

Some Characteristics of Human Problem-Solving in Chess¹

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Following the design of de Groot (1965) and Newell and Simon (1965), two Ss were asked to produce a total of six verbal chess protocols over a variety of conditions involving: middle and end game positions; real and artificial board positions; and differing time constraints. The analysis of these protocols yielded problem-solving episodes similar to those described by Newell and Simon. To account for these data, a modification of the Newell and Simon model was developed. The modified model gives a good account both of the data obtained in this study and also those described by Newell and Simon.

The rebirth of the chess problem as a tool for studying complex human thinking has two main causes: First, the chess game is precisely the type of problem that pushes human cognitive capacity to its limit, forcing the human to choose among a large number of alternatives with limited storage capacity; and second, the chess game is well-defined in that the objects (the chess pieces) and the primitive operators (the moves) are known, and thus may be identified in verbal protocols with a minimum loss of information. The first major modern study of problem-solving in chess was by de Groot (1965). He presented his subjects (Ss) with a series of board positions taken from tournament and private games, and asked each S to analyze a preset board situation by verbaliz-

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ing his thoughts. The resulting protocol was recorded by hand. De Groot found a general chess problem-solving process, which he called "progressive deepening," whereby promising move sequences were investigated in greater depth until a choice could be made. Newell and Simon (1965) followed the method of de Groot, with the aid of a tape recorder, in order to further specify and detail "progressive deepening." Using one S with one of de Groot's chess positions, they found that the obtained protocol could be divided into "episodes" or individual problem-solving scenarios. Further, they were able to posit a set of rules to describe a substantial portion of their S's protocol.

The present study uses the same procedures as Newell and Simon (1965), but applies them to a broader range of situations. Specifically, we study: the stability of one S over five different board positions; differences, if any, between artificial board situations and real game situations; differences under varying time constraints; and the stability of human chess play characteristics over three Ss (including the S of Newell and Simon).

METHOD

In general, the method used follows that of Newell and Simon. The S entered a room, was presented an artificial (i.e., previously constructed) board position, and was instructed as follows:

In a moment I shall show you a position taken from an actual tournament game. You get the side of the player on move [who moves next]. You are requested to think of a move and then to play it on the board as if the position had arisen during one of your own tournament games. In addition, however, I should like you to do all of your thinking out loud, insofar as is possible, so that I can follow and record the way in which you arrive at your move. The idea is for me to be able to study the thought process as it develops, so no special achievement is expected of you. Please voice everything that comes into your head regardless of its correctness. I should like to follow the course of your thought, so the unsuccessful tries and variations that you may later find are just as important to me as the correct ones [de Groot, 1965, p. 96].

The entire protocol was tape recorded.

Four protocols were obtained from S1, a graduate student in mathematics, and a class C chess player. There were variations in the types of board positions and in time constraints. Positions A (de Groot, 1965, p. 89) and F (Fine, 1952, p. 439) were middle game positions. Position A was that used by Newell and Simon, and had no time constraint. Position F had a 7 minute time limit. Positions B (de Groot, 1965, p. 91) and E (Fine, 1952, Position PB-6) were end game positions, and had time limits of 10 and 20 minutes, respectively.

The final two protocols, C and D, were obtained to test whether differences appear between the above artificial or constructed board positions and a real game situation. S1 faced an actual opponent and developed his position himself, rather than having it presented to him. S1 was therefore matched with another S, S2, a graduate student in astronomy, and also a class C chess player. After the 12th move, play was stopped and S2 left the room while S1 analyzed his position (Protocol C). When S1 had made his move, he left the room and S2 returned and analyzed the new board situation (Protocol D). Both Ss had 15 minute time limits.

Definitions

Terms used in analyzing the protocols are defined as follows.

- Move: The proposed movement by either player of one of his pieces from one square to another, either by occupying an empty square or by capturing a piece (e.g., $N \times B'$).
- Base move: An initial move proposed in the context of a given board position; the first move in any episode.
- Episode: A base move and the sequence of moves generated in response to that base move.
- Depth: The minimum number of moves required to reach a particular point from the base move.
- Line: The sequence of moves leading to the last evaluation made in an episode.
- Branch: Any move or sequence of moves, not included in the line, that leads to an evaluation.
- Evaluation: The S's estimate, in terms of his objectives, of the chess situation at the end of a line or branch.
- New move: A move that has not been proposed in the previous branch or line at the same depth.
- Different move: A move that has not been previously proposed in *any* previous branch or line at the same depth.

Typical Chess Abbreviations:

K = King, Q = Queen, R = Rook, B = Bishop, N = Knight, P = Pawn.

$Q \times R'$ means *white* Queen captures *black* (') Rook.

Q-Q4 means white Queen *moves* to the position three spaces in front of the initial Q position.

RESULTS AND DISCUSSION

The Problem Behavior Graph

After transcribing the tapes, the protocols were analyzed in the manner of Newell and Simon (1965). All protocols fell naturally into episodes, although we found it convenient to define an episode slightly differently from Newell and Simon's definition. We defined an episode as a base move and the sequence of moves generated in response to that base move. The only difference between our definition and Newell and Simon's is that they allowed a new episode to begin without returning to a base move where sufficient discontinuity occurred; we always required that there be a return to a base move. Thus, Newell and Simon included as separate episodes five that we would have included in other episodes. A representation of the entire set of such episodes is called a Problem Behavior Graph (PBG; Newell, 1968). The board for Position

TABLE 1
Summary of Protocol Statistics

	Protocols						
	A(S1)	A(S0)	B(S1)	C(S1)	D(S2)	E(S1)	F(S1)
Type of game	middle	middle	end	middle	middle	end	middle
No. of pieces on board	28	28	18	27	27	8	26
Time (minutes)	29	16	10	15	15	20	7
No. of different moves	115	66	51	66	38	68	51
Total No. of moves	328	124	103	152	79	224	74
No. of episodes	45	20	22	25	13	18	14
No. of positive evaluations	39	14	11	9	22	18	7
No. of negative evaluations	28	16	9	7	2	11	12
No. of neutral evaluations	25	10	6	12	5	4	5
Total No. of evaluations	92	40	26	28	29	33	24
Branchiness ^a	2.04	2.00	1.13	1.12	2.23	1.83	1.64
Average depth ^b	3.57	3.08	3.96	5.43	2.72	6.79	3.22
% of different moves ^c	35	54	50	43	48	30	70

^a This is a measure of branching and is given by the ratio between the total number of evaluations and the total number of episodes.

