"INVESTIGATION INTO THE USE OF THE AFRICAN BOARD GAME, AYO, IN THE STUDY OF HUMAN PROBLEM-SOLVING"

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ABSTRACT

An investigation conducted into the use of a computer presentation and simulation of a game, AYO, reveals its usefulness in the study of human problem-solving since opponents whose level of sophistication can be varied systematically can be provided; subject's performance under various psychological conditions can be analytically examined and simulated. Pilot studies consisting of three experiments involving subjects whose familiarity with game playing and interaction with computers varied enormously, are reported.

INTRODUCTION

The use of games in the study of cognitive processes has been proposed by many workers (2,3,4,6,7). However, research work has in the past concentrated on such games as chess, checkers, GO etc. - games widely played in European and Asiatic cultures. Most of these games lend themselves to mathematical and algorithmic formulation, with the result that both the creation of hypotheses for testing and the simulation of the games by computer programs are relatively simple. Most of the games used so far also have a highly developed literature built up around them and competence at the highest level often involves many years of study and application. In this paper, the authors seek to introduce a game from a completely different environment. The game, AYO, is widely played among the peoples of West Africa and is a game of the Kalah family, which is largely unknown to Eurasian cultures. Despite the large population who play this game, detailed information on such sophistications as opening theory, various styles of play or how to play endgames have been lacking although the game is at least as complicated as some Western games for which these have been developed - Checkers or Backgammon for example. AYO is here considered as a tool for research into cognitive characteristics of the problem approach among the large population familiar with the game as well as a tool for studying the acquisition of the skill in players drawn from a different population which is largely unfamiliar with the task.

The use of AYO is hereby discussed with respect to three different areas of psychological testing: cognitive research; one-off testing of a subject for clinical assessment; and the serial assessment of one subject's performance as external variables (such as therapeutic conditions) are manipulated. Two basic approaches adopted by clinical psychologists, as discussed by Jones and Weinman (5) are: the classical rigorous psychometric approach and a more intuitive clinical approach, dealing with each subject in isolation. The latter approach is adopted in this paper where the emphasis is more on the analysis of a subject's method of working and the characteristics of his performance. Data collection is therefore geared towards obtaining such parameters that measure problem-solving skills and give the characteristics of the performance of subjects who play AYO. The argument in support of the use of games in cognitive research as against the use of puzzles is contained in Elithorn and Telford (4). Furthermore, the idea of computer control of item presentation as an effective contribution towards the work of a clinical psychologist is taken up and pursued. The characteristics of AYO have a simplicity which makes it particularly amenable to computer control of the strength of the opponent which the subject is pitted against, so that the subject can always be set against a program which is about his own standard.

Armed with these concepts a computerized version of the game, AYO, was developed and implemented on a PDP 8/E computer. A basic program was written to present the game, together with various subroutines for selecting which move the computer would play. The subroutines have parameters of strength which can be changed at the start of every game to set the task difficulty of the subject. The program was felt to have three different functions:

(i) providing opponents whose sophistication could be varied systematically;

(ii) becoming analytical tools to examine the subject's performance by comparison of the move the programs would have made with that which the subject makes; and

(iii) simulating the subject's performance.

Other programs for analysis were developed on ICL 1904S of Queen Mary College (University of London), utilizing its large storage facility.

A brief description of the board and the rules of the game, AYO, were given in a paper in Lagos, Nigeria by Sonuga (8). However, a detailed and differently connotated description will be given here. Following this, the role of AYO in psychological testing will be discussed and then the experimental method and some small experiments will be described. Finally, analysis techniques and the analyses of our experiments will be set out.

THE GAME AYO

AYO is played between two players on a wooden board called "OPON" which is almost rectangular in shape, and from which two rows of six hemispherical holes have been dug. The pieces are spherical seeds of a tree found in various parts of West Africa; but any convenient stones (for example, the stones used in GO game) can be used instead. The size of each piece is such as to allow each hole of the board to hold at least twenty seeds before overflowing. There are forty-eight pieces in a game of AYO and unlike some of the other board games, there is no difference between the pieces. For simplification, the convention adopted in this paper is to denote

(a) the holes on the side of the player P to move by P_1, P_2, ...P_6, in the left to right order and those of the opponent by Q_1, Q_2, ..., Q_6 (see figure 1);

(b) the number of seeds in hole P_1 say by (P_1) and

(c) the capture made by player P by C(P).

