Title	ANALYZING EYE-FIXATIONS TO ASSESS INDIVIDUAL DIFFERENCES IN SOLUTION STRATEGIES FOR SPATIAL TASKS
Author(s)	SATOH, Kimiharu
Citation	乳幼児発達臨床センター年報, 14, 81-91
Issue Date	1992-03
Doc URL	http://hdl.handle.net/2115/25281
Type	bulletin (article)
File Information	14_P81-91.pdf

ANALYZING EYE-FIXATIONS TO ASSESS INDIVIDUAL DIFFERENCES IN SOLUTION STRATEGIES FOR SPATIAL TASKS

Kimiharu Satoh
Hokkaido University

The purpose of this study is to clarify the individual differences in solution strategies for spatial tasks in an intelligence test. Twenty-nine undergraduates carried out paper-folding tasks, of the type sometimes used in measuring the spatial ability of intelligence. Each subject's sequence of eye fixations was recorded during the task solution. The differences in solution strategies between high-spatial ability subjects and low-spatial abilities were demonstrated through an analysis of the eye fixation data. The high ability subjects were those who either constructed the spatial representations quickly with no backtracking through the stimulus items or used many searching eye movements back and forth between the stimuli and response alternatives. Low-ability subjects showed more eye tracking through the stimulus items and required more time to construct the spatial representations.

Key words: intelligence, spatial ability, scanning strategy

INTRODUCTION

Differential or psychometric approaches to understand the nature of intelligence dominated theory and research in the first half of this century. Investigators using such approaches have shared the desire to understand intelligence in terms of a set of underlying abilities, such as, for example, verbal ability and reasoning ability. These underlying abilities are identified by means of a mathematical technique called factor analysis. Indeed, we have become increasingly able to specify the knowledge used in response to various kinds of test items. Psychometric approaches have laid greater stress on the results of intelligence performance tests than on the processes used in responding to the test items. Psychometricians have been criticized for their inattention to the processes that give rise to the results measured by the tests (Sternberg, 1982).

During the 1970s, a lage number of investigators took an information processing or cognitive approach towards understanding intelligence. This approach is termed to be the " New look in Intelligence Research " (Resnick, 1981; Keating, 1984). The goal of this research is to discover the representations, processes, and strategies subjects use in solving problems widely acknowledged to require intelligence for their solution.

Sternberg (1981) has classified these cognitive approaches into four different categories, i. e. cognitive components, cognitive correlates, cognitive training, and cognitive contents approaches. Here, I will pay attention to the componential and correlational approaches.

The cognitive components approach is typified by the work of Robert J. Sternberg. The cognitive components approach is task analytic and attempts to directly identify the information processing components of performance of tasks generally used to assess mental ability. The fundamental unit of analysis is the component, which is an elementary information process that operates upon internal representations of objects or symbols. A componential theory consists of two parts: identification of the components involved in task performance, and specification of the combination rule for these components (Sternberg, 1977).

In componential analysis, individual differences may derive from five sources: (1) components, (2) combination rules for components, (3) order of components processing, (4) mode of components processing, (5) component time or power (Sternberg, 1977). Individual differences may occur in components. Some subjects may solve problems using components a, b, c, and others using components c, d, e. In terms of component time or power, some subjects may perform certain operations more quickly or more easily than do other subjects. Sternberg has succeeded in developing his unique theory and describing the individual differences using analogical reasoning tasks.

However, some questions have been posed regarding the componential approach. For example, that this approach could not sufficiently explain the existence of individual differences in performance on intelligence testings which are used in real life because it focuses mainly on analyzing and theorizing about the structure of cognitive components as task variables.