^b The ratio between the total number of moves considered and the total number of evaluations, where terminal evaluations have been substracted out, so as to distinguish the "process of branching" from the "termination" process.

^c The ratio between the total number of different moves and the total number of moves considered.

A, a portion of S1's protocol, and the resulting Problem Behavior Graph are shown in the Appendix.

The protocols were analyzed by the two authors independently and we believe there is sufficient consistency to enable us to generalize. Wherever possible, we have followed Newell and Simon's methods of analysis. For instance, "Pawn threatens to take Knight now" is considered $P \times N'$. When moves are inferred, but not explicitly mentioned they are put in parentheses; moves that are neither explicitly nor implicitly referred to are indicated by dotted lines.

Positive (+) and negative (-) evaluations are judged from the S's assessment of whether he has gained or lost material or position at the end of a branch or episode. Thus, in Protocol A, Episode 3, "... and I've caused the weakening of his Pawn structure ..." would be considered a positive evaluation (+). We have defined the neutral evaluation (0) to include evaluations that are unstated, equal or even, or undetermined. Thus, in Protocol A, Episode 18, "I might win a Pawn, but I'm certain to lose him back ..." would be considered a neutral evaluation (0).

Overall Comparisons Among Subjects

Table 1 lists some comparative statistics for our Ss, S1 and S2, and for S0, the S of Newell and Simon. A quick comparison of S0 and S1 on Position A reveals some similarities. Figures 1 and 2 show that certain patterns differ not in the shape of the function but in the magnitude of the values. For example, as indicated in Table 1, with respect to the

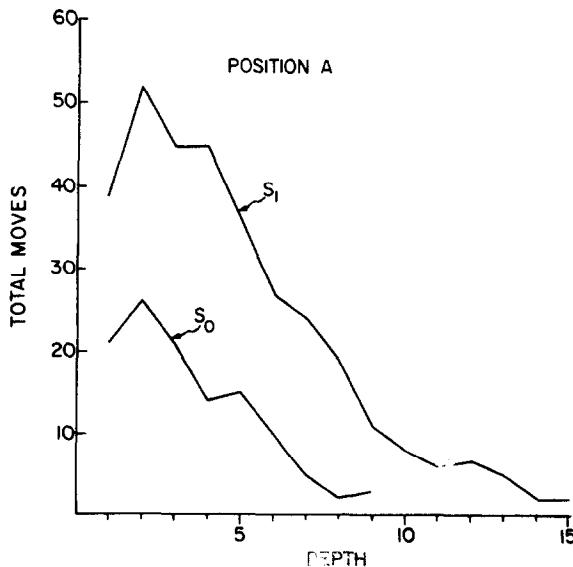


FIG. 1. The total number of moves as a function of depth on Position A.

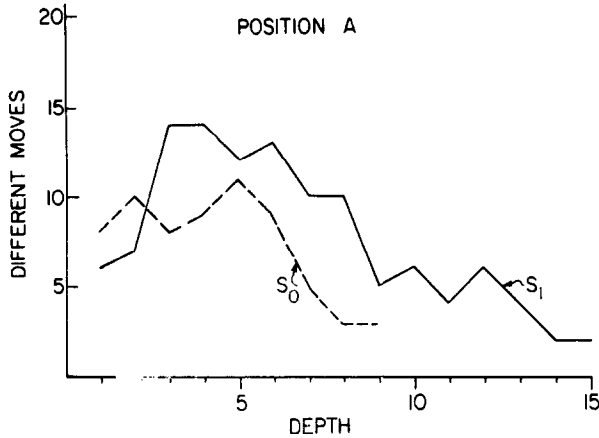


FIG. 2. The number of different moves as a function of depth on Position A.

measures of time, number of different moves, number of total moves, number of episodes, and number of evaluations, S1's values are consistently twice those of S0. Since S1 had available twice the time allowed S0, it is reasonable to suggest that these measures are indeed useful indicators of the course of the problem-solving process in chess.

In general, there seem to be no large systematic differences in the structure of strategies (or problem-solving) between Ss or between positions (middle, end, or real game). Some interesting variations do occur, however. For example, the large average depth of search in E (S1), an end game, might be explained by the very few chess pieces that had to be kept in memory during the analysis. Another case having a large average depth was C (S1). Here S1 also had to cope with a large number of pieces, but the depth may be explained by the greater familiarity S1 has with the real game position (C) that he had himself developed. Apart from this, there is no evidence to suggest that an artificially presented board position differs from the real game situation. Figure 3 compares the gross data output (total moves versus depth) of S1 and S2.

In general, the time constraints seemed to cause no large systematic differences in S1's overall problem-solving behavior, although several points can be made. One conclusion is that the more pressing the time limits, the larger the percentage of different moves S1 scans. Table 2 shows a clear negative relationship between the percentage of different moves (different moves/total moves) considered and the time taken in deciding upon a move (the regression slope is significant (*t*-test) at $p < .025$). This relationship suggests that longer time limits allow the S to be more repetitious (thorough?) in his analysis. Another interesting measure is that of the "processing rate" (moves/minute) of each S on a

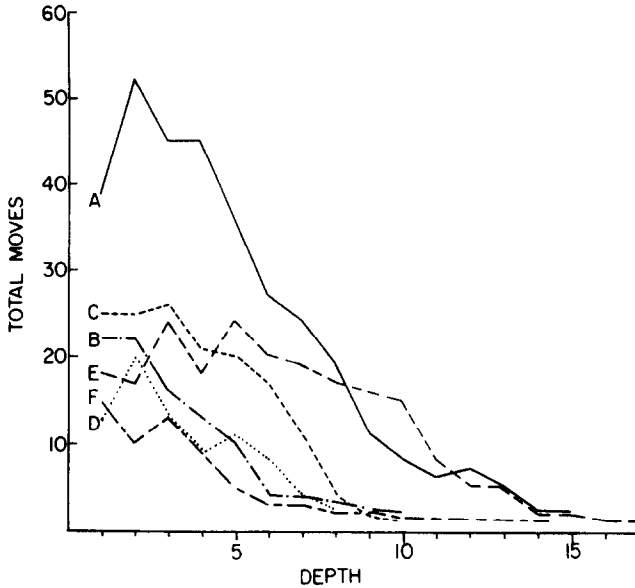


FIG. 3. The total number of moves as a function of depth on Positions A-F (using S1 and S2).

particular board position (Fig. 4). This is linear for S1 at about 10 moves per minute (regression slope significant (t -test) at $p < .01$). A measure related to the above points is the rate of scanning search, which, for S1, is about four different moves per minute. There are not enough data here, however, to state that each S has a characteristic "processing rate."

