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Original Article

Easy assessment tool for motor imagery ability in elementary scool students

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Abstract. [Purpose] The final purpose of the present study was to propose easy and quick mental rotation task. Since subjects can easily understand mental rotation task that they have to do, the task is considered to be available in particular children. However, existing mental rotation task using specific software asked subjects more than ten trials per one pictured stimulus, meaning that relatively long time is required to accurately measure. Thus, children have difficulty to keep their attention during the existing task and to demonstrate their ability accurately. To address the purpose of the present study, the performance of mental rotation task using paper was investigated whether the performance has similar characteristics to an existing mental rotation task using specific software, in order to verify the usability of the task using paper. [Subjects and Methods] Sixty-three elementary school participants were asked to determine whether a rotating hand picture was left or right as quickly as possible and indicate it by writing a diagonal line on the paper. The total time required judgment of 16 pictures and the number of judgment errors were counted. [Results] The number of judgment errors increased with an increasing stimulus rotation angle. Also, the mental rotation time improved with age. [Conclusion] These results suggest that the performance of mental rotation using paper has the same characteristics as the existing method using specific software. Therefore, the mental rotation using paper would be practical method for subjects having difficulty to keep attention relatively long time, such as elementary school children.

Key words: Mental rotation, Elementary school children, Development

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INTRODUCTION

Body-related mental rotation has been referred to as a pure cognitive activity of mental operation in response to the visual stimulus of viewing a body part. During body-related mental rotation, the brain activity involved in executing body movements was shown in a previous study. Meta-analysis of the previous studies showed that the premotor area, supplemental motor area, and superior parietal area were activated while participants performed mental rotations of hand stimuli[1)]. In behavioral studies, evidence of the association between mentally rotating a body part and physically rotating the body part is increasing. For example, the mental rotation of foot stimuli is related to (a) postural stability while standing (the performance of the foot and ankle)[2)], and (b) the frequency of leg injury in rugby players[3)]. In another behavioral study, the judgment reaction time was nearly equivalent to the time of the actual body movement to the orientation of the stimulus; for example, the reaction time at 90 degrees is similar to the time it would actually take to move the hand 90 degrees[4)]. Based on the previous studies, the mental rotation of body-related stimuli was regarded as inducing motor imagery.

The measurement of mental rotation performance is considered an efficient method for identifying motor imagery ability which is difficult to measure objectively. In particular, measuring the mental rotation ability in a child was useful for

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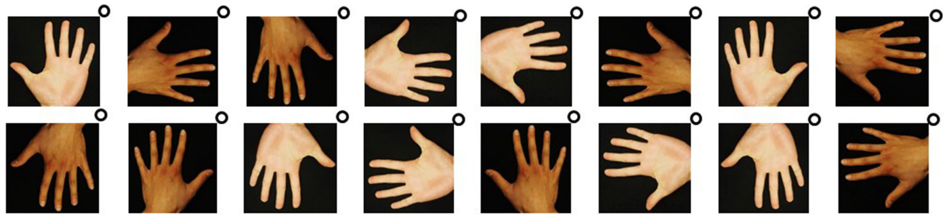

Fig. 1. The sheet of MR task for hand pictures (two hands (right and left) × four orientations (0°, right 90°, 180°, and left 90°) × two views (dorsal and palmar))

determining his or her motor imagery ability[5–7], since the mental rotation task must obviously be done while performing the task. Thus, mental rotation task is regarded as an available tool for subjects who cannot keep attention consistently during some task, such as children.

Understandably, the relationship of improving cognitive function with the development of brain structure in elementary school students has been revealed in previous studies[8–11]. More directly, Sekiyama et al. reported that mental rotation ability improved during the elementary school years[12].

However, in almost all reported previous studies measuring mental rotation ability, subjects were asked to respond by pressing a defined key on a keyboard based on the mental rotation stimulus presented on a PC screen. In general, the times required for judgments and the numbers of judgment errors were used as the dependent variables[1, 2, 4, 13]. To collect accurate data, researchers needed to use specific software to measure the response times to use these values. Additionally, when researchers use response times to measure motor imagery ability, they ask subjects to respond in more than ten trials for each stimulus to collect data with sufficient accuracy. This means that, because this method should take a relatively long time, it is not practical in a clinical setting. Thus, it is necessary to verify a modified method that is easier and can be accomplished in less time.

The purpose of the current study was to develop, for elementary school students, new mental rotation task using paper which can be easily available without a PC or any software. To address the purpose, regarding the performance of the mental rotation task, we focused on the similarity of characteristics shown in previous findings that during mental rotation, (a) the number of mental rotation judgment errors increased as the angles of rotation of the stimuli became larger[4, 14–17], and (b) younger subjects were slower, requiring more time for mental rotation[12, 18].

