Journal for Geometry and Graphics
Volume 3 (1999), No. 1, 111–119

A Mental Cutting Test on Female Students Using a Stereographic System

Emiko Tsutsumi, Kanakao Shiina, Ayako Suzaki, Kyoko Yamanouchi, Takaaki Saito, Kenjiro Suzuki

School of Social Information Studies, Otsuma Women's University
2-7-1, Karakida, Tama, Tokyo, 206-8540, Japan
email: tsutsumi@otsuma.ac.jp

Abstract. A stereographic mental cutting test (hereafter SMCT) was conducted to analyze 3D spatial abilities evaluated by a standard mental cutting test (hereafter MCT). The results of the analysis indicated that the MCT mainly reflects the abilities in making and manipulating three-dimensional mental images. The results also indicated that the subjects came to recognize 3D shapes more easily by using stereograms. However, the stereograms did not have any effect on complicated mental image processing tasks such as transformation of a section to a true shape view. Also, low scoring subjects in this study could not recognize the test solid and its cutting plane well, and they were unable to form correct images of objects, even when they used stereograms.

Key Words: mental cutting test, female, stereogram

MSC 1994: 51N05

1. Introduction

In courses on graphics at the undergraduate level of study, 3D spatial abilities have received much attention lately. In fact, for the past decade, several spatial ability tests have been given to evaluate spatial abilities of students. The MCT (a sub-set of CEEB Special Aptitude Test in Spatial Relations, see [1]) was used by Suzuki et al. [2] for measuring spatial abilities in relations to graphics curricula. Since then the MCT has been widely used for this purpose and a large amount of data have accumulated from tests conducted on various subjects .

The standard MCT consists of 25 problems for which the full score is 25. In each problem, subjects are given a perspective drawing of a test solid which is to be cut with an assumed cutting plane. Subjects are asked to choose one correct cross section among 5 alternatives. There are two categories of problems in the MCT (Suzuki et al. [2]). One category is called "pattern problem", in which the correct answer is determined by identifying only the pattern of the section. The other is called "quantity problem", in which the correct answer is

ISSN 1433-8157/$ 2.50

determined by identifying not only the pattern but also the quantity in the section, e.g., the length of the edges or the angles between the edges. It was shown by SAITO et al. ([3], [4], [5]) that in order to solve the MCT problems, subjects go through 3 phases of information processing, which are,

(1) Recognizing the solid from the perspective drawing,

(2) Cutting the solid by the assumed cutting plane, and

(3) Judging the characteristic quantity of the section, if necessary.

As for recognition from a projection drawing such as perspective, there may exist a difficulty caused by its paradoxical nature. A projection drawing is a chart consisting of a set of lines on a 2D surface and represents an image of a 3D object, which by its very nature can not exist on a 2D surface.

At the same time a projection drawing represents not an unique 3D shape but all possible 3D shapes in which every corresponding points are on the same projection lines. Our perceptions, however, usually make a fairly reliable judgment, or select proper "object hypothesis" against the object through the process of sensing the most possible object. Some of the objects among the MCT problems have, however, not so usual and common shapes.

The above discussion suggests that with perspective drawings like those in the problems in MCT, there may exist various factors, which may cause subjects to fail in recognizing the proper objects correctly.

Therefore, if the test solids are shown in the form of stereograms which approximate stereopsis, i.e., a depth sense based solely on stimulation of disparate locations on the retinae, the recognition process might be assisted and errors associated with phase (1) might be reduced. NISHIHARA et al. [6], [7] replaced the perspective drawing of the test solid in the MCT with an anaglyphic stereogram with red-green glasses in order to evaluate how much an anaglyphic view is able to assist subjects in solving spatial solving problems. A similar system was proposed by YAO et al. [8]. They presented a stereographic MCT system using a time-sharing display controller, glasses with synchronized liquid crystal shutters and a microcomputer. They compared the results of the SMCT with those of the standard MCT using a microcomputer network that has been developed by SUGAI et al. [9]. They showed that for the SMCT,

(1) the mean score was a little bit higher although there was no significant difference between the two tests,

(2) correct response rates of pattern problems had a tendency to increase, but those of quantity problems did not change.

However, most of the subjects in their research got extremely high scores. The correct response rates for 16 problems out of the 25 were over 90% and there were only 4 problems whose correct response rates were under 80%. Therefore, it was considered that the results might not reflect the true relation between the two types of tests because of the small number of subjects who could get higher scores in the SMCT.