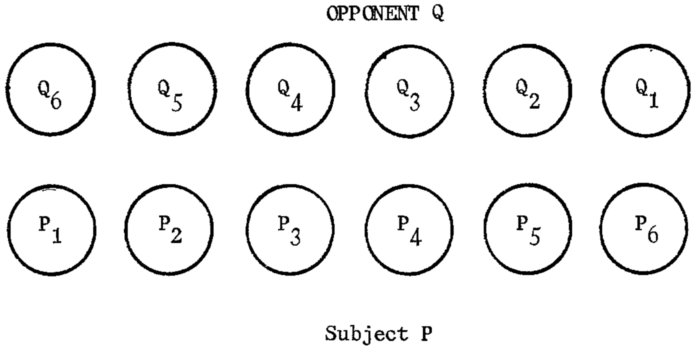


Figure 1. Notation

Play is commenced with four seeds in each hole of the players. The first one to move is decided in one of several ways. Like most board games, there is an apparent initial "advantage" to the first player.

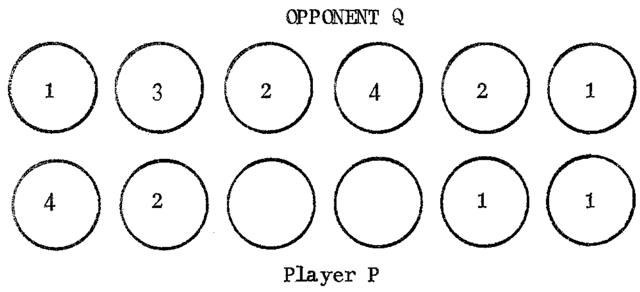
A player makes a move by selecting one of his holes, P_i say. He then picks all the seeds from P_i and starts to drop one seed in each hole starting with the hole immediately to the right of P_i (i.e., P_{i+1} if $1 \leq i < 6$ or Q_1 if $i = 6$) and proceeding counter-clockwise. If there are more than eleven seeds picked, then the hole P_i is always skipped during that move, so that at the end of the move, P_i is empty. The move ends when all the seeds picked up have been dropped. The player must, if possible, make a move which leaves the opponent with a move. If the last seed is dropped into one of the player's holes, the move ends and the opponent plays.

However, if the last seed is dropped into one of the opponent's holes, Q_m say ($1 \leq m \leq 6$) then the content of Q_m is examined leading to the following consequences:

(a) if (Q_m) is different from 2 or 3 after the last seed has been dropped into Q_m, then the move ends and the opponent, Q, plays next;

(b) if (Q_m) is 2 or 3 then
  (i) all the seeds in Q_m are removed; and
  (ii) working consecutively backwards in a clockwise direction, the contents of preceeding holes Q_k (where $1 \leq k \leq m$) are examined and removed if (Q_k) is 2 or 3; stopping when <u>either</u> the content of the preceeding hole is different from 2 or 3 <u>or</u> all the holes are exhausted and the opponent plays next;

(c) if a capture leaves all the opponent's holes empty, i.e., $(Q_n) = 0$ for all n satisfying $1 - n - 6$ then such a capture is illegal and the player makes no capture if he makes that move. Figure 2 shows a capture occurring in opponent's holes Q_5 and Q_6 but not in Q_2 where the last seed has been dropped into Q_5. At the end of the move, P captures five more seeds, i.e. $C(P) = 5$



<u>Figure 2:</u> P makes a capture on dropping the last seed into Q_5.

In normal play, the game ends when one of the players has captured more than 24 seeds or he is left with no moves.

COMPUTER BASED TOOL FOR PSYCHOLOGICAL TESTING

i) Psychological Testing

We wish to distinguish three different uses of psychological testing: research into cognitive functioning; one-off testing of a subject to assess whether there is any impairment to his intellectual abilities; and the serial assessment of a subject to assess whether his performance deteriorates or improves as external conditions (for instance therapy) are varied.

In cognitive research, we require tasks that expose to as great an extent possible the underlying thought processes behind the subject's performance. It is also of value for a task to be varied in such a way as to place emphasis on different aspects of performance, for instance, varying the memory component or changing the sense modality (as in presenting memory span visually or aurally.)

For one-off assessment, either a standard battery of tests is given and the subject's performance is compared to normative data or preset sequence of items arranged in order of difficulty is presented and testing ends when the subject begins to fail most of the items, a cut-off point between failed items and passed items indicating the level of performance. Thus a task should be capable of having its difficulty varied and before it can be used for this form of assessment a normative study should be run.

For serial assessment, there are completely different requirements, not a single series of items, but a large pool of items at each level of difficulty is needed. Serial assessment will then consist of one or more test sessions to set the subject's level of performance and then at subsequent sessions, items of about this level will be presented and fluctuations in the standard of performance noted.

ii) The Use of the Computer

For all three of these areas, computer control of item presentation is of great value. A fuller discussion of this point is given in Jones and Weinman (5), some benefits from computer presentation being: a tighter control of experimental conditions; the collection of more detailed information regarding test performance; the ability of the computer (given a suitable task) to generate countless items at any one level of difficulty; the ability to easily vary the difficulty as a function of previous performance; the immediate capture of data in a form amenable to further analysis; and the possible increase in subject motivation caused by interaction with the computer (1,5).