The cognitive correlates approach seeks to specify the information processing abilities that are differentially related to high and low levels of aptitude. Tests of intelligence are used to identify subgroups which are then compared in laboratory tasks involving cognitive processing characteristics defined by prior experimental investigation (Pellegrino & Glaser, 1979). The work of Hunt and his colleagues (Hunt, Lunneborg & Lewis, 1975; Hunt, 1976; Hunt & MacLeod, 1979; Hunt, 1985) provides a good example of this approach. They raised a series of questions about the differences between high and low verbal or spatial ability groups that relate to structures, processes, and parameters of the information processing system. The intent of this approach is to ascertain the basic information-processing differences that distinguish high from low-ability persons. The results obtained by Hunt and his colleagues strongly suggest the presence of basic information processing differences between high and low verbal ability groups. That is, a series of their experiments has suggested that undergraduates who score highly in a verbal ability college entrance examinations show faster performance in tasks that require information to be accessed in the long-term memory and manipulated in the short-term memory. In general, they conclude that verbal intelligence tests gauge a person's knowledge of language, such as the meaning of words, syntactic rules, and so on, and that these tests also indirectly assess to the information processing capacities fundamental to experimental studies of memory.

The central problem of this study is to specify the differences in the processes and selection of solution strategies which have been used by good and poor spatial thinkers faced with a spatial task. The eye tracking data has been analyzed in order to describe the solution strategies. The final goal of this study is to explain the causal mechanisms of occuring individual differences of the spatial ability, that is, what makes some individuals better than others at solving spatial problems.

Some cognitive psychologists are interested in eye-movement tracking which is a useful device for analyzing cognitive processes. Just and Carpenter (1976, 1985, 1986) have applied this eye tracking approach to the study of test-like cognitive tasks, including mental rotation, sentence-picture comparison, and quantitative comparison. Their data suggests that eye fixation sequences can be linked to cognitive processing models. Snow (1980) has also used the eye fixation data to identify solution processes used in spatial and verbal subtasks of intelligence tests.

METHODS

Subjects

Total IQ score and SS scores of 12 subtests of the Kyodai (Kyoto University) NX-15 intelligence test were obtained for 39 undergraduates. From these, 29 (14 females; 15 males) were chosen because of their high or low composite scores of visualization and spatial ability subtests of NX-15.

Four items plus a practice paper-folding task were carried out by these 29 final subjects under conditions allowing VTR recording of each subject's sequence of eye fixations during item solution.

Materials

(1) Paper-folding task.

The task chosen for this study was a modified version of the Paper Folding test (French, Ekstrom, & Price), in which subjects are asked to imagine that a square piece of paper is folded one or more times, punched once through the folded layers, then unfolded. In each item, a sequence of figures depicts the folding and punching process. The subject then chooses one of the five multiple-choise response figures that show a selection of locations of the holes in the unfolded paper. The paper folding task was also used to identifying the individual differences of spatial representations as cognitive aptitudes in Snow et al's Aptitude Process Studies. Using 17 undergraduate subjects, a pilot study determined two moderately difficult items of each F-2 & F-3

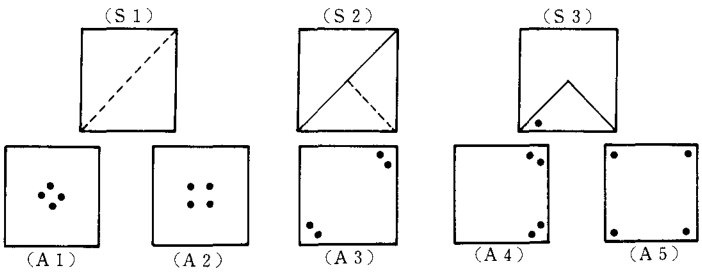

FIGURE 1 An Example of the paper-folding task (F-2 Task)

Task and one practice item. F-2 (2 folds) and F-3 (3 folds) Tasks differed in terms of the number of folds per item, i. e., the former being easy and the latter difficult. Figure 1 shows an example of F-2 Task. All items were presented on an opaque screen using a single frame projector.

(2) Recording of eye-movements

An Eye Mark Recorder (NAC) was used to record eye movement during item performance. This eye-movement recorder is head mounted and designed to record an observer's visual fixation and eye scans by imposing a fixation mark on the recorded visual field. Data was obtained with using a recording device and stored on VTR tapes.

