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Development of Software to Record Solving Process of a Mental Rotations Test

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Abstract. To collect data on the solving process for the Mental Rotations Test for large numbers of subjects, software was developed that restricts the appearance of alternatives. This software made it possible to record information corresponding to eye fixation data. This data was useful in analyzing the problem-solving process. A pilot study using the software was controlled in a computer network environment. The solving process data of each subject was collected via the network and analyzed. The time spent to judge each correct alternative was extracted from the time sequence data of each subject. Parameters were calculated from the extracted time. Its distribution corresponded to the variation of solving strategies observed in previous research in which eye fixation data and verbal protocol data were used. This approach presents the possibility of being able to use software to identify the source of the performance difficulties for subjects.

Key Words: spatial ability, solving process, solving strategy

MSC 2000: 51N05

1. Introduction

One of the main goals of graphics curricula is to improve students' spatial abilities. As an objective index of spatial ability, a Mental Rotation Test (hereafter MRT) developed by Vandenberg and Kuse [8] has been used extensively in this type of research. Research using the information processing approach has shown the solving process and/or solving strategies are very important in the performance of spatial tests. Analyzing eye fixation data and verbal protocol data has been used to understand the solving process and solving strategies (Just

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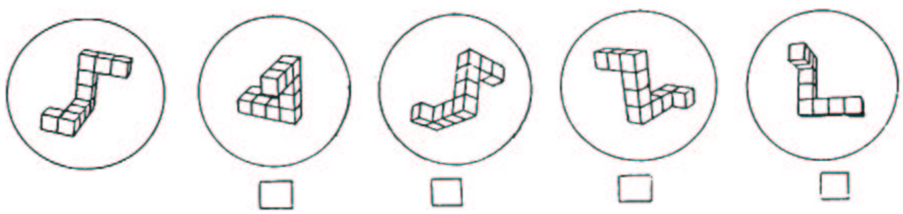
and Carpenter [2], Snow [7], Shiina, Saito and Suzuki [4, 5]). This research indicated a difference in the strategy preferences between high-ability subjects and low-ability subjects in spatial tests. In particular for students with low spatial abilities, it would help to analyze the source of their difficulty and form a basis for providing them well-tailored advice on how to better deal with a wide range of spatial tasks. The limitation is that these methods, i.e., getting eye fixation data and verbal protocol data, is difficult to apply to a large group of subjects.

Based on results of previous analysis of the solving process, software has been developed that can record it for each subject. This study will focus on a new approach to collecting solving process data for large numbers of subjects.

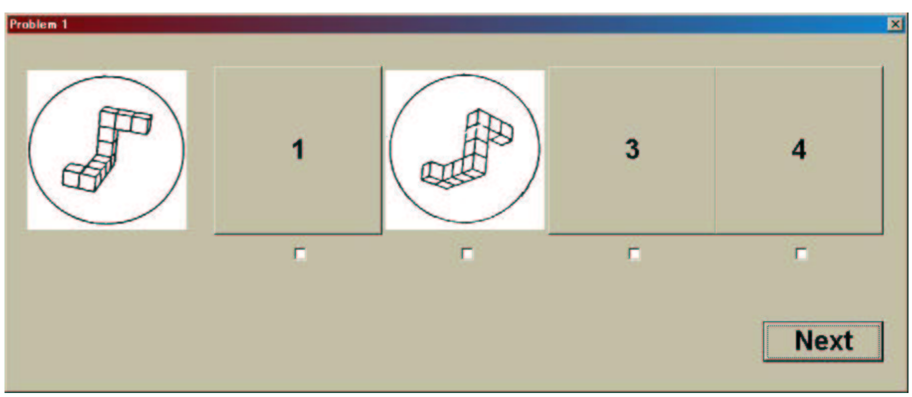
2. Development of Software to Record Solving Process

2.1. Mental Rotations Test

Fig. 1(a) indicates a sample of the MRT problem. Each problem is composed of a criterion figure, two correct alternatives, and two incorrect alternatives. Correct alternatives are structurally identical to the criterion but shown in a rotated position. The subjects are asked to find the two correct alternatives. The MRT contains 20 problems that are divided into two parts. Two points are given for a problem. The best possible score in the MRT is 40. The subjects are given a break between the two parts.