In summary, although we have shown some characteristics of human chess problem-solving here, we have not found any large differences in problem-solving behavior between Ss and positions that are attributable to the changes in conditions introduced by the experimenters.

The Model of Newell and Simon (1965)

Let us now apply the Newell and Simon model to our data. There are three components to the model that are relevant to this discussion: the

TABLE 2
Decision Times and Percent Use of Different Moves

Position-Subject	F(S1)	B(S1)	C(S1)	D(S2)	A(S0)	E(S1)	A(S1)
Time taken for decision	7	10	15	15	16	20	29
% different moves	70	50	43	48	54	30	35

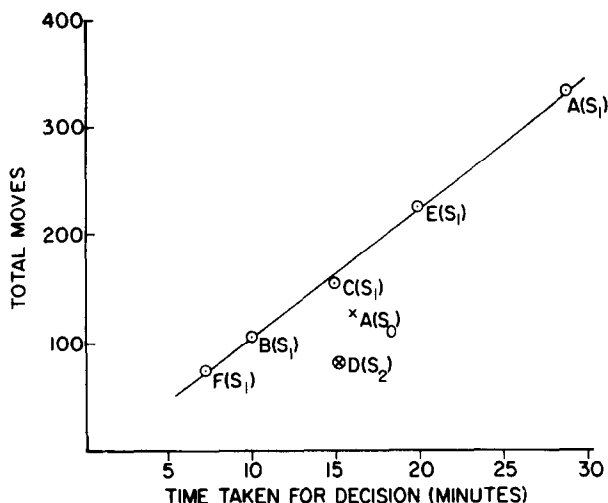


FIG. 4. The total number of moves as a function of protocol time taken for decision as to choice of move on Positions A-F. Regression line through S1 only.

first deals with the specific choice of moves; and the others deal with how the *S* decides among classes of moves (e.g., base move or line move), and thus determines the structure of his problem-solving search.

Generation of situation-response moves (GSRM). The first component is a system of situation-response generators (GSRM) which answers the question "What particular move will *S* choose next?" Newell and Simon suggest that *S* recognizes certain "functions to be performed"—that *S* has "an available collection of fixed responses to specific situations" (1965, p. 50). For example, among their situation-response rules they list: "man captures last move—recapture with no apparent loss," and "man attacked—counter-attack of equal value." We accept this idea and we shall use it later in our model.

Modified progressive-deepening. The second part of this theory, the "Modified Progressive-Deepening Search Strategy" (MPD), was an attempt to specify the hypothetical structure of *S0*'s problem-solving behavior as displayed in the analysis of episode branching. MPD does not attempt to reproduce or explain the actual mental processes of *S0*, but they hope that the "hypothesized organization is sufficient to reproduce the *S*'s observed behavior." In general, this type of structural modeling is the first step toward computer simulation, which was one of the aims of Newell and Simon.

MPD is given as follows.

² The "Modified" refers to a broadening of their originally hypothesized "Progressive-Deepening Search Strategy."

In considering the base position:

—Either an old base move (i.e., one from the base position) is re-considered, or a single new base move is generated and considered.

—A summary is kept of the state of analysis of each base move.

In considering a position, X, other than the base position:

—The state of analysis of the base move leading to X is available.

—If X is static, return to the base position.

—If X is dynamic, generate a set of moves from X. Consider each in turn, but only statically. Select one of these moves and consider it dynamically.

The terms “static” and “dynamic” refer to the evaluation state of each move. A move that is “static” is capable of being evaluated. A move is “dynamic” if it leaves matters in a state in which evaluation is impossible. As Newell and Simon say of MPD, “This strategy will produce a sequence of explorations, each starting from the base position, but with the tree of each exploration resembling a skinny Christmas tree: the tree would have a main trunk, and at each node there would be a tuft containing a number of branches, each one more deep” [p. 40].

Rules for episode sequence. In their analysis and discussion of the episodes into which their protocol was divided, Newell and Simon suggested six rules for generating a sequence of episodes, which could hypothetically create a FBG like that they show for S0. These Rules for Episode Sequence (RES), a third component of their model, sought to predict which base move would be selected for the next episode and what context governed the exploration of subsequent episodes of the same basis. The following is a listing of RES:

- RES 1: The analysis of each base move is independent of the analysis of other base moves, except that it can be interrupted by other activity. That is, each episode in the analysis of a base move is determined only by the results of the prior episodes of that base move.
- RES 2: The first episode of the base move employs normal moves and subsequent episodes utilize increasingly unusual moves.
- RES 3: If the evaluation of an episode gives a favorable result, then an analysis of its base move is continued; if the evaluation is unfavorable, a different base move is analyzed.
- RES 4: When exploring, moves for the opponent may be considered that are favorable to self (in order to place an upper bound on the possibilities).
- RES 5: The analysis of a base move will be interrupted to pursue other moves, discovered during the episode, that seem to have merit either for self or for the opponent.

RES 6: Before a base move is finally chosen, a check is made for other alternative base moves.

After analysis of the 25 episodes (or 20 episodes, using our definition of episode) in their S's protocol, Newell and Simon concluded that "there is substantial evidence that the S is observing the first three rules; and more limited evidence for the remaining three" [p. 43].

The data for S1 and S2 generally are consistent with Newell and Simon's findings, except in the case of RES 3. In general, where the RES were applicable, they were confirmed. However, RES 4-6 had relatively few applications in our data. RES 6 did not apply in any of the five protocols of S1, although it did apply to the one protocol of S2—suggesting that it is an individual, non-general, search strategy.