For research purposes, the tight control over conditions and ease of manipulating variables given by the computer makes it an essential aid. For routine assessment, a standard battery of tests can be automated, restandardised for the new set of conditions and then new subjects can be run by relatively untrained staff, thus freeing the clinician for more important work. If the subject's level of performance at a particular task is required, it is much easier for the computer to run a process controlled assessment, than for the clinician who would need after each item to score that item, calculate the level of difficulty to be given for the next item, find or generate an item of that difficulty and then present it to the subject. This may be relatively simple for tasks such as memory span, where length of series constitutes an easy measure of difficulty to manipulate and a simple list of numbers forms an easily accessible pool of items, but for more complex tasks this method of presentation is unworkable without the use of computer controlled presentation. In the case of serial testing, computer presentation again is valuable in the large-scale item generation necessary, as well as freeing the clinician from what would be a time-consuming job.

iii) The Use of Games

So far, these ideas of using computer presentation for the test items which are versions of standard psychological tests and which are essentially problems for which a solution possibly needs to be found have been developed - memorising a sequence of digits and then repeating them correctly or finding a path through a maze (5). We seek to extend some of these ideas to the use of automated games as a tool for psychological testing. The performance of a subject in playing an intellectual game is clearly no less an indicator of psychological functioning than performance on the puzzles which form the basis of many psychometric tests (4). The problem in using unautomated games is that it is even more difficult for the tester to provide a standardised opponent than it is for him to perform a process controlled assessment as described above. The variation introduced into the results by the unstandardised procedure by which the tester selects his moves will obscure any conclusions which can be drawn from them. If, however, the computer is used to simulate an opponent with a fixed strategy, then not only do we have a standard test situation for examining many subjects, but by varying the quality of the strategy provided we may also provide opponents of varying difficulty and so can home in on the subject's level of performance in much the same way as has been suggested for standard psychological tests. It should be pointed out here that it is unlikely that the construction of just one really strong opponent (the aim of workers in the field of artificial intelligence) will be of much value.

There are some desirable features which a game should have to be of use in the test situation. For a start, the game must be well-defined, in the sense of being formally describable and the simpler the description the better, since the game will then be easier to program and so make the creation of many opponents possible. The game should not however be easy, but should allow for considerable variation of expertise, which variation should be easily describable as a hierarchy of strength of performance. It is also desirable that there be many different strategies available to the player, so that the strategy adopted by the subject may be a reflection of his personality. If there are also a number of tactics to master it will prove illuminating to observe how a novice subject learns to use them. The degree of outward manifestation of thought processes behind a subject's performance is also an important parameter in the selection of a game. While protocols may be used to make performance more explicit, information derived from the performance itself is more reliable. Finally, if the form of presentation may be changed to place greater emphasis on one aspect of performance or another, then the game will be even more useful.

iv) The Selection of Ayo

With these criteria in mind, we were satisfied that Ayo was a useful game to try. It is simple to implement, the small number of available moves at each position meaning that programs which simply perform a complete search to a fixed depth of look-ahead can provide an effective opponent since the depth can be set much larger than that for many board games without running into time trouble. A large range of look-ahead also means that look-ahead is an effective index of strength on its own.

The game is not easy, but there are many identifiable strategies and tactics which can be built into opponents and which can be searched for in the subject's performance. The explicit data available from a game is not much, but the simple perceptual structure of the board makes it particularly amenable to eye-movement analysis.

Finally, we can vary the presentation in a number of ways. The standard presentation gives the board as a set of rectangles representing the holes with figures in them representing the number of seeds. Transition from one position to the next upon input of a move is instantaneous. Two ways of changing this presentation to examine different factors are making the transition period slower, giving more visual information to the subject regarding the move being played, and changing the presentation of the number of seeds to dots placed in the rectangle. For the first point, the example of examining the improvement in play of a novice, comparing subjects who get the instantaneous transition and subjects who get more information would be interesting. Changing the representation of the number of seeds in the holes, is of use in situations in which there are large numbers of seeds in some holes. As the game is played between humans, there is a rule governing this situation, which says that a player may count the seeds in his own holes by picking them up, but not those of his opponent, so that a memory component is introduced into the game. This may be simulated on the computer in a number of ways. For a start, if the computer builds up a large number of seeds in one hole, the number displayed may be set to upper limit, for instance, 10. Alternatively, the number of seeds may be displayed as dots, either spaced regularly, or, more usefully, irregularly, the difficulty of counting thus growing with the number in the hole in a way which exactly mirrors the real life situation. A further reason for using dot display, is the universality of counting which makes it applicable in non-European situations and in areas where the use of conventional numerals may impose some constraints on its acceptability.