(a) Sample Problem from the original MRT



(b) Sample Problem from the RSP Version of the MRT

Figure 1: Sample Problem

2.2. Basic Function of Recording-Solving-Process Version of the MRT

Shiina et al. [4, 5] analyzed the solving process of the MRT and Shepard-Metzler tasks (Shepard and Metzler [3]) by looking at eye fixation data and protocol data. Her research revealed that most subjects, except for those with extremely low scores, tend to use mental rotation strategy, in which they looked between a criterion figure and each alternative in turn. Aoki, Shiina and Suzuki [1] divided each problem of the MRT into four Shepard-Metzler tasks (Shepard et al. [3]) that were given subjects via the network. They fixed the order of the tasks and did not allow the subjects to decide the order of the appearance of alternatives. It is possible that such restriction reduced the flexibility of the subjects' strategy choice. Based on the results of this research, software was developed that restricts the appearance of alternatives by a subject's own mouse. In this software, a subject cannot look at all four alternatives at once. Only one of the four alternatives, selected by the mouse, appears on the display at any one time. By restricting the appearance of alternatives for each subject, the software makes it possible to record information corresponding to eye fixation data, which would be useful in analyzing the problem solving process. Fig. 1(b) indicates a sample problem in the software. Hereafter, the software shall be called "Recording-Solving-Process version of the MRT (RSP-MRT)".

2.3. Design of RSP version of the MRT

2.3.1. RSP-MRT Instructions

The RSP version of the MRT is composed of two parts: instructional and testing. To familiarize subjects with the RSP-MRT, it is important to provide sufficient instruction on what they are to do and how it is to done before the test is administered. As for "what to do", instructions are nearly identical to the original MRT. Subjects are required to find the two correct alternatives from the four. As for "how it is to be done", instructions become more complicated than the original MRT test. Subjects understand that only one of the four alternatives selected by a mouse appears on a display at any one time. They can choose the alternative as a correct answer by clicking a square under each alternative. After practicing how to answer the problems, they are given three example problems identical to the original MRT, except for the way the alternatives are displayed.

In the instructional part, subjects are allowed to go back anytime to the previous screen by clicking "Back". They can repeat instructions and example problems periodically if necessary. Subjects can review the instructions at their own pace.

2.3.2. RSP-MRT Administration

During testing, subjects are not allowed to skip any problem or go back to any previous problem. In each problem, subjects must click on the "Start" button, prompting a criterion figure to appear on the display. A criterion figure is always displayed while the subject solves the problem. As for alternatives, only one chosen by the mouse appears at any one time. After choosing two alternatives as correct answers, a subject can go to the next problem by clicking "Next". If the subject clicks the "Next" button before he/she chooses two alternatives, a warning appears to notify the subject not to skip the problem. The subject is given a one-minute break between the two parts (one part contains 10 problems).

2.3.3. Data Collected

The last four digits of the student identification, sex and year of birth are required before the instructional part of the RSP-MRT will begin. This data is recorded in a file. In the instructional part, the amount of time spent and repetition information for each instructional screen is recorded. In the sample problem area and testing part, the RSP-MRT records the following time sequence:

(1) which alternative appears on the display,

(2) when it appears,

(3) which alternatives are chosen as correct answers,

(4) when two alternatives are chosen as a correct answer, and

(5) when the subject goes to the next problem.

During the RSP-MRT, all subject behaviors are recorded to a file.

3. Pilot Study Using the Software

3.1. Experiments Using Network Environment

Fig. 2 indicates concepts of the pilot study using a network environment. The program of RSP-MRT was placed at a folder that can be seen from each PC via the network. Permission to read and write to the folder was given to ID that was available during this experiment. The solving process data of each subject was stored as a data file in a folder whose permission was only given to the ID for the experiment. The permission was controlled though the Windows NT 4.0^{TM} operating system.