In this research, the SMCT was conducted on female subjects, who are much less likely to get high scores in the standard MCT (TSUTSUMI [10], KASHIMA [11]). The results, together with the results of the standard MCT, were analyzed to get some insight to spatial abilities evaluated by the MCT.

2. Methods

2.1. Stereographic MCT

The SMCT system designed by Yao et al. [8] was used in this study. The system includes a Crystal Eyes Process Controller, glasses with liquid crystal shutters, a color display and a microcomputer. The system presents alternately two different perspective views of the test solid on the display. The two views are drawn based on the principle of binocular disparity. The opening and shutting of the shutters for each eye built in the glasses are synchronized with the renewal of presentation of the perspective views. The results of the test include response time for each problem and the choice of alternatives made by the subject.

2.2. Standard MCT

The standard MCT using a microcomputer network (hereafter PMCT) developed by Sugai et al. [8] after making the necessary changes to make it run on Windows 95© was used as a control. In this system, perspective drawings of test solids were shown. The results of the test include response time for each problem together with the choice of alternatives made by the subjects.

2.3. Subjects

Seventy subjects participated in the SMCT and 51 subjects in the PMCT during the period of October to November, 1997. All the subjects are female students in the first and the second grade at the School of Social Information Studies, Otsuma Women's University.

3. Results and discussion

3.1. Mean scores

Mean scores for the SMCT and PMCT were 13.97 ($SD = 4.22$, $N = 70$) and 13.68 ($SD = 4.23$, $N = 51$), respectively. Though there was no significant difference between the mean scores of the two tests, the distribution of scores of SMCT showed a tendency to be somewhat higher than that of scores of PMCT (Fig. 1). These results agree with those of experiments by Yao et al. [8] in which mean scores were 21.87 ($SD = 2.05$, $N = 61$) and 21.35 ($SD = 2.77$, $N = 333$), respectively. As there is a difference of about 8 points (out of a possible 25 points) between the mean scores of present experiments and their experiments, we will consider the subjects in their study to be a "high scoring group" and those in the present experiments to be a "middle scoring group".

3.2. Correct response rates for each problem

Fig. 2 shows correct response rates for each problem. Correct response rates on the SMCT increase significantly ($P > 0.05$) for problems 5, 7, 12, and 14 and decrease significantly ($P < 0.05$) for problems 18, 19, and 23. These problems are pattern problems except for 23. Correct response rates do not increase significantly ($P < 0.05$) in quantity problems. These results agree with the results given by Yao et al. for the problems for which the correct response rates show significant difference between two tests, i.e., problems 12 and 23. In their study, other problems showed no significant differences except problem number 9. As was

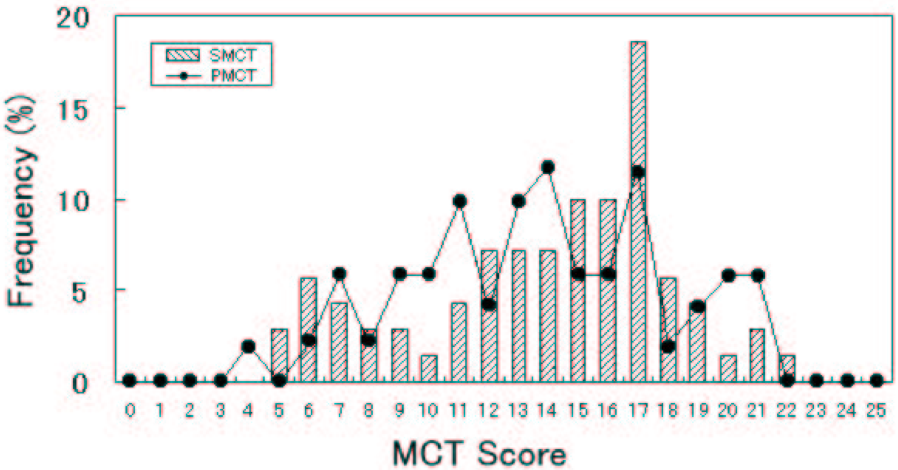

Figure 1: Distribution of scores for SMCT and PMCT

already mentioned above, most of the subjects in their study got extremely high scores even in the PMCT, and there might remain little space for the scores to increase in the SMCT.

