deal	Mean cards/ look	Mean pieces of information/look	Mean efficiency rating (cards/ sec)	Mean efficiency rating (pieces of information/ sec)	Pieces of information deduced/ look	Mean errors deal	Mean spots/ deal
Structured deals										
Expert	4.2	3.67	15.41	9.36	7.69	2.58	2.12	2.33	.2	5.5
	(.14)	(.14)	(.80)	(.27)	(1.28)	(.13)	(.12)	(.13)	(.42)	(.39)
Life master	2.6	15.08	35.68	18.96	13.78	1.37	1.00	1.4	.7	1.5
	(.23)	(2.06)	(3.36)	(2.2)	(1.6)	(.13)	(.10)	(.57)	(.67)	(.55)
Average	5.1	5.21	25.24	11.13	6.76	2.21	1.35	0	4.1	0
	(.53)		(1.96)	(.85)	(.52)	(.17)	(.11)		(.67)	
Novice	6.5	5.70	36.68	8.3	5.26	1.53	.98	0	3.6	0
	(.28)		(3.04)	(.29)	(.21)	(.12)	(.08)		(.85)	
Unstructured deals										
Expert	4.6	10.87	49.08	8.70	6.77	.82	.65	2.25	.6	4.3
	(.23)	(.88)	(2.95)	(.39)	(.37)	(.04)	(.03)	(.14)	(.28)	(.16)
Life master	3.1	23.99	74.04	12.68	9.65	.53	.38	2.95	1.1	3.0
	(.11)	(1.0)	(2.99)	(.34)	(.33)	(.02)	(.03)	(.19)	(.53)	(.67)
Average	6.1	14.13	77.22	9.91	5.49	.70	.39	0	7.4	.2
	(1.97)	(1.36)	(3.40)	(.96)	(.50)	(.03)	(.02)		(.63)	(.14)
Novice	8.5	8.78	74.33	6.26	3.95	.72	.45	0	3.2	.3
	(.24)	(.31)	(2.34)	(.11)	(.11)	(.02)	(.02)		(.68)	(.33)

Note. Standard error is given in parentheses.

of cards which E deduced on each look while A tried to recall an entire hand on each look. In spite of the fact that A recalled more cards on each look, E still recalled more pieces of information (distributions and honor cards) than A or N.

The efficiency scores for both the cards and the POI recalled per second of looking are a function of ability level with E being most efficient and N least efficient. In other words, E not only picked up more pieces of information per look, he did it in less time than the less competent subjects.

The number of cards deduced per look was judged by the experimenter after observing the subject's manner and pattern of recall, e.g., a long pause following the output after a look followed by the subject counting the cards in a given suit and hand. Debriefing at the end of each deal showed this to be a perfectly reliable manner of obtaining the measurement since the subjects could tell you which cards they had deduced, and in every case this agreed with those written down by the experimenter. Of the three subjects being discussed here, the expert was the only one that deduced cards, and he did it regularly in a very systematic manner as described below.

The chunking technique refers to the strategy used by the subject to configure the cards either during the look or during retrieval. It was found that after each look the expert would try to reconstruct the cards of a given suit as they belonged to the North, East, and South hands. The cards in the West hand from that suit would be deduced by counting the missing cards from the three hands recalled. This strategy would allow an average of 3.25 cards deduced on each look, i.e., one complete hand per deal, while placing a minimum burden on the short-term memory. This strategy is very similar to the technique of card-reading described above in which the player attempts to deduce the hands of his two opponents by the bid and play of certain cards. It was thus not surprising that the expert used this strategy, which we call chunking by suit, 93% of the time. The only deviations occurred because of re-checks at the board to assure accuracy.

Neither the average player nor the novice was an accomplished card-reader and their chunking technique shows they did not use the optimal strategy of chunking by suit. The average player tried to recall a hand on each look 65% of the time while 31% of the time choosing to chunk by distributions within a hand. The novice used this latter and least efficient strategy 92% of the time.

The first thing that should be noticed in the data from the Unstructured hands is that the pattern of results is very similar to that from the Structured hands except that the efficiency is much reduced for all

subjects. As with the memory task, the lack of structure seems to cause the greatest decrement, at least in terms of efficiency, to the expert and least to the novice. The number of looks required to reconstruct the deals in the perception task give a pattern of results different from that in the memory task. With the perception task the novice required 2 looks more to reconstruct the Unstructured hands than she did for the Structured hands, while the expert needed on the average only .4 more trials to complete the reconstruction of the Unstructured hands than he did for the Structured hands.

The subjects recalled the Unstructured hands in a structured fashion. That is, cards of a given suit were recalled together as a distribution even though they were scattered at presentation. This seemed to allow the expert to restructure the Unstructured hands mentally and then to use the same strategy he used on the Structured hands. Thus, he needed essentially the same number of looks to be able to reconstruct the Unstructured as structured deals and was able to recall nearly the same number of pieces of information per look on the two types of deals but the cost of this practice was a much reduced efficiency rating both in cards/second and pieces of information/second.

These findings are similar to those of Chase and Simon (1973) in that their unstructured chess boards yielded similar differences due to ability level. We would argue that, even though Chase and Simon's chess boards and our bridge deals were nominally unstructured, there existed enough inherent structure in either presentation or recall to allow the expert subjects to use some of the efficient strategies and unitized perceptual configurations that allowed them to perform at the higher rate in the structured task.

The data from the present experiment certainly support the contention of Chase and Simon that the superior performance of expert subjects in tasks of memory and perception is not the result of superior intelligence and capacity except to the extent that intelligence and capacity are defined in terms of the sophistication and efficiency of the cognitive structures that the person can and will utilize in any given situation. In fact, in a number of areas of cognitive psychology there is support for the view that individual differences in cognitive functioning are frequently the result of use, by individuals with very similar capacities, of cognitive strategies of differential effectiveness and efficiency. For example, Flavell (Flavell, 1971; Appel, Cooper, McCarrell, Sims-Knight, Yussen, & Flavell, 1972) has argued that younger children remember less than older children because they have deficits in knowing what to do to and with information rather than because they have generally lower physiological or intellectual limits to their mental

capacity. Likewise, Ellis (1970) has argued that educably mentally retarded children remember less than normal children because of deficiencies in the strategies the EMR children use rather than in reduced memory capacity. It certainly seems to be the case with our subjects that differential performance on the tasks we used reflects differences in strategies of configuring and storing information rather than in our expert subjects having a supranormal capacity.

Notes

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