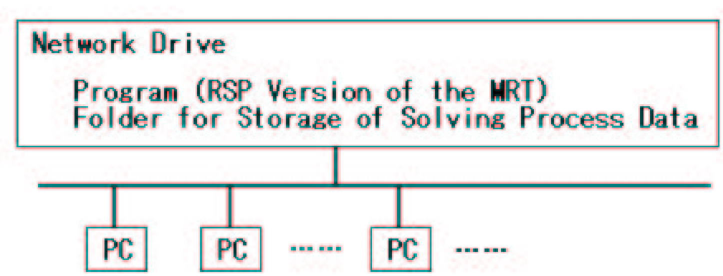


Figure 2: Experiment Using Network Environment

3.2. Procedures

The subjects for this study were enrolled students recruited from CGT 155 (Spring 2000) at Purdue University. All students, regardless of age or sex who qualified by being enrolled in the course for the first time and were willing to participate in the experiment, were allowed to participate. Students who volunteered as participants were informed verbally about the experiment and its purpose. It was emphasized that the result of this experiment would not be used to determine grades in the course, that enrollment in this experiment was voluntary, and that students could quit this experiment at any time.

The location of the PC laboratory room was announced to the students who volunteered for the experiment. The subjects chose one of the 13 sessions held at the PC laboratory room for 7 days. The subjects were told to log on to the network and take the RSP-MRT during the announced session.

The displays had a viewing area of approximately 15 inches diagonally. The distance between the subject's eyes and the display was between 365 mm to 432 mm with the average distance approximately 381 mm. Each problem was displayed in the area of nearly 1150 mm × 2730 mm. Each alternative was displayed in the square of nearly 47 mm × 47 mm.

4. Results and discussion

The RSP version of the MRT was administered to 35 subjects (29 males and 6 females) in January 2000. Of these subjects, 33 were born in 1979, 1980 or 1981.

4.1. Required Time for instruction and testing

Table 1 shows the mean time that subjects spent to execute the instructional part and each testing part of the RSP-MRT. Although female subjects tended to spend more time for the testing part than male subjects, there were no significant differences in required time between sexes.

Table 1: Mean times required to finish instruction part and each testing part (sec.)

		Instruction		*Part 1*		*Part 2*	
	n	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Male	29	258.5	98.6	294.9	148.6	295.4	120.2
Female	6	259.8	44.5	389.6	158.7	358.9	123.8
All	35	258.7	91.1	311.2	152.3	306.3	121.4

In the original MRT, Vandenberg et al. [8] recommended 180 seconds for each part as a time limit for university students. In the original MRT, the rates of subjects who completed the last problem of each section was calculated from data of 2058 Japanese subjects (1407 males and 651 females), which were 20.6% and 34.7% respectively (Shiina and Suzuki [6]). In the RSP-MRT, only 17.1% (6 subjects) and 11.4% (4 subjects) finished all problems of each part in 180 seconds. Although the subjects were instructed to "work as quickly as you can without sacrificing accuracy" in both the original MRT and the RSP-MRT, subjects in the RSP-MRT might have felt less time pressure than in the original MRT. In a network environment, each subject uses a PC. Such a style of experiment might make it easier for subjects to execute problems at their own pace. Other factors, such as a national character difference between USA and Japan, might have had an effect on subject performance on the RSP-MRT. One such example of national character differences the authors' theorize is that Japanese students may be more impatient to solve problems than American students.

4.2. Mean Scores and Time Limit

In the original MRT, the time limit was fixed to 180 seconds for each section of this test. In the RSP-MRT, it is possible to calculate mean scores for a particular time limit by using solving time data for each problem. Fig. 3 shows the calculated mean scores for each time limit (from 30 to 600 seconds for each part). The number of subjects who spent more than

600 seconds for either of two parts was only 1. Fig. 3 suggests that the mean scores for both males and females linearly increased to 240 seconds and 300 seconds, respectively. Table 2 indicates the mean scores with a time limit of 180 seconds for each section of the RSP-MRT and those without a time limit. There were no significant sex-based differences of RSP-MRT mean scores corresponding to any time limit. The reason of no significant difference might be attributed to the smaller number of female subjects.