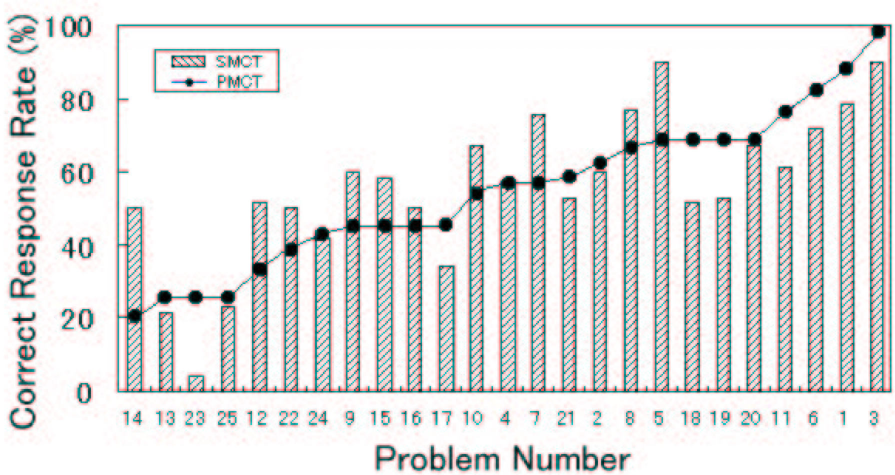

Figure 2: Correct response rates of MCT

At first it was expected that if the test solids were shown in the form of stereograms, the errors related to recognition of 3D objects from 2D projection views might be reduced, and hence, the mean scores might increase. However, only some of the 25 problems had higher correct response rates

and there were some which did not register any increases, nor some registered decreases. We may conclude from these results that an increase in the correct response rate of a problem in the SMCT was influenced by some specific aspects of a given problem and not necessarily shared by all problems, so no significant difference was observed between the mean scores of the SMCT and PMCT.

3.3. Error analysis

3.3.1. Causes of error in the SMCT

From a close analysis of the distribution of the incorrect alternatives selected by the subjects, the following factors were considered as probable causes of errors in the SMCT.

(1) Difficulty in recognizing 3D shapes of test solids from the stereograms.

(2) Difficulty in recognizing 3D shapes of portions of test solids hidden by the test solids themselves.

(3) Having an excessive sense of depth vis-a-vis the test solids.

(4) Difficulty in recognizing relative locations of cutting planes with respects to the test solids.

(5) Difficulty in judging the characteristic quantity in the sections.

Fig. 3a shows a typical example for factor (2). Each nine percent of subjects selected incorrect alternatives 4 and 5. Factor (1) is affected by, among others, the inability to integrate the characteristic appearance of the test solid being distracted by partial appearance such as surface of the striking shapes. As for factor (1), some subjects seem to consider the 3D object as if it is a depthless 2D figure. For example, incorrect alternative 3 in problem number 13 Fig. 3b may be selected by such subjects. Similarly, factor (4) is influenced by the inability to recognize a cutting plane as if it was a projecting plane or having an image of the whole silhouette as a cross section. Incorrect selection of alternative 1 in problem number 21 (Fig. 3c) is consider to show the case.