Finally, a particular reason for using Ayo is that the familiarity with the game may be more easily controlled than with European games. The average non-African subject will have little familiarity not only with Ayo but with any game like it, and so it is possible to study the growth of ability from absolute beginnings to mastery, without having the cross-over effect from other games inherent in the use of European games.

THE PRESENTATION OF THE GAME

i) The Equipment

The experiments described were all run on a PDP 8/E computer with 12K of core (of which only 4K was needed by the computer), attached to which was a point-plot display on which the game was presented and an ASR33 teletype for recording responses. A real-time clock was used to record response times and this was set to record in tenths of a second, this figure being adequate to distinguish decision times and also being the shortest time easily recordable on our 12-bit machine. Responses and times were captured on paper tape for later analysis.

ii) The Test

The subject is seated at a teletype, with the display at eye-level immediately behind the keyboard. The variable parameters for that particular test are preset at both the console and the clock interface as follows: depth of look ahead and the controlling parameters for the strategy are "toggled" in, while the appropriate switches are manipulated for required timing. The testing program is then started.

The subject is confronted with the position of the board represented as twelve rectangular boxes (Figure 3), in two rows, the upper six rows representing the simulated opponent's (or the computer program's) holes and the lower row representing the subjects'. In each box, a number is displayed representing the number of seeds in that hole. Above the boxes are two numbers - the left one represents the last move made by the computer while the other represents the score, or the number of seeds captured, of the simulated opponent. Similar numbers are displayed below the boxes for the subject's side. Initially, these numbers are set to zero and each box contains 4.

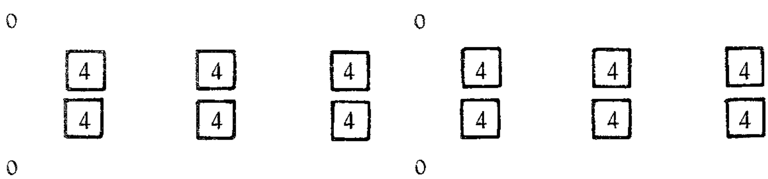


Figure 3: Test Presentation on the computer

The clock is started; the subject is then invited to type in one of the numbers 1 to 6, representing his move (1 represents that he desires to play from the leftmost hole, while 6 represents the rightmost hole). The display changes instantaneously to the position following that move unless the hole selected has no seed in it (or the key pressed is not within the range) in which case the response is ignored. The valid response is recorded both on the teletype and in core. If the subject is not satisfied with the move, he has the option of typing "R" (which is also recorded for subsequent analysis) to retract the move whereupon the display instantaneously reverts to its previous position and the subject may make a different choice. If, however, the subject is satisfied with the result of this move, he types "N" and the computer selects a move (sometimes removing the display for a short time) and changes the board instantaneously to represent the position after its move. In this case, the computer's move, the time taken for the subject to make the move, and (if the score has changed) the scores of the subject and the opponent, are recorded. Illegal moves which leave the computer with no move are not, as yet, trapped and result in the end of the game as the computer program desperately searches forever for a move. A legal end of the game occurs when the board is reduced to three seeds when no more captures are expected.

iii) The Simulated Opponent

Of the great range of possible strategies which may be programmed, the simplest only so far have been programmed. The first program, AYOR, selects its move randomly and is expected to simulate a "blind" player with no goals. It will be shown later that such a program is easily beaten by the merest novice. The second range of programs, AYOLn, use a complete search of the next n halfmoves from the position making a maximin estimation of the values of the available moves based solely on the number of seeds captured as an index of value and selecting the move with the highest value. The depth of look-ahead, n, is a variable parameter of the program and is used as the main component in a measure of the opponent sophistication. The strategy employed to choose between moves of equal values forms the other component of program difficulty. One variation, AYOLnD, of AYOLn, selects the leftmost hole of the equally-valued holes (that is preferring Q_1 to Q_2 etc), thus employing an essentially attacking strategy. Analyses of a few games revealed that AYOLnD provided a more powerful opponent than did AYOLnA and so the strength of programs are in the order AYOR, AYOL1A, AYOL1D, AYOLnA, AYOLnD, etc.

iv) The Experiments

The experiments reported here were all in the nature of pilot studies, to familiarise ourselves with the test situation and to try to find some of the important variables of performance and obtain some measures of performance. All of the subjects were of graduate level, although their familiarity with the game Ayo, game playing in general, and interaction with computers, varied enormously.