Procedure

Subjects were given a paper-folding demonstration and one practice item. They were then fitted with an eye movement recorder and performed 4 items of F-2 and F-3 Tasks. Subjects were asked to press the response key and report the position number of the response alternative verbally as soon as they detected the correct alternative. Reaction time and correctness of response were recorded on VTR tapes in which eye movement data was recorded in a synchronized fashion. Subjects performed items and were handled individually.

Data Analysis of Eye-Movements

The eye fixation data was analyzed semi-automatically by a computer-assisted eye-movement data processing system (Figure 2). In this system, the eye tracking

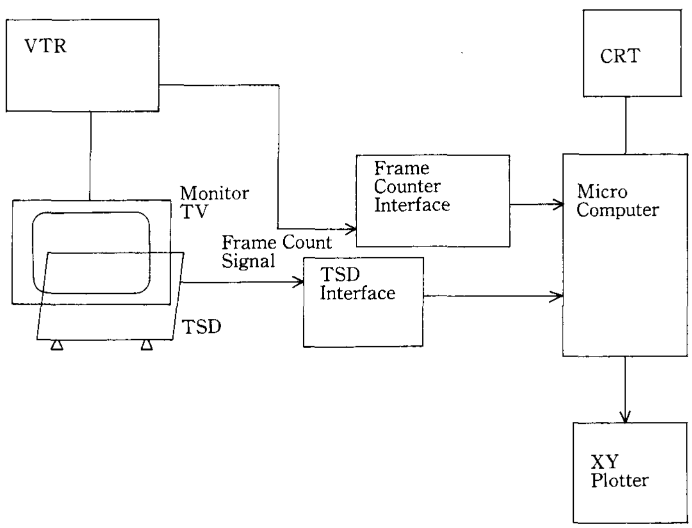

FIGURE 2 A Schematic diagram of eye-movement data processing

data was entered into a micro computer through a TSD (Touch Screen Digitizer), which was mounted on the display of the monitor TV. The duration time of each eye fixation and the distance between two fixation points were computed automatically, with the scan paths being traced by an X-Y plotter.

RESULTS and DISCUSSION

Overall Performance

The first stage of analysis examined correctness and reaction time for the paper -folding task. Table 1 shows the mean initial RT and the mean number of correct responses of high and low-spatial-ability subjects on both F-2 and F-3 Tasks. High ability subjects showed shorter reaction time than did low ability subjects, with the difference being especially pronounced in the F-3 Task. However, in general the reaction time data seemed to reflect more complex kinds of underlying individual differences in information processing than can be ascertained by simple generalizations associated with reference abilities.

TABLE 1

RT and correct response of high- and low-subjects on paper-folding task

	composite score of spatial ability (NX-15)	Paper-Folding (F-2)		Paper-Folding (F-3)	
		initial RT	correct	initial RT	correct
High-ability sub. (n=14)	60.54 (6.04)	12.04 (4.29)	1.86 (0.36)	24.93 (11.33)	1.43 (0.76)
Low-ability sub. (n=15)	46.45 (4.50)	15.41 (7.12)	1.73 (0.45)	31.58 (16.56)	1.0 (0.75)

The mean number of correct responses in the F-2 and F-3 Task were moderately correlated with the composite spatial ability score of NX-15 ($r=.44$, $P>.02$). A major direction of the cognitive correlates approach for intelligence was sought to identify the basic cognitive processes that distinguish between high and low scores on a particular intelligence test. It has been justly expected that there should be a strong relationship between performance in laboratory information-processing tasks and scores on global measures of aptitude, such as IQ tests. However it has been frequently pointed out that a positive correlation could not be obtained between them. The theoretical argument is supported by data from studies that have indicated a positive relationship between the laboratory tasks and intelligence measures. The results of the significant correlation from this study permits us to examine and discuss the following results.