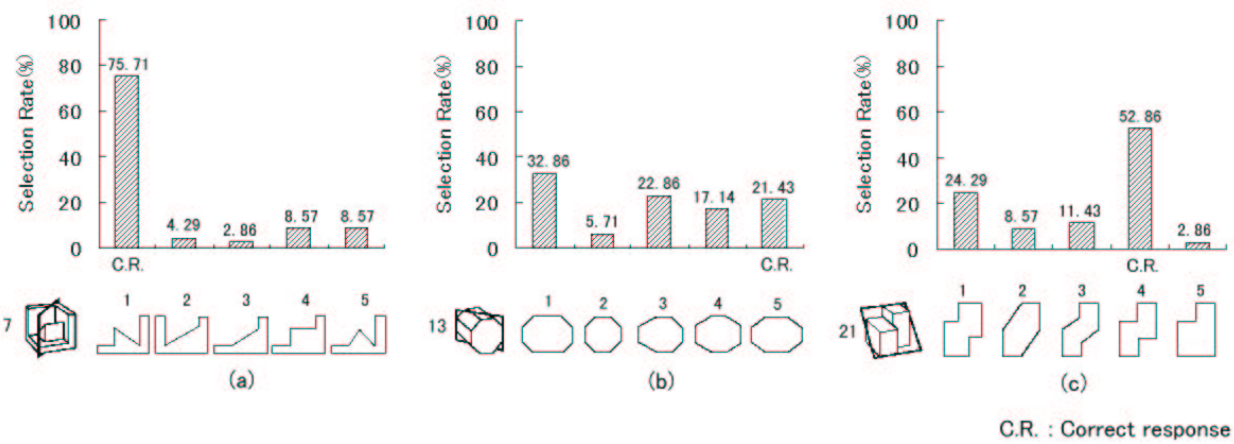

Figure 3: Incorrect alternatives in characteristic problems

The above-mentioned factors which could potentially cause errors in the SMCT correspond to different phases of the process of problem solving of the PMCT in Chapter 1 as pointed out by Saito et al. [5]. Namely, factor (1), (2), and (3) mentioned above correspond to their phase (1), factor (4) to their phase (2) and factor (5) to their phase (3). Moreover, our results, except for factor (3), agree with the interpretations of the problem solving process for the PMCT which were extracted using data on eye fixations, Saito et al. [3].

3.3.2. Effects of stereograms on errors

Although the likely causes of errors in the SMCT were similar to those of the PMCT as a whole, there was one factor peculiar to the SMCT, namely factor (3). In addition, it was found that there were some incorrect alternatives in which the selection rates showed a certain decrease or increase in the SMCT. Fig. 4 shows selection rates of the alternatives for three problems. From a detailed analysis of the differences of selection rates of incorrect alternatives between the SMCT and PMCT, the following factors were considered as likely causes of increase in correct response rates as a direct consequence of using stereograms.

(1) Improvement in recognizing 3D shapes of test solids from the stereograms (Fig. 4a)

(2) Improvement in recognizing relative location of cutting planes with respect to the test solids (Fig. 4b).

In addition, there were some problems, e.g., 9 and 13, in which the subjects selected incorrect alternatives that were much more similar to the correct alternatives, though the correct response rates did not show significant increase (Fig. 4c).

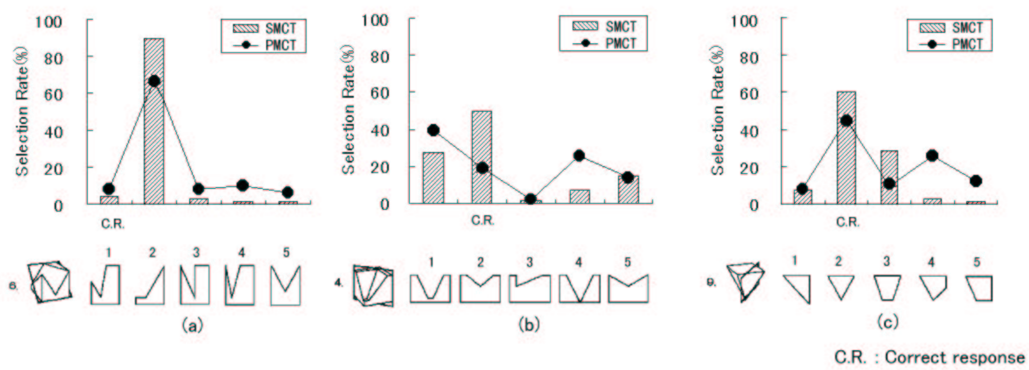

Figure 4: Difference of selection rates between SMCT and PMCT

Saito et al. [5] pointed out that low scoring subjects solved pattern problems in the MCT by what appeared to be at times redundant and inaccurate manipulation of mental images. They also pointed out that many of the errors for pattern problems were caused in phase (2), i.e., the subjects made errors in recognition of the cutting planes from the pictorial views and in locating the sections. In the preceding Section 3.2, it was noted that the correct response rates of several pattern problems in the SMCT increased significantly. With these points in mind, it is very likely that subjects in the middle scoring group of the SMCT could increase their correct response rates by using stereograms for those problems which were solved by a redundant and an inaccurate manipulation of mental images in the PMCT. Thus it appears that the process in making and manipulating mental images are assisted by the use of stereograms, suggesting that the standard MCT reflects the ability to make 3D images from 2D representations, as has been suggested by Saito et al. [5].

Also, there are other things to note. All the problems except one for which the correct response rates increased in the SMCT were given with vertical cutting planes. On the contrary, most of the problems in which correct response rates did not change or decreased were given with inclined cutting planes. It is possible, therefore, to assume from these results that stereogram did not have any effect on the complicated mental image processing such as oblique rotation or transformation of a section to a true shape view.