Experiment I was an initial attempt to examine the effect of opponent strength upon performance. Three opponents were selected, AYOR, AYOL2A and AYOL2D and three subjects, JJ, SN and JOL (all of whom were relatively inexperienced at the game) were tested on all three opponents in one test session. The order of presentation was balanced for the three subjects in such a way that each opponent appeared as the first opponent of one subject, the second opponent of another subject and the third opponent of the remaining subject. We would predict that the final score of the game would be related to opponent strength but, given an objective measure of move quality, we would also be interested to see if this were related to opponent strength.

Experiment II turned to the effect of different quality of subjects all playing the same opponent. Opponent AYOL2D was chosen and eight subjects, four rated as inexperienced subjects (the three subjects from Experiment I and the subject JH from Experiment III) and four rated as relatively experienced Ayo players (RC, BO, AS and FA). We would predict that the scores of the games would be related to subject quality, but would also be interested to test our objective measure of move quality and also to see the effect on other variables such as average time of move.

Experiment III was a pilot run for an examination of the effect of learning on one subject's performance. Novice subject JH was tested on two opponents each day for 14 days; the first day the subject played against AYOR and AYOL1A (the two easiest programs) and on subsequent days the difficulty of the opponents was adjusted in a subjective manner, so that the subject was required to play a better opponent if she performed well, an easier one if she performed badly. We were interested in examining improvements in her performance over time, as well as making the technique more rational. We would expect that if our measures of competence were valid that they would improve over time, and that other parameters such as time would also vary.

RESULTS AND ANALYSIS

The subject's performance can be examined from the following angles: (i) what strategies are the subjects employing; (ii) how far ahead is the subject able to plan; (iii) what errors in carrying out his plan is the subject making. In the analysis, use is made of the responses, times and captures to extract underlying plans from the game. For instance, examples of a long response time followed by a series of short times culminating in a capture may be said to show a plan being formulated and then being executed over the moves. Similarly, if a computer simulation of a particular strategy gives the same moves as the subject makes, there is reason to believe that the subject is carrying out this strategy. Analysis of this kind is complicated by two factors: two different strategies may give the same response; and errors in the subject's application may indicate that the subject is attempting to carry out a different strategy than the one he is following. Averaging over many moves should bring out whether there is any plan consistent with most moves and at the same time spotlight deviations from this general strategy.

The output of a sample is given as appendix A and consists of the moves selected by the subject, as well as those tried and rejected (S), the moves selected by the computer (C), the subject's response time (T) and the scores (SS and CS). In the analysis of a particular game, the immediately availables - the scores and average response times - were examined before the data was subjected to more detailed analysis to obtain the distribution of holes selected, the distribution of response times and the captures made by the subject. Finally, we attempted to match the subject's responses with those that would have been made by some simulated opponents, from which we derived an objective measure of move quality, by considering the best of the simulated opponents.

In examining the distribution of holes selected, the percentage of moves made from each of the six holes were calculated and the distribution was tested by a one-way X^2 to see if it deviated from the uniform distribution.

Analysis of the response times concentrated on the long times, the distribution of the number of moves between each long time giving an indication of existence of planning. Sample traces of response time are given as figures 4 and 5. These show three main phases of the game - a short opening where the subject has no firm indication of the nature of the game and has medium-length response times; a middle game characterized by long planning times; and end game in which a few medium length planning times are tempered by many very short times.

Next, the performance relating to each capture was considered. The sequence of times leading up to each capture were examined to see if long-term planning preceded this capture. Another indication of planning was felt to be the case where the hole selected for the capture, had not been selected for sometime before. This was felt to show that the move was being prepared for some time in advance.