Solution Strategies and Eye-Movement Analysis

(1) Patterns of processing

With Paper Folding, the subject's task is to examine the upper row of pictures, understand the series of folds made in the piece of paper, and note where the hole is punched in the folded paper in the final frame. He must then decide what the paper would look like when unfolded, and find it among the five response alternatives in the lower row. It was hypothesized that there were three different stages or steps of processing before the subject reacted to the response. These steps were tentatively labeled "constructing spatial representation," "selecting response alternatives or reacting," and "reconstructing spatial representation." The third step did not occure other than when the subject detected the inaccuracy of their own spatial representation. Figure 3 shows a flowchart model of a solution process in the paper-folding task. Some subjects appeared to repeat these steps several times, often in a rather disorderly fashion. Others seemed to spend almost all their time constructing, some shifting between stimulus and response parts of the item, and some not.

It is expected that the following patterns of processing exist. The high spatial ability subjects seem to perform a systematic and efficient analysis of the folding and unfolding steps in the stimulus row. Only after this systematic analysis of the stimulus does he look at the response row. He systematically scans across the response alterna-

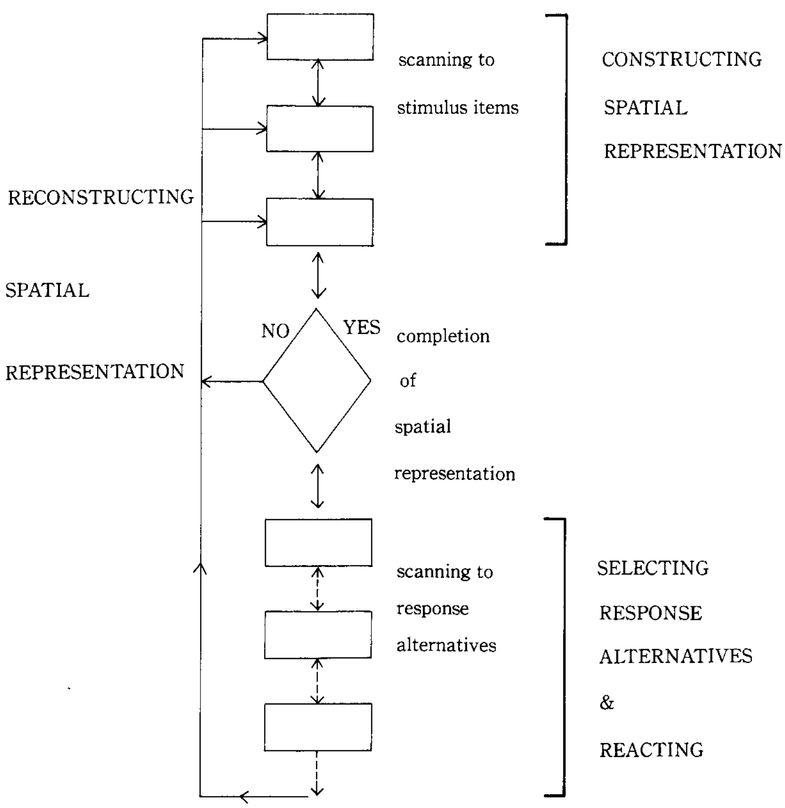

FIGURE 3 A flowchart of solution process in paper-folding task

tives. He then completes his scan, checks back to be sure, and finishes. The pattern for the low ability subject on the same item is unsystematic and inefficient. In particular, he spends more of his time comparing the stimulus row and constructing the representation, because of his poor ability to visualize the folding-unfolding process and to construct the representation of the unfolded paper.

(2) Eye-movement analysis

The upper part of Figure 4-(a) and -(b) shows the gaze time of both high and low ability subjects on each stimulus item and response alternatives in the F-2 Task. The low spatial ability subject spends more of his time looking at the third stimulus item in both steps of the constructing and the reconstructing representation. This would indicate that he needs more time to construct his spatial representation.