3.3.3. Error analysis of low scoring subjects

Although the mean score in the present study was fairly low and the subject group was considered to be middle scoring, the individual scores have a large variation ranging from 5 points to 22 points, as was indicated in Fig. 1. Accordingly, the subjects of our study were classified into 3 sub-groups according to their individual scores. Fig. 5 shows the selection rates of the high scoring (score ≥ 18, $N = 10$) and low scoring (score ≤ 9, $N = 13$) groups. The points to observe are as follows:

(1) Correct response rates of both groups were high for the problems for which the configuration of the test solid and the shape of the alternatives were both simple (Fig. 5a).

(2) In most of the problems, the high scoring group selected the correct response or a specific incorrect alternative, whereas the low scoring group selected all possible kinds of alternatives. Half of the problems had their respective portions hidden by the test solid itself which in turn were required to be imaged (Fig. 5b). It is likely that even if the test solids are presented as stereograms, low scoring subjects recognize 3D objects vaguely from 2D drawings with only partial information about shapes that appeared directly on the 2D display surface.

(3) In the problems 13, 23 and 25, both groups selected many incorrect alternatives. These problems were quantity problems or presented objects only by contours of curved surfaces (Fig. 5c). It is to be noted that in the quantitative problems, the correct answer is determined by identifying not only the pattern but also the quantity in the section. Yao et al. [8] had already pointed out that stereogram does not appear to have any effect on quantitative problems which need analytical thinking, and that it is difficult to recognize curved surfaces without adding generatrices, even if stereograms are used.

(4) Most errors in the high scoring group were caused by an excessive sense of depth vis-a-vis the test solid and by an insufficiency of analytical thinking (Fig. 5d).

The low scoring subjects showed influences of most of the error factors mentioned earlier. There were lots of incorrect responses in which the subjects did not seem to have proper mental images or were unable to understand the cutting process itself. Other incorrect responses showed that surfaces with characteristic appearances on the test solid influenced the subjects. These results lead to the conclusion that low scoring subjects were unable to recognize the test solid and its cutting plane satisfactory, and therefore they could not construct correct images of the test solids. In the SMCT, the test solids were shown in the form of stereograms and, generally speaking, there was no doubt about the improvements in recognizing the objects. However, it was concluded that, even with stereograms, the low scoring subjects in the present study still solved the problems by what appears to be redundant and inaccurate manipulation of mental images.

4. Summary and conclusion

The SMCT was conducted to analyze the 3D spatial abilities evaluated by the standard MCT. The principal results are as follows:

(1) The process for making and manipulating mental images are assisted, and the subjects came to recognize 3D shapes more easily by using stereograms. These results suggested that the standard MCT reflects the ability to make 3D images from 2D representations.