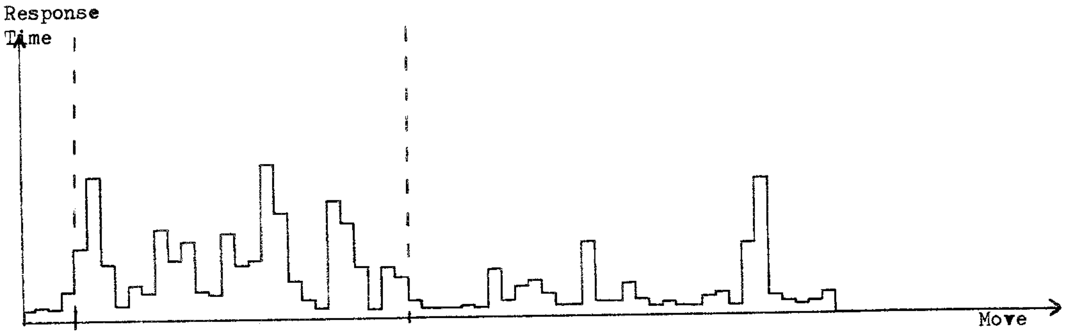


Figure 4: Response Times of Subject RC versus AYOL2D

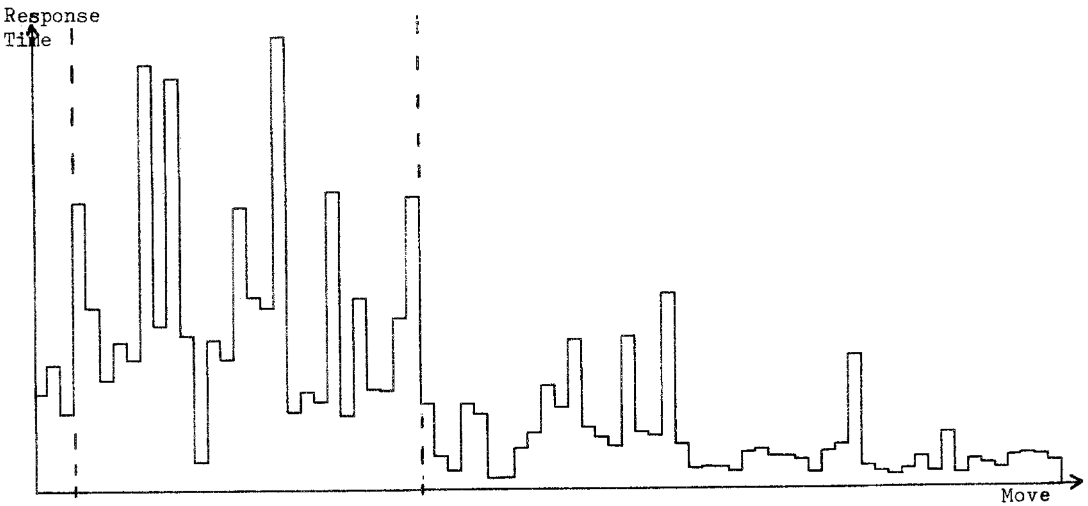


Figure 5: Response Times of Subject SN versus AYOL2D

The final analysis was at first just an attempt to discover if any underlying strategies of performance exist. The technique was to input each of the positions that the subject encountered in his game to a program which simulated a given strategy. The program then output for each position its evaluation of each of the moves, together with the number of moves it considered better, equal and worse than the move the subject chose. These numbers were then summed over the whole game giving totals B (better moves) E (equal) and W (worse moves) and the index $\frac{W}{B+W}$ was felt to be an index of the subjects agreement with the strategy. Contributions to the total B indicate where the strategy and subject part company and these situations can either be due to the subject not using the strategy at that point or to an error in carrying out his plan. The only strategies so far used are the simplistic AYOLn strategies - in which complete search of look-ahead n, for values of n ranging from 1 to 8, was tried. At this point, it was felt that AYOL8 was our best objective estimate of a good move-simulated opponent, AYOL8D being able to defeat our best subject (a very experienced Ayo player). So, it was felt that the value $\frac{W}{B+W}$ obtained from look-ahead 8 should be used as an index of game "quality". In averaging this value over several games, W and B were calculated for all the games considered as a whole and $\frac{W}{B+W}$ recalculated; rather than averaging $\frac{W}{B+W}$ separately. Testing the difference between the quality of two games or the set of games could then be achieved by use of X^2 test between pairs (B,W) of the games.