RES 3, which had the most application (90%) and the least confirmations (58%) among the RES, is worth considering further. Table 3 lists the number of cases in our data in which RES 3 was applicable, confirmed or disconfirmed. Newell and Simon summarize RES 3 by saying: "Stay with a winner, switch off a loser." That is, base moves giving positive evaluations will continue to be explored until a negative evaluation is reached, where a new base move will be explored. RES 3 was highly confirmed by S0 and S2, and poorly confirmed by S1, which again may indicate that the Ss used different search rules, as with RES 6.

Table 4 is a detailed analysis of the disconfirmations of RES 3, broken down by protocol and nature of disconfirmation. Also shown in Table 4 is the percentage of episodes starting from the "most favored" (most frequently analyzed) base move in each protocol with regard to S1. A larger proportion of disconfirmations of Type 2, a negative evaluation followed by the same base move, was associated with a high concentration on the analysis of a single base move (e.g., Positions A, C, and E). Type 1 disconfirmations, switching from a positive evaluation to a new base move, had a low concentration of the analysis of a single base move (e.g., B and F). A reasonable explanation for the Type 2 dis-

TABLE 3
Summary of RES 3 Applications

	Protocols							
	A(S1)	B(S1)	C(S1)	E(S1)	F(S1)	Total S1	A(S0)	D(S2)
Confirmations	26	8	12	12	8	66	16	11
Disconfirmations	15	9	11	5	7	47	2	1
Non-applications	4	5	2	1	0	12	7	1
Total	45	22	25	18	15	125	25	13
Percent confirmations	63	45	52	70	55	58	90	92
Percent applications	93	77	92	94	100	90	72	92

TABLE 4
Types of Disconfirmations—RES 3

Protocol	A positive evaluation, followed by a new base move (Type 1)	A negative evaluation, followed by same base move (Type 2)	Total disconfirmations	% use of "most favored" base move
A(S1)	—	15	15	68
B(S1)	5	4	9	36
C(S1)	1	10	11	60
E(S1)	—	5	5	100
F(S1)	3	4	7	25
Total (S1)	9	38	47	57
A(S0)	—	2	2	57 ^a
D(S2)	—	1	1	77

^a In calculating, the number of episodes has been adjusted from 25 to 20 to make comparisons possible.

confirmations may be that when S1 analyzed a base move and found that it yielded primarily positive results early in the protocol, he was encouraged to explore this line further. As the positive evaluations continued, S1 built up an "investment" of time and effort (and memory storage) in this base move and thus was reluctant to abandon it for another base move when negative evaluations showed up later in the analysis. This seems to explain Protocols A and E fairly well. Episodes 3–6 and 8–10 of Protocol A, and 1–4 and 6–9 of Protocol E, began with the most frequently explored base move and ended with positive evaluations. Later in the protocols, negative evaluations often were followed by the same base move (e.g., Protocol A, Episodes 14, 16, and 17).

However, this explanation does not fit Protocol C. In this case the favored base move continued to be analyzed despite neutral and negative evaluations from the beginning. Furthermore, this persistence led S1 to choose an exceedingly bad move. To find an explanation, we must note again that Position C was developed from the beginning by S1, and thus he had not only prior knowledge, but perhaps also a prior "investment" in a certain move strategy. For even in the first episode of Protocol C, S1 said: "So the most natural move is Pawn to King 5. . . ." In sum, it appears that S1 made Type 2 disconfirmations when he had some sort of cognitive investment in a particular move, either by previous development, or during problem analysis.

A reasonable explanation for the Type 1 disconfirmations abundant in Protocols B and F is the fact that B and F had the most constrained time limits (10 and 7 minutes, respectively). As we noted before in the discussion of the effects of time limits, the more constrained the time, the more

widely S1 searched. Thus, Type 1 disconfirmations—“switching from a *winner*”—would be necessary for an appropriately wide search.

An Alternative Theory of Move and Episode Generation (MEG)

We have discussed the rules in RES, particularly RES 3, and have found them less than complete for describing the behavior of our Ss, and particularly S1 (for whom we have the most data). We have suggested several explanations for the differences, but we have not yet offered any hypotheses that would explain S1's behavior in any detail. This section presents a set of rules that encompasses some of the ideas in MPD and RES, but explains S1's behavior to a greater extent than the Newell and Simon model, and is also applicable to S0 and S2.

With MPD and RES, Newell and Simon propose an integrated description of the behavior of their S. The following is a set of rules for Move and Episode Generation (MEG) that determines the episode and branching structure, and thus describes a part of the decision behavior of our S.

- MEG 1: (a) If the evaluation is negative (—), the first new move in the next branch or episode, i.e., a new line move, will be made by the S.
 (b) If the evaluation is positive (+), the first new move in the next branch or episode, i.e., a new line move, will be made by the opponent.
- MEG 2: A generated new move will replace the last move made by the opponent or S in accordance with MEG 1. In a few cases, the second-to-last move will be replaced, rather than the last move.
- MEG 3: If the evaluation is negative (—) and all plausible line moves have been considered, the new move generated will be a new *base* move.
- MEG 4: If the evaluation is positive (+) and the S has a time constraint or limit, he may switch to a new base move.
- MEG 5: If the evaluation is positive (+) and all plausible line moves have been considered, the present base move will be chosen by the S.

MEG 1 says: “That is *not* good for me (—), what other move can I make?” or “That is good for me (+), but what other moves can my opponent make?” This rule forms the basis of new move generation not only within episode branching, but also in the choice of branch moves. RES 3 says, “Switch from a loser, stay with a winner.” Thus, MEG 1 is not contradictory to RES with regard to new base moves. However.

MEG 1 goes further than RES 3 with regard to non-base move generation. MEG 1 says that branching may occur even if preceded by a negative evaluation. Thus the *S* is not "switching from a loser," but is attempting to rectify a bad situation within the same base move. MEG 1 is illustrated in Fig. 5; one can see that this rule allows for two types of new move generation: base moves and branch (or line) moves. A further specification to determine which type this new move will be is contained in MEG 2-4.