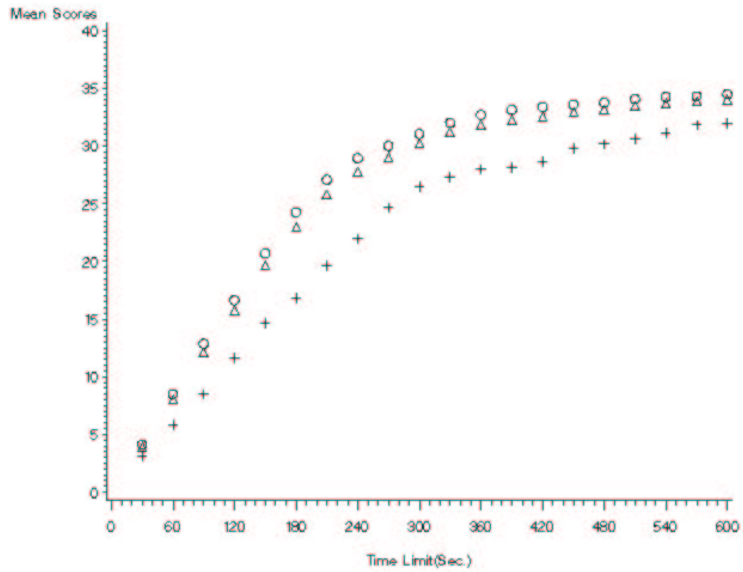


Figure 3: Calculated mean scores for each time limit.
(Triangle: All, Circle: Male, Plus: Female)

Table 2: Simulated mean scores with time limit and without time limit

		180 sec. time limit for each part		*No time limit*	
	n	*Mean*	*S.D.*	*Mean*	*S.D.*
Male	29	24.3	8.9	34.7	6.7
Female	6	16.8	8.9	32.0	10.0
All	35	23.0	9.2	34.2	7.2

4.3. Performance in Mental Rotations and Score

It is possible to extract the time spent to judge each correct alternative from time sequence data of each subject. For each subject, the extracted times of each correct alternatives were plotted as a function of the *angular disparity*, i.e., the angular difference between each criterion figure and each correct alternative. Fig. 4 shows an example graph with a regression line of a typical subject.

The slope and the intercept of the extracted time function were calculated for each subject. A slope and an intercept of the regression line can be considered as indices of the performance in mental rotations. High slopes mean the low speed of mental rotation. High intercepts

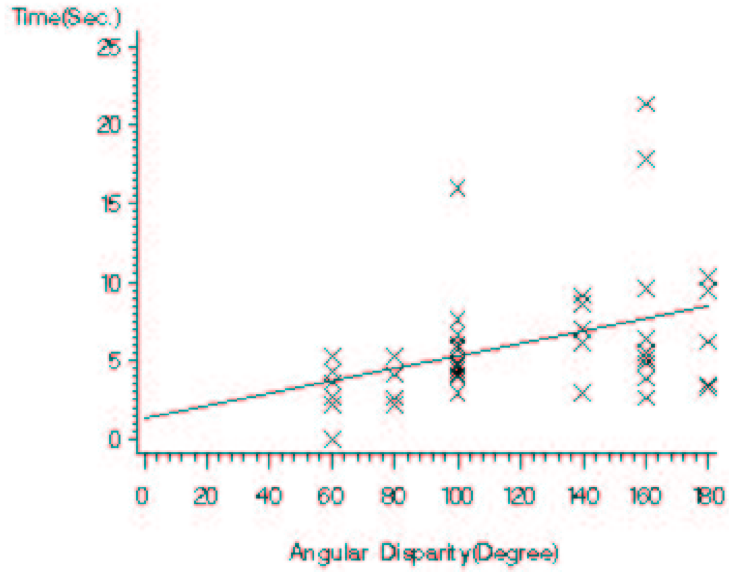


Figure 4: Example of an extracted time function of angular disparity

indicate the existence of strategies other than mental rotation. For each subject, scores that correspond to a time limit of 180 seconds for each part were calculated. Hereafter the calculated score shall be called *"c-score"*. The c-score virtually corresponds to the score of the original MRT, although there might be a little difference of time pressure between the two versions.