The mean number of fixations on each stimulus item and response alternatives, and some results of the sequential patterns of fixation are illustrated on the lower part of Figure 4. When analyzing the sequential patterns of fixation, the following two main scanning strategies were observed. They were respectively named " Backtracking " and " Checking ". " Backtracking " refers to the backtracking of the scan between stimulus items. A comparing and switchbacking type of eye tracking between stimulus items and response alternatives is defined as " Checking ".

The number of fixations on the stimulus items during the constructing period is greater for the low spatial ability subject than for the high. Especially the number of " Backtracking " in this first step is significantly greater for the low-ability subject.

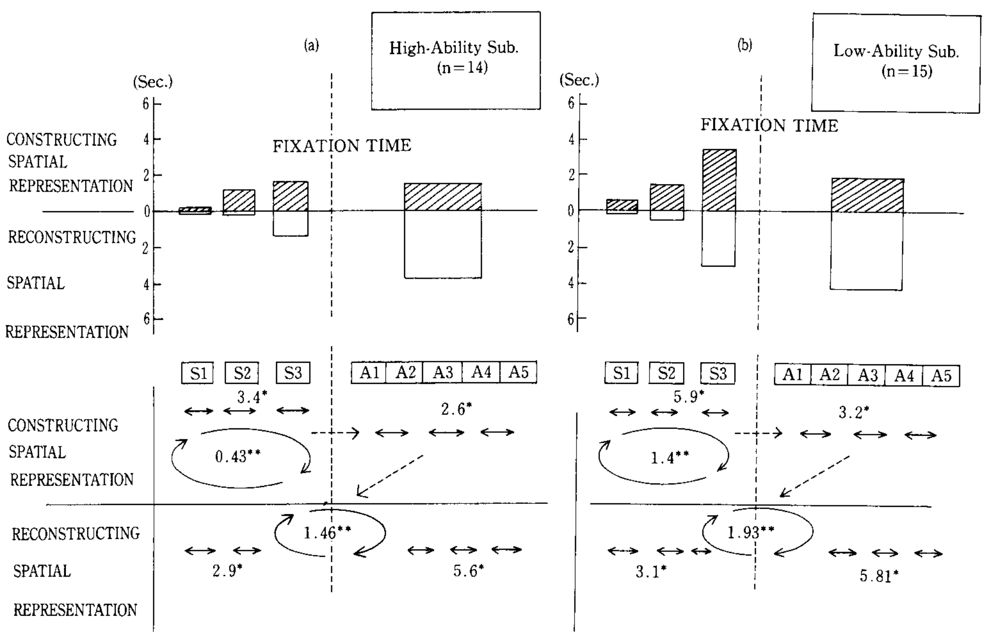

FIGURE 4 Fixation time and sequential patterns of fixation
* : number of fixation points
** : backtracking scan between stimulus item
*** : comparing and switchbacking type of eye tracking between stimulus items and response alternatives

This would correspond with the results of the gaze time.

(3) Four different types of problem-solving strategies

By analyzing the sequential pattern of fixation, four different types of subject can be identified. The " High-speed Scanning (HS)" subject performs a rapid and systematic analysis of the stimulus items. He also systematically and rapidly scans across the response alternatives after the analysis of the stimulus. He then completes his scan, checks back to be sure, and finishes (see, Figure 5-a and 6-a). In contrast with the HS subject, the " Low-speed Scanning (LS)" subject scans unsystematically and inefficiently. He continually jumps from stimulus row to response row without any clear purpose (Figure 6-b). A sample eye-movement track of LS subject is illustrated on Figure 5-b.