MEG 2 is described empirically in Table 5, which shows that new moves occur in "primary placement" with 78% occurrence, and in "secondary placement" with 12% occurrence. An illustration of the structure that MEG 2 imposes on MEG 1 can be seen in Fig. 5. Two methods of branching are shown. "Primary placement" of branching stands for the event when the new move replaces the last move made by the opponent or *S* (e.g., ζ' replaces δ'). "Secondary placement" of branching stands for the event when the second-to-last move is replaced by the new move (e.g., θ' replaces δ'). For example, in Position A, Episode 29, S1 says:

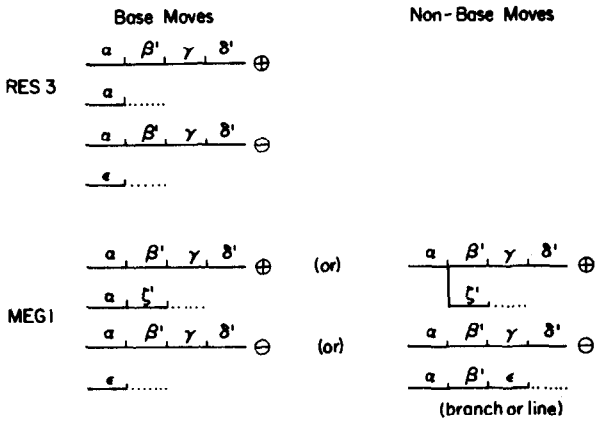
TABLE 5
Statistical Data on MEG 1 and MEG 2

	Protocols							Total
	A(S1)	A(S0)	B(S1)	C(S1)	D(S2)	E(S1)	F(S1)	
<i>MEG 1</i>								
No evaluations	25	10	6	12	5	4	5	67
Total evaluations	92	40	26	28	29	33	23	271
Confirmations	66	27	20	14	23	28	17	195
Disconfirmations	1	3	0	2	1	1	1	9
Applications	67	30	20	16	24	29	18	204
% confirmations	98	90	100	87	95	96	94	95
<i>MEG 2</i>								
Branches with no evaluation	15	9	1	1	1	1	2	30
Total No. of branches	50	16	4	3	17	15	8	113
Primary confirmations	31	4	2	1	14	9	4	65
Secondary confirmations	4	1	1	0	2	1	1	10
Disconfirmations	0	2	0	1	0	4	1	8
Applications	35	7	3	2	16	14	6	83
% confirmations	100	71	100	50	100	71	83	90
Average branch length	1.8	1.5	2.0	1.0	1.6	2.2	1.9	1.6

So if Queen takes Pawn; say, Rook to either at the moment; and Queen takes the other Pawn; I now have Knight to Bishop 4, hitting the Queen. . . . No, maybe it would have been better to go to Rook to Knight 1, and cut off his squares on the Knight file. . . .

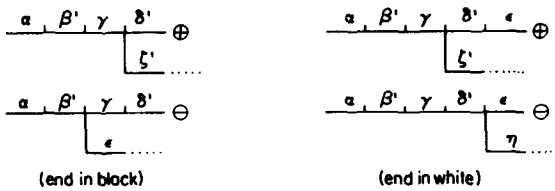
MEG 3 presents a new word: "plausible." "Plausible line moves" are not difficult to conceptualize if they are seen in terms of the normal-to-

RES 3 vs MEG 1



PLACEMENT OF NEW MOVE (MEG 2)

1. "Primary Place" of Branching:



2. "Secondary Place" of Branching:

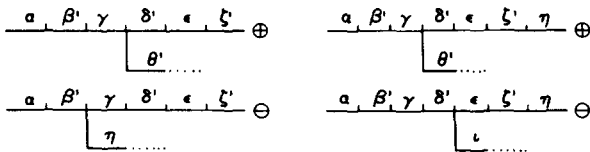


FIG. 5. A comparison of RES 3 with MEG 1; and an indication where branching will take place, in accordance with MEG 2.

unusual sequence of moves seen in RES 2 earlier. Plausible moves appear in this sequence; and "all plausible line moves have been considered" when the S has reached his subjective limit of what is "unusual." He will then switch to a new base move from his normal-to-unusual sequence of base moves. The concept of "plausible moves" here is similar to the "plausible move generators" of computer programs (Newell *et al.*, 1958; Greenblatt *et al.*, 1967).

MEG 4 is simply a derivative from the earlier discussion of Type 1 disconfirmations of RES 3. It indicates that the S may not "stay with a winner" (a positive evaluation) if he desires to scan the possibilities quickly (a wide search) under what the S feels is a time constraint. This type of quick-scan strategy is found in human decision-making tasks under time constraints. Yet, even this wide search for alternatives will not prevent the S from returning to an analysis of previously favored base moves. MEG 5 is intuitively reasonable, and perhaps only an extreme time limit would prevent the S from considering all his plausible line moves.

Analysis and Discussion

MEG 1 and 2 will be analyzed with the tabulated data of Protocols A to F listed earlier in Table 5. This theory, of course, relies upon the existence of an evaluation, but the fact that branches with no evaluation (25% occurrence) appear identical to the evaluated branches indicates that often some type of evaluation may be implicit, but not verbalized by the S. The verification of MEG is made somewhat easier than that of RES because MEG was for the most part empirically derived. We see that MEG 1 is confirmed at a consistency over 90% in almost every protocol (195 confirmations out of 204 applications); this is a high figure when compared to RES. MEG 2, the rule for placement, has 90% total confirmations (75 out of 83 applications).

As mentioned earlier, the criterion for judging "plausible" was the same as the normal-to-unusual sequence of RES 2. MEG 3 is an adapted part of RES 3 which says: "If the evaluation is unfavorable, a different base move is analyzed." Given that MEG 4 and MEG 5 do not have priority, we can find several examples of MEG 3. A clear example is Position B, Episode 19, where S1 is finally going to give up developing B'-Q2 (i.e., all plausible line moves have been considered). He said: "And, all in all, that seems to be a good line for him. So I think I'm going to give up on Bishop to Queen 2. . . ." With regard to the negative evaluation leading to a new base move, this follows the normal MEG 1 pattern—namely, "what other move can I make?" Therefore, discon-

firmations of this are rare, and are included in the MEG 1 disconfirmations.

The rule MEG 4 is “weak” in that it is not widely applicable in our protocols—although, for example, five applications occur in Protocol B. An example from Protocol B, Episode 1, states: “A Rook to Knight 1 move is possible, attacking his Knight Pawn; force a possible weakening in it, but I’m looking for something sharper here, because I’m down a bit of material, and I’d like to see if I could win something back immediately. . . .” It seems likely that with more constrained time limits than 7 or 10 minutes, there would be even more forced scanning of available moves.