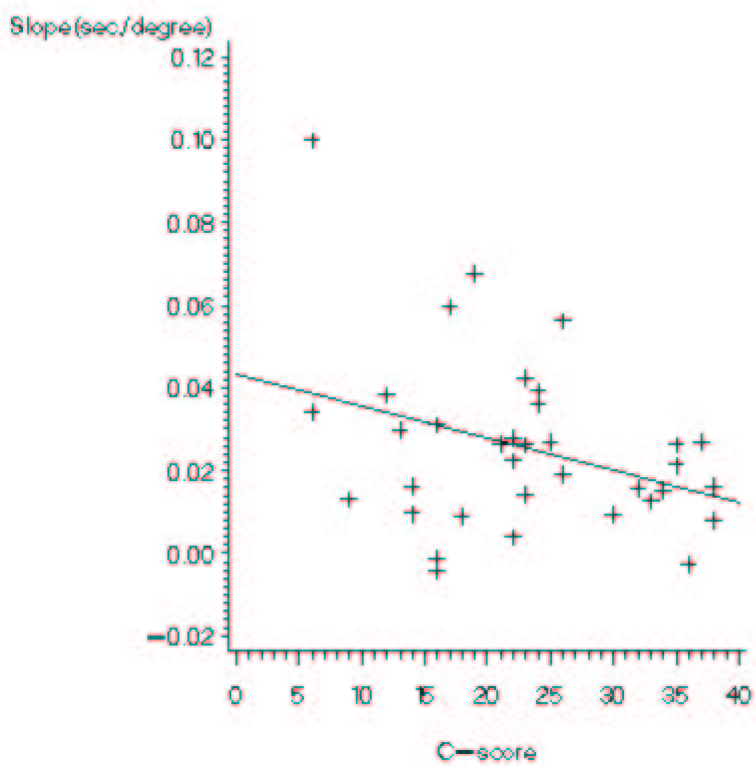


Figure 5: C-scores and Slopes

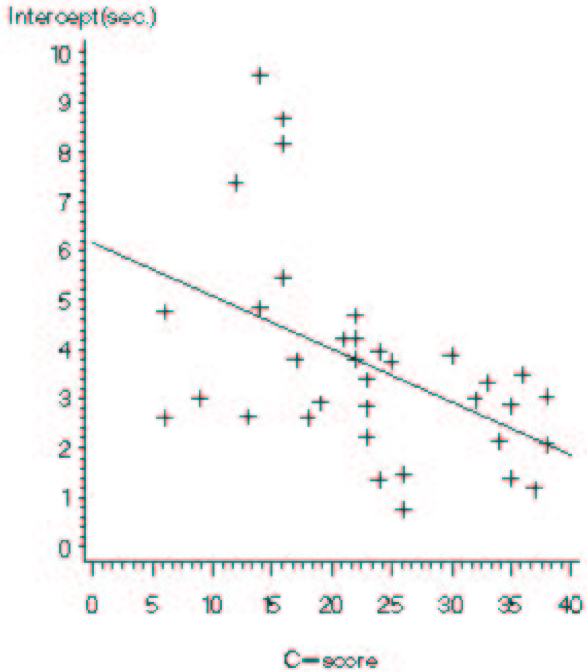


Figure 6: C-scores and Intercepts

In Fig. 5, c-scores and slopes of all subjects are plotted with a regression line. In Fig. 6 c-scores and intercepts of all subjects are plotted with a regression line. The distribution range of slopes and intercepts is smaller in high c-score areas than in low c-score area. The regression lines of both figures indicate that the slopes and the intercepts get smaller in high c-score area. This data suggests that the subjects with high c-scores tended to solve the RSP-MRT by high speed of mental rotation and to spend less time for strategy other than mental rotation. On the other hand, the slopes and intercepts distribute over wider ranges in the low c-score area. This suggests the variation of strategy for subjects with low c-scores.