" Systematic Comparison between Stimulus Items (CS)" is used by several low -ability subjects. They show systematic and sustained stimulus comparison processes, backtracking many times and devoting most of their time to this step (Figure 5-c, 6

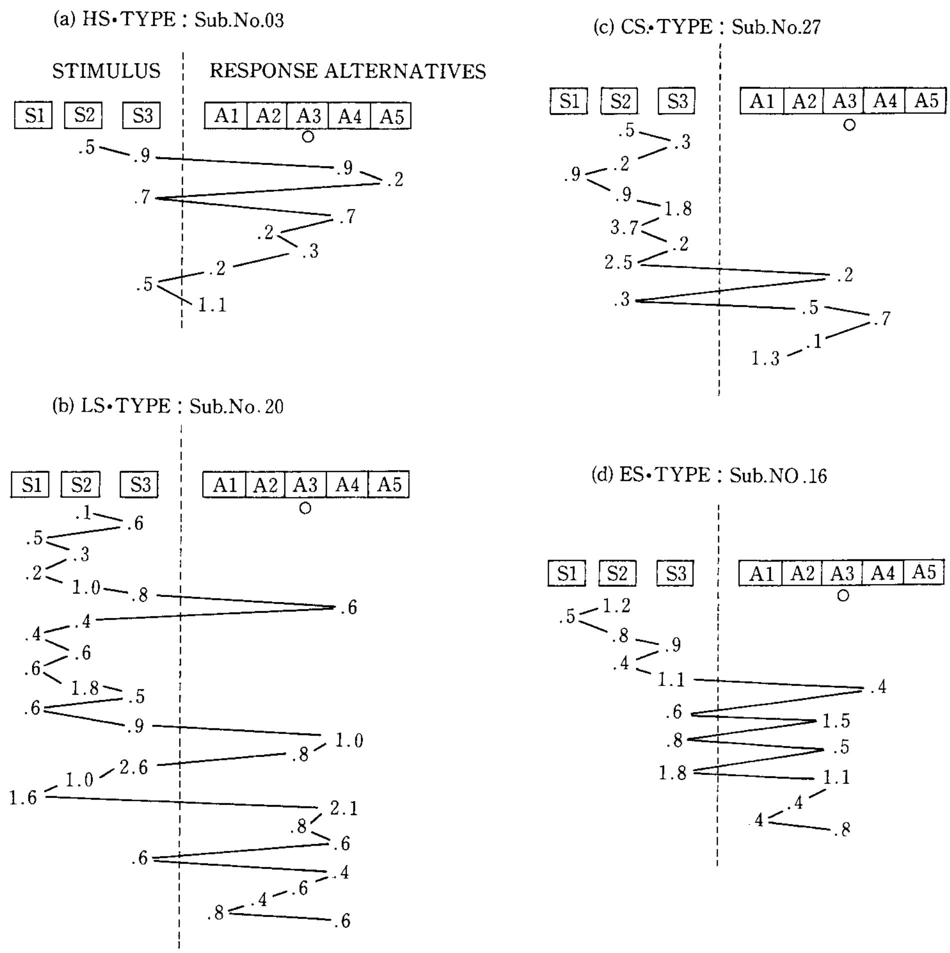

FIGURE 5 Eye-movement tracks for four subjects.
Time runs from top down in each track. Numbers indicate pauses in seconds.