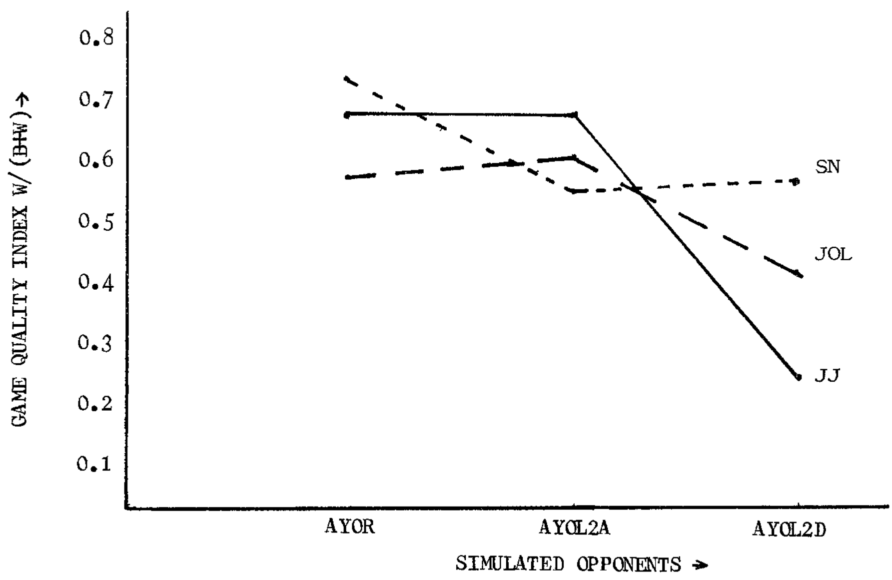


FIGURE 6: PERFORMANCE OF 3 SUBJECTS AGAINST 3 OPPONENTS

Experiment I

Table I sets out the results of the analysis of the three games of each subject. In the first three columns, the subjects simulated opponent, the subject and the sequence in which the subject played this opponent are given. Then the score of the game (subject score first), average response time and quality score for the game are given. As expected all subjects defeated AYOR, the random opponent, thus showing the existence of sufficient prior knowledge for a naive subject to perform better than random. All three subjects lost narrowly to AYOL2A and while one subject managed a draw with AYOL2D, the other two lost heavily. From the combined computor scores of the three subjects an index of strength of the three opponents' strength, AYOR = 34, AYOL2A = 69, AYOL2D = 74 giving the order of strength described above, (this order is confirmed by data gathered more informally).

Simulated Opponent	Subject	Seq	Score	Av. Time	$\frac{W}{B + W}$
R	JJ	1	27–10	39.8	.681
	JOL	3	33–11	25.5	.572
	SN	2	32–13	22.2	.744
AYOL2A	JJ	2	20–22	24.5	.675
	JOL	1	21–23	21.7	.603
	SN	3	19–24	13.0	.545
AYOL2D	JJ	3	3–38	17.8	.282
	JOL	2	7–34	15.6	.407
	SN	1	22–22	20.2	.569

Table I: STRENGTH OF SIMULATED OPPONENTS

Figure 6 gives a representation of the performances of the three players against the three opponents. One of the simulated opponents, AYOL2D, gives more discrimation among the subjects than do the two others.

Turning to more objective measures, the average response time appears to drop with opponent, but this is more likely to be due to games against poorer opponents tending to be of shorter duration and so to be lacking the short times characteristic of the final part of the game. The results with move "quality" are more complex. There are no differences between subjects, but there appears to be a significant deterioration of performance as the opponent gets stronger. This effect is however confused by other apparent effects - a fatigue effect (the third game being worse than the first two) and a morale effect, as games following defeats seem to be played somewhat worse than games following wins and draws. The small number of games makes it impossible to untangle these features.

Experiment II

In Experiment I, opponent AYOL2D gave more discrimination between the subjects than the other programs and so it was selected for use in the analysis of subjects of varying competences. The eight subjects fall into roughly two groups - four experienced and competent Ayo players and four relatively naive subjects. Table II gives the results of the eight subjects. It can immediately be seen that the more experienced subjects do much better than do the naive subjects against the common opponent and take less time over their moves. The objective measure also distinguishes the two groups, the worst of the experienced subjects being better than the best of the naive subjects.

Subject	Score	No. Moves	Av. time	$\frac{W}{B+W}$
JJ	3-38	22	17.8	.292
JOL	7-34	45	15.6	.407
SN	22-22	78	20.2	.569
JH	25-15	39	18.8	.739
BO	25-20	100	9.2	.840
RC	25-21	61	8.0	.822
AS	37-8	42	14.6	.794
FA	32-14	51	5.6	.797

Table II: Two groups of subjects vs. a common opponent, AYOL2D.

Day No.	Opponent	No. Moves	Score	Av. Time	$\frac{W}{B + W}$
1	R	54	41-4	26.8	.807
	1A	44	35-10	18.5	.865
2	1D	37	27-12	18.2	.760
	2A	140	10-32	16.7	.753
3	2A	84	20-22		.805
	1D	32	24-18		.702
4	2A	156	35-7	11.8	
	-				
5	2D	71	23-21		.756
	3A	43	14-18	27.2	.813
6	3A	40	8-32	12.8	.745
	2D	97	25-18	11.4	.803
7	3A	43	24-20	27.7	.868
	2D	39	15-25	18.8	.739

Table III: Serial Results of the first 7 test days of subject, JH.

Experiment III

It is to be expected that if other conditions are kept constant, putting a subject through a series of runs on the game should produce some performance affected by learning. Improvement over time and a pattern of approach to problem-solving should be exhibited. Table III gives the analysis obtained from the data of the first seven days of the experiment. Improvement in time is noted as Figure shows. However, the index, $\frac{B}{B + W}$ for measuring move quality within a game does not show any particular trend.