MEG 5 is relatively easy to test. If the last evaluation is positive and the *S* feels that he has considered all plausible line moves (as in MEG 3), he will choose that present base move. For example, in Protocol B, Episode 22, S1 said: “guess I can’t ask for much better . . . I really don’t have much else in this position,” and chose the present base move as final. Thus, MEG 5 was confirmed in Protocols A, B, C, D, and F. The exception was Protocol E where S1 continued his first and only choice, in the end trying more unusual alternatives to improve upon it.

On the whole, MEG appears to describe S1’s behavior quite well, and

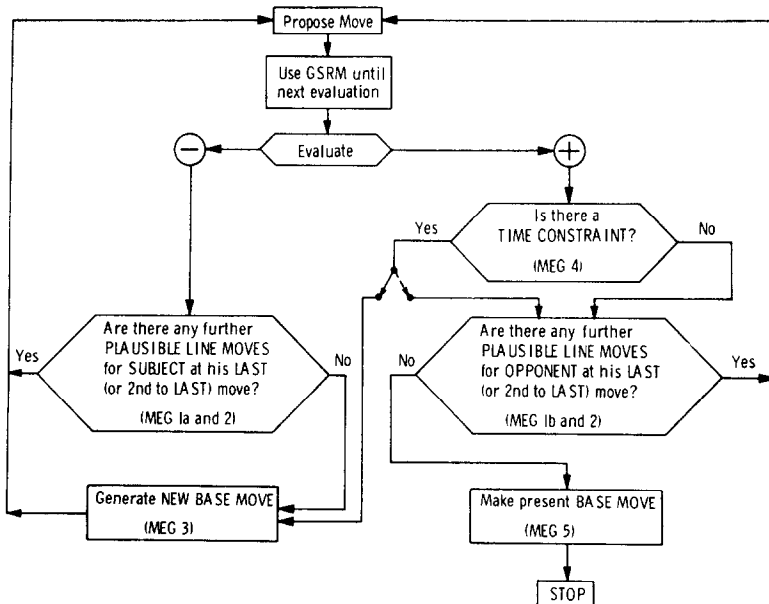


FIG. 6. A flow chart of the rules for Move and Episode Generation (MEG 1-5). The “branch point” with the dotted and solid arrows (following MEG 4) is to indicate uncertainty in that branch.

does almost as well with $S0$ and $S2$. The data shown in Table 5 indicate a strong confirmation of MEG 1 and MEG 2. MEG 3-5 have fewer applications, but the data generally seem confirmatory.

The flow chart in Fig. 6 shows the MEG rules in a schematic form (recall that GSRM stands for the Newell-Simon proposal accounting for the generation of specific moves).

Search strategies. Previously we briefly discussed two strategies and the structure of episode branching that they produce: MPD and MEG. The general features of MPD are the existence of episodes with a return to a base move, and "single level tufts at each branching node." Although the first part is in no conflict with MEG, the second part (single move tufts) causes some difficulty. Newell and Simon suggest that the S comes

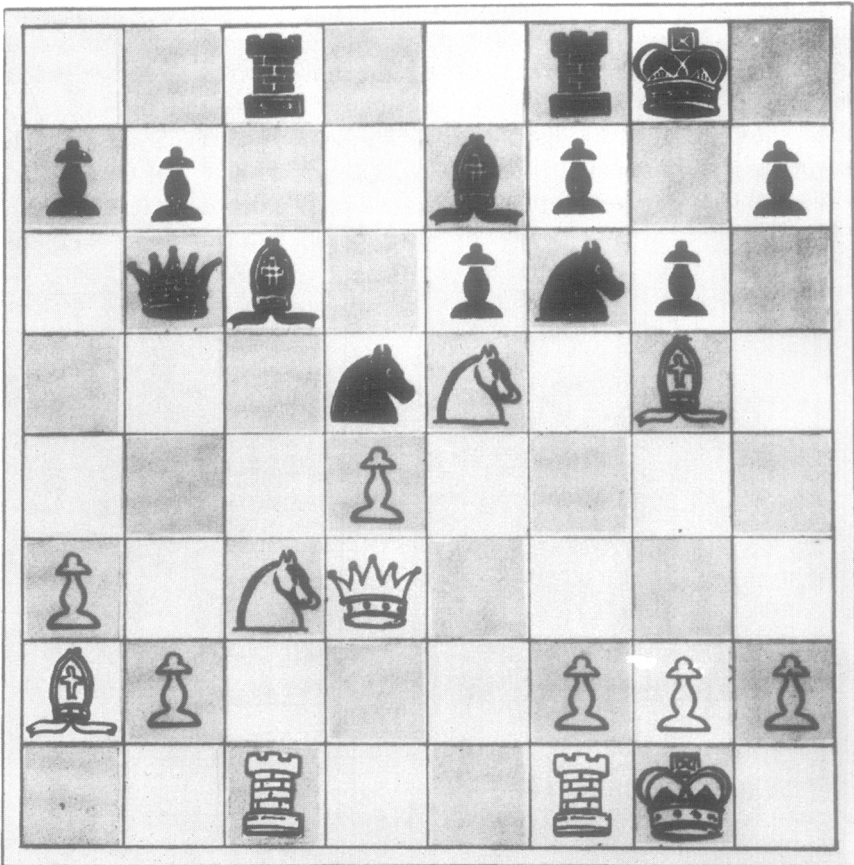


FIG. 7. Position A (de Groot, 1965). Used by the authors with $S1$, and previously by Newell and Simon (1965) with $S0$. It is white's move; the choice made by $S1$ was $N \times N'$. (Note: The black pieces are "primed" in the written text.)

to a certain (dynamic) point and generates a series of alternatives, each one of which is considered, and selects one for deeper searching. The basis for the application of MPD to their *S* apparently rests on the word "or." For example, in *S0*, Protocol A, Episode 21, their *S* says: "It can, of course, move to Rook 4—can move to Rook 4 or it can retreat to Bishop 2 or Queen 1. . . ." Thus, we see that the word "or" (possibly "and" in some cases) is actually the only way for a *S* to consider alternatives and then pick one; that is, this manner of speaking is necessary for MPD. With respect to single tuft branching, *S0* seemed to follow MPD with some consistency (11 out of 15 instances of multiple branching), while *S1* did so only 16 out of a possible 35 instances—or less than 50% of the time.