SUBJECTS AND METHODS

Sixty-three right-handed elementary school children participated in this study (35 females and 28 males, mean age=9.6 years, SD=1.6 years) . These consisted of 13 children in grades one and two (assigned to the lower-grade group), 18 children in grades three and four (assigned to the middle-grade group), and 32 children in grades five and six (assigned to the higher-grade group). Sixteen pictures of hands (palmer and dorsal) were displayed on sheets of A4-sized paper in sets of two hands (right and left) × four orientations (0°, right 90°, 180°, and left 90°) × two views (dorsal and palmar) (Fig. 1). In this study, 0° was defined as the hand being wide open with all fingers pointing upward. Participants were asked to determine as quickly as possible whether a picture showed a right or left hand and to draw a diagonal line into a blank circle on the upper right part of the picture when they judged the picture to be a picture of a left hand. Participants positioned their left hand on their left knee to hide the hand from their sight. Using a digital stopwatch, the researcher measured the time required for mental rotation from the researcher's verbal starting signal to the time participants placed their pens on the table after they finished judging 16 pictures. Before the main trials, a researcher orally instructed participants on how to judge.

The errors for each angle (i.e., two aspects and right-left) were added up. The total number of errors in each angle was analyzed using a 3 (groups: lower grades, middle grades, and higher grades) ×4 (stimulus angles: 0°, R90°, 180°, and L90°) mixed ANOVA. To determine the relationship between age and the ability to mentally rotate, Pearson's correlation analyses between age and mental rotation time were carried out. The level of significance was 0.05.

All participants gave informed consent prior to participating in the study. Experimental protocols were approved by the institutional ethics committee of Ryotokuji University (approval number 2642). The tenets of the Declaration of Helsinki were followed.

RESULTS

The errors for each angle (0°, R90°, 180°, and L90°) were 0.47 ± 0.71, 0.54 ± 0.73, 1.05 ± 0.99, and 0.49 ± 0.71, respectively (Table 1). The main effect of the angle was significant ($F(3, 186)=13.20$, $p<0.001$). Post-hoc analysis showed that the number of errors increased significantly as the rotation angle increased (0° vs. R90°: $t(186)=0.60$, $p=0.55$; R90° vs.

Table 1. Mean (± SE) number of judgment errors at the hand stimuli angles

	0°	Right 90°	180°	Left 90°
Low	0.69 ± 0.17	1.00 ± 0.20	1.38 ± 0.27	1.31 ± 0.33
Middle	0.44 ± 0.17	0.56 ± 0.20	0.83 ± 0.22	0.50 ± 0.19
High	0.41 ± 0.13	0.34 ± 0.11	1.03 ± 0.19	0.41 ± 0.11

180°: t (186)=4.77, p<0.001; 180° vs. L90°: t (186)=5.21, p<0.001) (Table 1). For the mental rotation time, a significant main effect of the group was obtained (F (3, 72)=9.05, p<0.001). Post hoc analysis showed that the students in higher grades were significantly quicker than the students in lower and middle grades (t (72)=4.31, p<0.001, t (72)=2.26, p=0.03, respectively). Also, the middle-grade group was significantly quicker than the lower-grade group (t (72)=2.67, p=0.04). In addition, there was a significant correlation between age and the mental rotation time (r=−0.54, p<0.001) (Table 1).

DISCUSSION

The total number of errors made for each angle increased as the stimulus angle increased. The increase in errors dependent on the stimulus angle was demonstrated in previous studies in younger adults[14, 17)] or elementary school children[12, 18)]. Notably, based on previous studies showing error rates and the time required for judging, the laterality judgment of stimuli rotated 180 degrees was most difficult. The results of the present study were congruent with those of previous studies, suggesting that participants used a mental process of their own body movements during a mental rotation task using paper. In other words, they would imagine their own hand movements during the mental rotation task.

There were significant differences in the mental rotation times between groups. In particular, the lower-grade group was slower than the other groups (middle-grade and higher-grade group). Additionally, mental rotation times were correlated with participants' ages. The findings are fully acceptable because spatial information processing is developing in elementary school children. For instance, Anderson et al. reported that development of executive function (cognitive flexibility, goal setting, and information processing) was shown between the ages of seven and twelve (i.e., the elementary school period)[11)]. Klingberg et al. also showed the development of a superior frontal–intraparietal network for visuo-spatial working memory[9)]. Considering that mental rotation tasks require cognitively demanding spatial information processing[19)], aging in elementary school children would lead to the development of mental rotation abilities. In fact, improving mental rotation abilities with increasing age in elementary school children have been reported in previous studies[12, 18)]. The current result regarding the relationship between mental rotation time and age indicates that mental rotation tasks using paper also required cognitively demanding special information processing. This suggests that mental rotation tasks using paper have the same characteristics as mental rotation tasks using a PC and specific software.

In conclusion, the mental rotation task using paper was demonstrated to be efficient for easily and quickly measuring individuals' motor imagery ability in the present study. This means that the present study would approach to propose a practical mental rotation task for subject having difficulty to keep attention relatively long time, such as elementary school children. The limitation of the present study is that investigations in the reliability of mental rotation using paper were not conducted. To propose mental rotation task using paper, future studies are needed in order to verify the reliability (e.g., inter-rater reliability or test-retest reliability). And, there is a possibility that the differences in the mental rotation times between the groups may be influenced by students' ability to quickly draw diagonally in a small circle because writing speed also increases throughout elementary school. To exclude this possibility, additional examination investigating this influence by measuring students' simple writing abilities are needed (i.e., simple writing speed that is not cognitively demanding).

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