In Fig. 7, slopes and intercepts of all subjects are plotted with the category of c-score. C-scores were classified according to the following three categories:

(1) High: larger than 33.0 (mean score + standard deviation),

(2) Intermediate: between 33.0 and 14.0 and

(3) Low: smaller than 14.0 (mean score − standard deviation).

As for the slopes and intercepts for subjects with "high" c-score, the values do not vary much between subjects.

Whereas, the values for subjects with "low" c-scores distribute over a wide range. Fig. 7 indicates the existence of the "low" c-score subjects whose values of intercepts and slopes are almost the same as those of "high" c-scores. This suggests that there are "low" c-score subjects who could solve the RSP-MRT by mental rotation with similar speed to "high" c-score subjects. It is considered that their low correct rates made their c-scores low. There are "low" c-score subjects whose slope are larger than that of other subjects but the intercept is not as large. This suggests a low speed of mental rotation. These results suggest differences of mental rotation speed and its accuracy between the subjects with "low" c-scores. Although it appears that there are differences of mental rotation speed and accuracy between subjects with "low" c-scores both seem to solve these problems using similar strategies.

Fig. 7 also indicates the existence of the "intermediate" c-score subjects whose intercepts

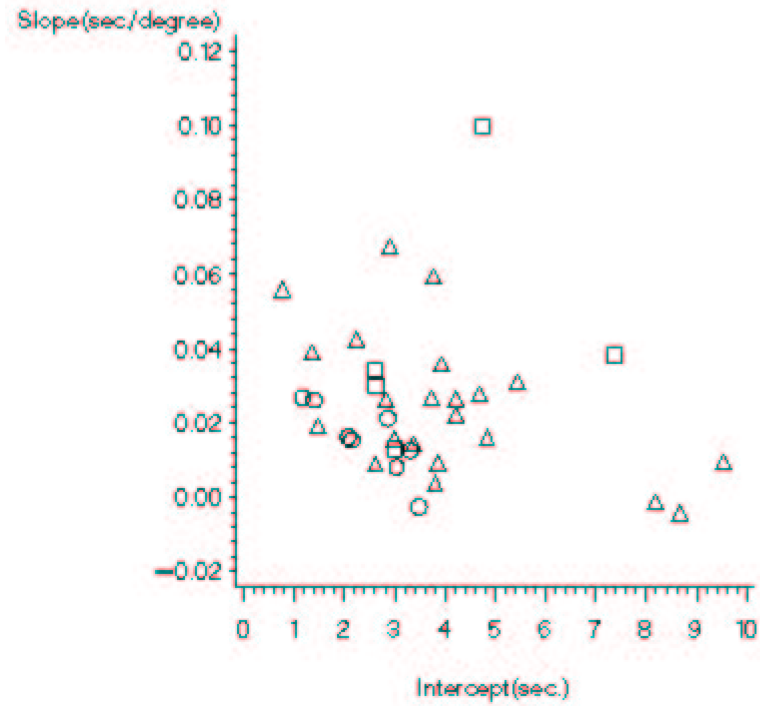


Figure 7: Intercepts and Slopes (Circle: High, Triangle: Intermediate, Square: Low)

are large and slopes are small. It is possible that such subjects used strategies other than mental rotation.

5. Conclusion

It was revealed that the distribution of the parameters calculated from data of the RSP-MRT corresponds to the variation of solving strategies observed in the previous research (Shiina et al. [4, 5]). This suggests the possibility of the RSP-MRT to identify the source of the difficulty of each subject and to give the student well-tailored advice.

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