If MPD is applied to *S1*, serious problems arise. Single branches occur in only half the cases of branching for *S1*. There are many episodes that have a two move branch and several with multiple branching with each branch two or more moves long (e.g., Position A, Episode 34; Position E, Episode 10). Thus, for MPD to work here, the *S* would sometimes have to generate alternatives that were two moves deep and then choose one to consider more deeply. The net effect of this would be a doubling (or more) of the memory that is needed to consider the alternatives. That is, each alternative has an average of two moves compared to the original MPD theory of a single move. It seems, then, that *S1* shows little indication of using MPD search strategy.

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APPENDIX: POSITION A

Protocol of Subject S1

Well, it looks like White has the initiative
 Black's King side is weakened with its Pawn on King
 Knight 3 its got a centralized Knight at King 5 . . .
 strong position it's Queen, Bishop seem to be
 ready to line up. And . . . uh . . . it's a complicated
 position as . . . uh . . . obviously there's not going to
 be any sacrifice . . . I say obviously because Black
 has a relatively well developed position with good
 control of the strong points. So it looks like
 it's, uh, positional plan here I would look for
 any immediate tactical shots. Perhaps if we
 actually play on the Queen side rather than on
 the King side here because, uh, we actually have
 the Queen Bishop file here ready for use and

Episode 1 the Knight on King 5
 hitting the Bishop there, Queen Bishop 3,
 if we could force a weakening in the Pawn structure
 so we could recapture with a Pawn
 and we'd have a target on the Bishop file
 but at the moment that's not quite feasible
 because it's too well protected.
 It's not (attacked) often enough
 This Pawn Queen 4 is also an alternative
 but that also seems to be attacked very well

Episode 2 So off hand it's not too clear to me what's a
 strong move here

And now I might try something different
 like taking off a Knight here
 and remove some of his defense
 and see how that would affect things
 so if I look at Bishop takes Knight,
 he has a couple of ways of recapturing
 If he takes back with the Knight
 and then [I] take his Bishop—
 recaptures with his Knight—
 and I've decentralized his position
 of course I've made too many exchanges.
 Not too good
 unless I can get something definitely out of it
 But I could now play Knight into King 4
 and that would uh enable me to uh put pressure
 on his weak black squares
 which is also the [weaker]
 because his black squares Bishop has been cut off
 But this Bishop is controlling King 4 unfortunately
 so you've clipped the Knight right off
 and I'm back where I started from
 It's very difficult . . .
 Let's see . . .
 It's very hard to think of something here, I uh . . .

Episode 3 Try another line.

Seems to be the best opportunity.
 Immediate capture of Queen 5 again
 Again, if we go Knight takes Knight
 Well, but I guess last time
 my Bishop takes Knight.
 Let's continue on that line
 and see if we can exhaust that possibility
 again
 Now, now let's see
 Now let Knight takes Knight,
 we'll try that again and see if anything else comes up
 Knight takes Knight
 he plays Knight takes Knight
 now I can't play Bishop takes Knight,
 leaving that Bishop in the air
 Now, if he goes Bishop takes Bishop

I can put a Bishop takes Bishop
 and I've caused the weakening of his Pawn
 structure on the Queen side
 which was one of my original ideas
 because uh he has to recapture with the Pawn
 and Knight guarding the Bishop

Episode 4 So let's look at that again
 and Knight takes Knight
 and he goes Knight takes Knight
 I go Bishop takes Knight
 Now he cannot play Bishop takes Bishop
 But Bishop takes King . . . Queen Bishop
 So he must recapture this Bishop here
 But if he recaptures this Bishop here
 his other Bishop I take off next move
 So this seems to be fairly promising

Episode 5 Try that one more time
 Knight takes Knight
 Knight takes Knight
 Bishop takes Knight
 Now his Bishop on King 2 is hanging
 as he cannot recapture my Bishop on Queen 5
 so he must take (back to the old variation)
 I then take over here on Bishop 6
 he recaptures
 and uh I have achieved my objective of weakening
 his Pawn structure

Episode 6 Now uh let's see . . .
 His only chance to veer from that line
 would be on a first move of the alternative
 So again, Knight takes Knight
 He does not have to play Knight takes Knight
 leaving his Bishop open to attack.
 He has 2 alternatives,
 both Bishop takes Knight
 and Pawn takes Knight
 Uh, I'll look at Bishop takes Knight first
 because Pawn takes Knight
 because it would probably be favorable to me
 because it blocks the scope of his Bishop

and in general would be a move he wouldn't want to make,
I don't think

Episode 7 So let's look at what would probably be his better move
so play Knight takes Knight
He plays Bishop takes Knight
Now an idea here is instead of immediately
recapturing Bishop takes Bishop
because that allows him to safely play Knight
takes Bishop
is to now interpolate Bishop takes Knight
The idea behind that is if he now normally recaptures
I can play Bishop takes Bishop
and then he cannot recapture the Knight
it having been recaptured
and he must play Pawn takes Bishop
Trying to weaken his Pawn structure
but it wouldn't be weakened I guess
because his Bishop's off the board
so I haven't blocked the scope of his Bishop
which was the idea,
but let's look at it anyway

Episode 8 Knight takes Knight
Bishop takes Knight
Bishop takes Knight
and if he just takes the normal move,
Bishop takes Bishop
I play Bishop takes Bishop
plays Pawn takes Bishop
and the position seems to be approximately equal
except I just noticed that I have a fork on
Queen 7 with my Knight
which wins material
and therefore this alternative is ruled out for him
which is another good sign . . .
A little light in the darkness here

Episode 9 So to look at that again
Knight takes Knight
Bishop takes Knight
Bishop takes Knight . . .