Problem-solving Approach (Planning)

In examining the characteristics of the performance of the subjects, a general picture of the whole game is considered as against individual variables like time, score and total number of moves. The first indication that a subject is not playing randomly is shown in an uneven distribution of hole-selection. Table IV gives the

Subject	1	2	3	4	5	6	1+2+6
JJ	22.7	18.2	13.6	9.1	13.6	22.7	63.3
JOL	26.7	15.6	11.1	11.1	13.3	22.2	64.5
SN	17.9	14.1	19.2	16.7	16.7	15.4	47.4
JH	12.8	25.6	23.1	12.8	7.7	17.9	56.3
BO	17.0	25.0	13.0	18.0	17.0	10.0	56.0
RC	11.5	21.3	21.3	21.3	11.5	13.1	44.9
AS	14.3	16.7	14.3	23.8	21.4	9.5	40.5
FA	17.6	11.8	21.6	23.5	11.8	13.7	43.1

Table IV: Percentages of Selection of each hole percentages of each subject playing from each hole. An immediate difference is noticed between the values for experienced and inexperienced players.

Three of the four experienced players make less than 45% of their moves from holes 1, 2, and 6 whereas three of the four inexperienced players make more than 55% of their moves from these end holes. The game of the only inexperienced player SN deviating from this trend is discussed at length later. This shows that the inexperienced players, as expected, tend to concentrate their attention on the sides of the board where pieces seem to them to be more vulnerable. The experienced players, who have come to realise that this is not the case, do not make this type of inadequate judgement.

In real life situations, attacking players tend to play from the rightmost holes (i.e. 5 and 6) so as to get pieces in the opponent side for subsequent capture. From the games analysed and reported, none of the subjects exhibit this trait. On the other hand the defending players make most of their moves from the leftmost holes (1 and 2). The results show that subjects JJ,JOL and JH in Group 1 and BO in Group 2 fall into this category.

Group 1 subjects make more of planned captures than group 2 subjects, as shown in the table below where each major capture is preceeded by a high response time a few moves before the capture. It is expected that if the subject is clear in his mind that the plan is sound, the response times leading to the final execution of the plan should be lower than the time spent in planning.

Subjects	Major Capture	Move No.	Time for Move	Preceeding times Prior to Capture
JJ	3	16	67	34, 55, 92, 406
JOL	3	19	215	81, 94, 111, 176
SN	8	26	403	155, 620
JH	6	37	49	114, 24, 60, 26, 108
BO	10	27	267	39, 71, 142
RC	8	16	179	50, 57, 103
AS	12	16	468	128, 148, 217
FA	14	12	64	180

<u>TABLE V</u> : PROBABLE INDICATION OF SUBJECT PLANNING.

The Special Subject, SN

SN's results are worthy of separate analysis and comments. We hesitate to hypothesise that the personality of the player shows immediately in one single game. However, SN's approach to problem-solving and new challenges (e.g. performance at a new game ADVICE) has shown that she calculates her moves quite methodically and is known not to possess extreme tendencies. Her average time of 20.18 and total moves of 78 in Table II point in this direction. In Table IV, her hole selection is fairly uniform and the fact that her game, of all, ends in a draw is a further indication. Figure 6 (Graph) gives a clear picture of the characteristics of her game as being immediately (or spontaneously) methodical.

SUMMARY

Having created an automated version of the game, Ayo, whose strength can be varied at will, and run a few subjects through the test situation, we feel able to suggest that the test generates sufficient information to be of use in the psychological laboratory. However, a more useful stage can be achieved when the simulated opponent can be made flexible enough to modify its strategy to match the competence of the subject. The requirements at this stage will be larger storage facility, faster processor and more efficient searching algorithm.

Indication not only of problem solving competence and planning ability, but also of performance style and personality, which are the features of any demanding game can be quantified by the use of a standardised test procedure. By varying the presentation of the test, different facets of performance can be investigated. The game can also take its place alongside Chess, Checkers and GO in the field of cognition research, particularly as the board has a simplicity, which makes it an ideal task for analysis by eye-movement methods. In short, with sufficient refinement, the automatic, test presentation of Ayo should prove extremely useful in many areas.

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Appendix A. Sample Output from a Game

S	C	T	SS	CS
6	1	274		
4	1	78		
6	1	202		
5	1	288		
1	4	187	0	4
1	6	480	0	6
3	3	383	0	12
2	4	83	0	15
3	1	488		
4	3	121		
5	2	169		
6	6	406	0	23
5	1	92		
6	3	55		
1	5	34	0	28
6	4	67	3	34
1	2	120		
2	6	43	3	38
1	3	69		
2	4	35		
3	5	57		
2	6	183		

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