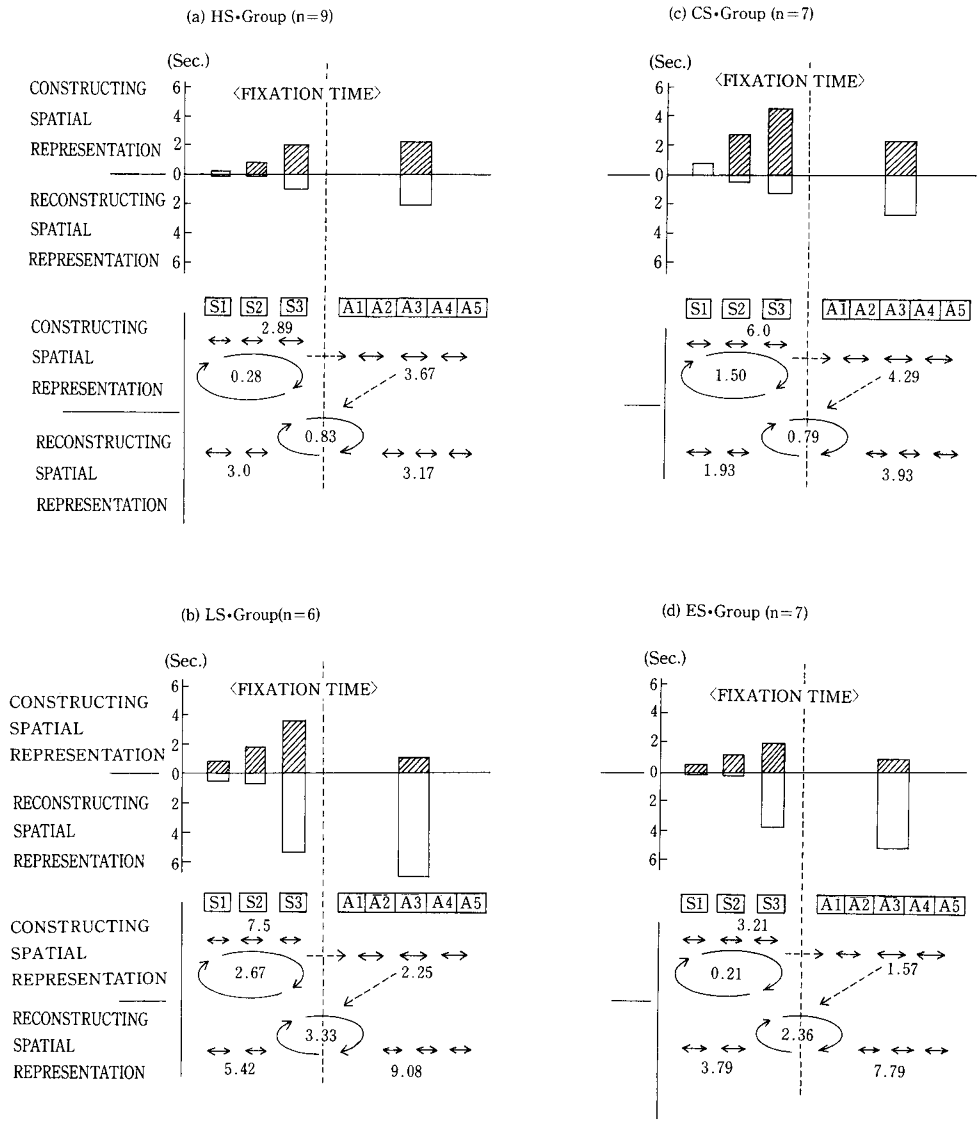

FIGURE 6 Fixation time and sequential patterns of fixation for four types

-c). Processing strategy which depends heavily on scanning the stimulus row is due to the poor ability to visualize the folding-unfolding process and to construct the representation of the unfolded paper. Comparing with LS, however, the number instances of " Checking," scanning between stimulus items and response alternatives, is less for CS (see, Figure 6-c).

The subject in Figure 5-d uses what we termed " Response Elimination Strategy (ES)", in which he attempts to select the correct alternatives by an elimination process of comparing specific stimulus and response features of cues. He scans the stimulus folds rapidly, and shows many searching eye-movements back and forth between stimuli and response.

Figure 6 provides the results of the duration data of gazing and the sequential

TABLE 2
Types of solution strategy in high- and low-ability group

	Type of solution strategy
High-ability sub. (n=14)	HS : 6, ES : 6 LS : 0, CS : 2
Low-ability sub. (n=15)	HS : 3, ES : 1 LS : 6, CS : 5

Number indicate the number of subjects who use the each strategy.

patterns of fixation corresponding to each type of problem solving strategy.

Table 2 shows the subject number of four types of solving strategy per each high and low spatial ability subject group. There was a tendency for subjects who use HS and ES strategies to belong to the high-ability group. On the other hand there were many subjects using LS and CS in the low-ability group.