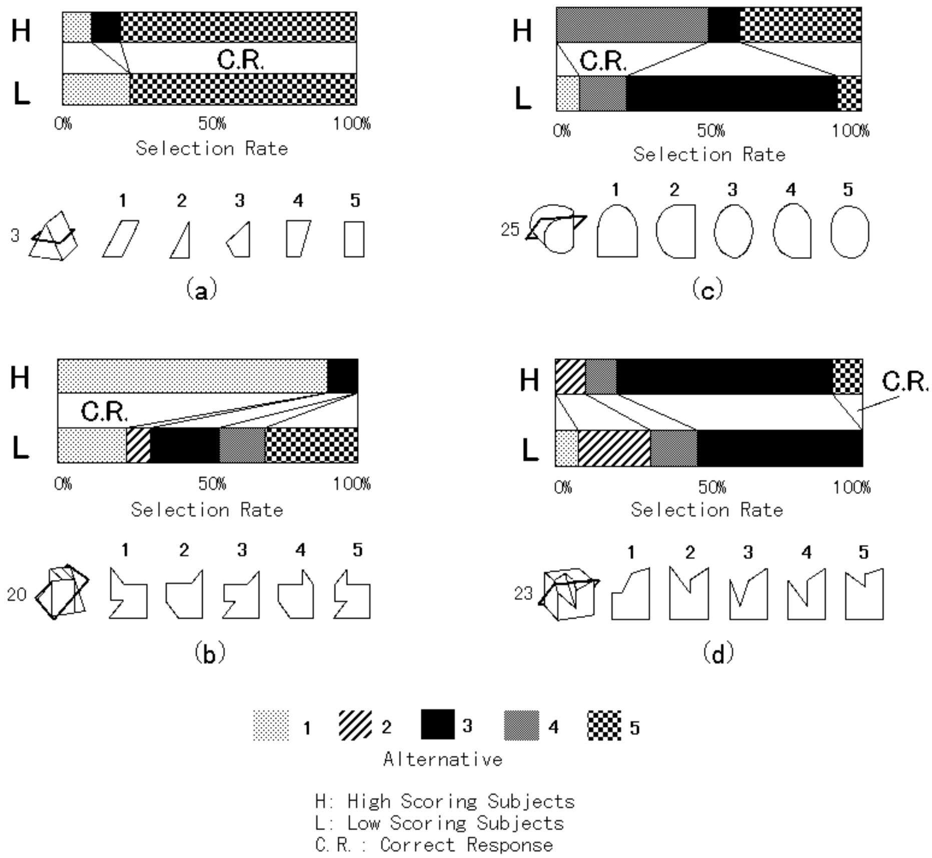

Figure 5: Selection rates of alternatives for SMCT and PMCT

(2) The stereogram did not have any effect on complicated mental image processing tasks, such as transformation of a section to a true shape.

(3) Low scoring subjects in this study could not recognize the test solid and its cutting plane well, and they were unable to construct complete images of objects, even when they used stereograms.

References

[1] *CEEB Special Aptitude Test in Spatial Relations*, Developed by the College Entrance Examination Board, USA 1939.

[2] K. Suzuki, S. Wakita, S. Nagano: *Improvement of Spatial Ability through Descriptive Geometry Education* [Japanese]. J. Graphic Science of Japan **49**, March, 21–28 (1990).

[3] T. Saito, K. Makino, K. Shiina, K. Suzuki, T. Jingu: *Causes of Error in a Mental Cutting Test – Analysis of Problem Solving Process by the Use of Eye Fixations Data (2)*. Proc. 6th Internat. Conference on Engineering Computer Graphics and Descriptive Geometry, Tokyo, 815–819 (1994).

[4] T. Saito, K. Shiina, K. Makino, K. Suzuki, T. Jingu: *Analysis of Problem Solving Process and Causes of Error in a Mental Cutting Test*. Proc. 2nd China-Japan Joint Conference on Graphics Education, Chengdu, China, 259–264 (1995).

[5] T. Saito, K. Shiina, K. Suzuki, T. Jingu: *Spatial Ability Evaluated by a Mental Cutting Test*. Proc. 7th Internat. Conference on Engineering Computer Graphics and Descriptive Geometry, Cracow, Poland, 569–573 (1996).

[6] K. Nishihara, S. Nishihara, K. Chibana, K. Yoshida: *Effect of Anaglyphic Representation on Spatial Abilities – using the Mental Cutting Test* [Japanese]. Proc. 1993 Annual Meeting of Japan Society for Graphic Science, 127–132 (1993).

[7] K. Nishihara, S. Nishihara, I. Sakamoto, K. Chibana, K. Yoshida: *Effect of Hidden line Removal on the Score of Mental Cutting Test – Remodeled by Anaglyphic Representation*. Proc. 6th Internat. Conference on Engineering Computer Graphics and Descriptive Geometry, Tokyo, 786–790 (1994).

[8] Y. Yao, T. Saito, K. Suzuki: *Analysis of Causes of Errors in a MCT through the Comparison with Stereographic MCT* [Japanese]. Proc. 1996 Annual Meeting of Japan Society for Graphic Science, 122–127 (1996).

[9] Y. Sugai, K. Suzuki, T. Ezaki, K. Irie: *A Mental Cutting Test Using a Micro Computer Network*. Proc. 6th Internat. Conference on Engineering Computer Graphics and Descriptive Geometry, Tokyo, 776–780 (1994).

[10] N. Tsutsumi: *Evaluation of Spatial Abilities by a Mental Cutting Test at Musashino Art University* [Japanese]. Proc. 1990 Annual Meeting of Japan Society for Graphic Science, XIII (1990).

[11] S. Kashima: *A Mental Cutting Test and Graphics Education* [Japanese]. Proc. 1990 Annual Meeting of Japan Society for Graphic Science, XIV (1990).

Received August 14, 1998