EPISODE SUMMARY TREE

Ep	White	Black	White	Black	White	Black	White	Black	White	Black	White	Black	White	Black	White		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	<u>N/5(XQB/P'XN) -</u>																
2	<u>BXXN/5 N'XB</u>	<u>BXB'</u>	<u>N-K1</u>	<u>N-K1</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>(QXB') C</u>										
3	<u>NXXN' N'XX</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>KBXB'</u>	<u>P'XKB +</u>											
4	<u>NXXN' N'XX</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>QBXB' +</u>												
5	<u>NXXN' N'XX</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>KBXB'</u>	<u>P'XB +</u>											
6	<u>NXXN' B'XXN C</u>																
7	<u>NXXN' B'XXN +</u>																
8	<u>NXXN' B'XXN</u>	<u>KBXB'</u>	<u>N'XB</u>														
9	<u>NXXN' B'XXN</u>	<u>QBXXN'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>KBXB'</u>	<u>P'XB C</u>											
10	<u>NXXN' B'XXN</u>	<u>QBXXN'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>KBXB'</u>	<u>P'XB</u>	<u>N-Q7 --</u>										
11	<u>NXXN' B'XXN</u>	<u>QBXXN'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>KBXB'</u>	<u>P'XB</u>	<u>N-Q7 +</u>										
12	<u>NXXN' P'XXN C</u>																
13	<u>NXXN' P'XXN --</u>																
14	<u>NXXN' P'XXN C</u>																
15	<u>NXXN' P'XXN</u>	<u>B'XB'</u>	<u>N'XB</u>														
16	<u>NXXN' P'XXN</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>KBXB' O</u>												
17	<u>NXXN' P'XXN</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>(R'XB) --</u>												
18	<u>NXXN' P'XXN</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>(R'XB) --</u>												
19	<u>NXXN' P'XXN</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>(R'XB) --</u>												
20	<u>NXXN' P'XXN</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>B'XB'</u>	<u>(R'XB) --</u>												

B'XQP
Q'XQP
Q'XNP

(KR-QB) O
B-N4 -
K-N2 C

21	N×N'	P'×N'○							
22	N×N'	P'×N'○	(Q'×NP,○						
23	N×N'	P'×N'	Q-move--						
			R-move --						
24	QB×N'/6	B'×B	N-K4 ±						
		N'×B	.....	B' 3-move--					
25	P-KB4--								
26	.....	Q'×NP	R-B2 ○						
		R-N1	Q'×RP	R-N3				Q'-R4 --	
		R-N1	Q'×RP --						
27	.....	Q'×NP	R-N1	Q'×RP --					
28	.....	Q'×NP	R-N1	Q'×RP	N×N'	Q'×Q	N×B'	N×Q'	N×Q' -
					N×N'	QB×B'	Q'×KB'○		
						Q×Q'	B'×Q --		
29	.....	Q'×NP	R-N1	Q'×RP	N×N'				
		R-B2--							
		N-QB4○							
30	.....	Q'×NP	R-B2	Q'×RP	N-QB4--				
		R-N1							
		R-N1	(Q'×RP)	(N-QB4)	Q-R3			N-move --	
31	R-B2	Q'×NP	(R×Q')+						
		N'×N	R×N' --						
32	R-B2	(N'×N)	(R×N')○						
		P×N' +							
33	R-B2	N'×N	R×N'	B'-K5 --					
34	.....	N'×N	Q×N'	B'-away	Q×R'○				
		N'×N	.....	N'-K5 ○					
		N'×N	.....					
35	N×N'	P'×N'	.....	B'-QN4 --					
			Q-KB3	--	(B×N') +				
				B'-QN4	(B×N') +				
				N'-move	(B×B') +				
				K'-N2 ○					
				B'/3-move +					
				K'-N2					
				R-K1	.....	N×B'	.....	R×B' ±	

EPISODE SUMMARY TREE

E#	White	Black	White	Black	White	Black	White	Black	White	Black	White	Black	White	Black	White	Black	White
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
36	N'XN'	P'XN	Q-KB3	Q'XQP	B'XN'	B'XB	Q'XB'+										
				K'N2	R-K1	Q'XP	N'XB'	P'XN	R'XB'+								
								R'XN+									
								R'XN	R'XR'	P'XR	R'XB'	Q-Q8	(Q'XQ)+				
37	N'XN'	P'XN	Q-KB3	K'N2	(R-K1)	R'K1	N'XB'	R'XN	R'XR'	P'XR	R'XB'	R'XR	B'XN'+				
								R'XN	R'XR'	P'XR	R'XB'	R'XR	Q'XN'+				
38	N'XN'	P'XN	Q-KB3	K'N2	R-K1	(R'K1)+											
								Q-Q1+									
39	N'XN'	P'XN	Q-KB3	K'N2	R-K1	B-Q1+											
								Q-Q1	N'XB'	R'XN	R'XB'	(Q'XR)-					
								P'XN									
								R'XN	N'XB'	B'XB'	Q'XB+						
40	N'XN'	P'XN	Q-KB3	K'N2	R-K1	Q'Q1	N'XB'	P'XN+									
								N'XB'	N'XB'	R'XR	R'XR'	Q'XB	B'XB	Q'XB	Q'XB	Q'XB	Q'XB+
								R'XN	B'XB'	B'XB'	R'XR'	Q'XB	B'XB	Q'XB	Q'XB	Q'XB	Q'XB+
								N'XB'	B'XB'	B'XB'	R'XR'	Q'XB	B'XB	Q'XB	Q'XB	Q'XB	Q'XB+
41	N'XN'	P'XN	Q-KB3	K'N2	R-K1	Q'Q1	N'XB'	P'XN+									
42	N'XN'	P'XN	Q-KB3	K'N2	R-K1	Q'Q1	N'XB'	P'XN+									
								B'back									
								B'N4	R-K1+								
43	N'XN'	P'XN	Q-KB3	B'N4	R-K1	.....	R'XB'	R'XB'									
								R'K1	B'XB'	N'XB	Q'XB'	Q'XB	Q'XB	Q'XB	Q'XB	Q'XB	Q'XB
44	N'XN'	P'XN	Q-KB3	B'N4	R-K1	R'K1	R'XB'	(error made)									
								B'XN'ch	B'XB	(error made)							
								N'XB'									
45	N'XN'	P'XN	Q-KB3	B'N4	R-K1	.....	R'XB'	R'XB'									
								R'K1	B'XB'	B'XB	Q'XB'	Q'XB	Q'XB	Q'XB	Q'XB	Q'XB	Q'XB+
								B'XN'ch	B'XB	B'XB	Q'XB	Q'XB	Q'XB	Q'XB	Q'XB	Q'XB	Q'XB+

(error)