CONCLUSION

The purpose of this study was to identify the solution strategies which used by high and the low spatial ability subjects in the spatial tasks. In this study a paper-folding task was used as the spatial task, and some eye-tracking measures were considered to ascertain the differences in scanning strategies between good and poor spatial thinkers.

It seems possible to distinguish some classes of variables important in analyzing individual differences in solution processes. These classes are as followings: parameter variables, reflecting differences within a particular processing step (e. g., time spent on each target), looking sequence variables, reflecting differences in the order in which processing steps are taken (e. g., stimulus scanning systematically before looking at response alternatives versus searching back and forth between stimuli and response alternatives rapidly), and so on.

By analyzing the sequential patterns of eye-tracking, four basic patterns of processing were identified. Some subjects performed a rapid and systematic analysis of the stimulus items before searching the response alternatives. It was concluded that the high-speed scanning of high-ability subjects were attributable to their greater constructing ability of the spatial representation.

The response elimination strategy was used by some high-ability subjects. It seemed that such eye-tracking patterns were used either when an item proved difficult to solve by constructive matching, or when the subjects selected this somewhat risky strategy by themselves as their prefered strategy for solving such a task. This strategy also contributed to a rapid response the attendant possibility of mistakes. The two different strategies were used by high-ability subjects.

Analysis of eye-movements revealed that low-ability subjects in particular took longer to perform a construction of the unfolded paper. Because of this they were unable to visualize the folding process and ultimately guessed, some subjects used the response elimination strategy which appeared to be one of several fallback approaches used when an item proves too difficult to solve by constructive matching at the same time.

The typical eye-tracking pattern of this solution processing was that of " Low -speed Scanning (LS)" which was observed only in low-ability subjects.

REFERENCES

Carpenter, P. A., & Just, M. D. (1986). Spatial ability: An information processing approach to psychometrics. *In R. J. Sternberg (ed.) Advances in the Psychology of Human Intelligence,* Vol. 3 Erlbaum.

Hunt, E. (1976). Varieties of cognitive power. In L. B. Resnick (ed.) *The nature of intelligence.* LEA.

Hunt, E. (1985). The correlates of intelligence. *In D. K. Detterman (ed.) Current topics in human intelligence.* Vol. 1 (Research methodology) Academic Press.

Hunt, E., Lunneborg, C., & Lewis, J. (1975). What does it mean to be high verbal? *Cognitive Psychology*, **7**, 194-227.

Hunt, E. & MacLeod, C. M. (1979). The sentence-verification paradigm: A case study of two conflicting approaches to individual differences. In R. J. Sternberg & D. K. Detterman (eds.) Human intelligence: *Perspectives on its theory and measurement.* Academic Press.

Just, M. D., & Carpenter, P. A. (1976). Eye fixations and cognitive processes. *Cognitive Psychology*, **4**, 277-299.

Just, M. D., & Carpenter, P. A. (1985). Cognitive coordinate systems: Accounts of mental rotation and individual differences in spatial ability. *Psychological Review*, **92**, 137-172.

Keating, D. P. (1984). The emperor's new clothes: The " new look " in intelligence research. *In R. J. Sternberg (ed.) Advances in the Psychology of Human Intelligence*, Vol. 2 Erlbaum.

Pellegrino, J. W. & Glaser, R. (1979). Cognitive correlates and components in the analysis of individual differences. In R. J. Sternberg & D. K. Detterman (eds.) Human intelligence: *Perspectives on its theory and measurement*. Academic Press.

Resnick, L. B. (1981). Instructional psychology. *Annual Review of Psychology*, **32**, 659-704.

Snow, R. E. (1980). Aptitude Processes. *In R. E. Snow, P. Federico & W. E. Montague (eds.) Aptitude, Learning, and Instruction*, Vol. 1. LEA.

Sternberg, R. J. (1977). Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities. LEA.

Sternberg, R. J. (1982). Introduction. *In R. J. Sternberg (ed.) Advances in the Psychology of Human Intelligence*, Vol. 1 Erlbaum.