

Received: 11.07.2016  
Accepted: 22.12.2016

A – Study Design  
B – Data Collection  
C – Statistical Analysis  
D – Data Interpretation  
E – Manuscript Preparation  
F – Literature Search  
G – Funds Collection

DOI:10.5604/17307503.1227058

# RELATIONSHIP BETWEEN RESPONSE TIME AND THE ALPHA ATTENUATION OF CONGRUENCE JUDGMENTS IN TWO-MODEL IMAGERY

Tadao Ishikura<sup>(A,B,C,D,E,F)</sup>

Faculty of Health and Sports Science, Doshisha University, Japan

## SUMMARY

### Background:

In a mental rotation study, if the degree of the rotation angle of a visual stimulus becomes large, the response time for congruence judgment increases. Simultaneously, the cranial nerve becomes active. However, the relevance of the reaction response time to the same mental rotation angle degree conditions (e.g., the angle difference is 180°), and cranial nerve activity is unclear. Therefore, this study examined the relationship between the reaction time for congruence judgment in the degree of the rotation angle of the same visual stimulus, and the cranial nerve activity that resulted in alpha attenuation of the index.

### Material/ Methods:

Twelve university students (seven male and five female; mean age = 20.3 years, standard deviation  $SD = 0.9$ ) judged as quickly as possible whether two poses corresponded to each other or not. The angular difference between the two poses was 0° or 180°. The EEG signals were recorded from Fp1, Fp2, F3, F4, C3, C4, P3, and P4 electrodes according to the international 10-20 electrode system, and the frequency bands of  $\alpha$  (8–13 Hz) was analyzed.

### Results:

The results showed the response time at 0° was faster than that at 180°, and the response time was correlated with the amplitude of P4 while judging at 180°.

### Conclusions:

These results indicated that the 180° visual stimulus needs to be mentally rotated; the cranial nerve activity of the right parietal region increases when the response time is quick and the cranial nerve activity of the right parietal region become comparatively small.

**Keywords:** mental rotation, EEG, alpha wave, cognitive load

## **BACKGROUND**

Numerous studies using a mental rotation task have examined the relationship between perceived visual imagery and mental representation. Shepard and Metzler (1971) concurrently presented participants with two three-dimensional objects at several different orientations, and requested judgments if the two objects were same shape or not. The result showed that reaction time for these judgments increased as the degree of difference between the two objects increased. This result raises the possibility that participants first represent an object, and then compare the object with other objects using mental rotation. Moreover, since the reaction time for the judgment became faster when participants were told the rotation angle of the object in advance, it was inferred that participants can prepare for mental rotation before manipulating the representation (e.g., Cooper, 1976; Cooper & Shepard, 1973).

In contrast, it has been reported that the frontal and parietal regions of the brain were activated when participants had to mentally rotate or invert from left to right the direction of a visual object (e.g., Heil, 2002; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999). For example, Roberts and Bell (2003) measured the electroencephalogram (EEG) as male and female university students undertook two- and three-dimensional object mental rotation tasks. Although males exhibited faster reaction times and more correct responses than females for complicated three-dimensional rotations, the response amplitude of both male and female right parietal lobe was larger than that of other brain areas. Kosciak, O'Leary, Moser, Andreasen, and Nopoulos (2009) reported that the gray matter of the parietal lobe in females was larger than that in males, and that this morphologic difference makes the mental rotation task disadvantageous in females. In contrast, the male parietal lobe area is larger than that of females, which is more advantageous for mental rotation. Moreover, the synchronization pattern of the amplitude of alpha 1 (8.5-10 Hz) and alpha 2 (10.5-12 Hz) between the electrode of the frontal lobe and the parietal lobe increased during the mental rotation of letters (Thomas, Dalecki, and Abeln, 2013). In the mental rotation and mental transmission of the others' body part when compared to the observer's own body part, the left posterior parietal lobe was strongly activated (Overney, Michel, Harris and Pegna, 2005; Overnry and Blanke, 2009; Dhindsa, Drobinin, King, Hall, Burgess and Becker, 2014; Mikicin and Kowalczyk 2015).

From these reports, it is clear that the response time on the mental rotation task becomes longer as the degree of the rotation angle of the visual image in mental rotation increase, and the parietal lobe is activated. However, the relation of the response time and cortical activity in the same degree of rotation angle on the mental rotation task was not considered. For example, if the relationship between the response time and cortical activity in the same degree of the rotation angle on the mental rotation task is considered, then it becomes possible to evaluate response time as an indicator of the cognitive efforts in a cerebral infarction patient's rehabilitation during mental rotation.

We examined the relevance of the response time and alpha attenuation, as an index of cognitive decision processes activation (e.g., Boiten, Sergeant, & Geuze 1992; Gevins & Smith, 2000; Stipacek, Grabner, Neuper, Fink, & Neubauer, 2003), in the same degree of the rotation angle of a mental rotation task. We predicted that the conditions in which the rotation of a visual imagery is required delays reaction time, since increased cognitive efforts are needed when compared to the conditions where no rotation is required. Moreover, it is expected that the alpha wave is attenuated when a quick response time is observed since the participants increase cognitive efforts to respond quickly to the conditions asked for rotation. In mental rotation, due to activation of the parietal lobe, we predicted a positive correlation between the response time and the degree of parietal lobe activity.

## **MATERIAL AND METHODS**

### **Participants**

All experiments were conducted with the approval of the Doshisha University Ethics Committee for Scientific Research Involving Human Subjects. All participants signed an informed consent form. Twelve healthy university students (7 male and 5 female; mean age = 20.3 years, standard deviation [*SD*] = 0.9) participated in this experiment.

### **Task, materials, and design**

Participants were required to judge as quickly as possible whether two wooden dolls were posed in the same way. The poses were presented on a 22-inch wide CPU monitor, which was placed 50 cm away from the participants' eyes (see Figure 1).

After participants received an explanation of the experiment, an electrode cap (Electro-Cap International, Inc., USA) was placed on their head. The cap was placed according to the international 10-20 electrode system: signals were recorded from Fp1, Fp2, F3, F4, C3, C4, P3, and P4 electrodes. Both EEGs and EOGs were sampled at 500 Hz using an EEG-1200 system (Nihon Kohden, Inc., Japan), and band-pass filtered at 0.15–60-Hz. The impedance of all electrodes was 10 k $\Omega$  or less.

First, the participant relaxed for one minute with eyes open and one minute with eyes closed. Next, two wooden dolls were shown simultaneously on the monitor, one on the left and the other on the right side. There were three possible poses. The left-side model was presented at a front or rear angle, whereas the right-side model was presented at 0° or 180°, relative to the front of the pose (i.e., a front parallel view). The participant pressed "1" with their left index finger on a ten-key panel if they judged that the models had the same pose, and "3" with right index finger if they judged a different pose. After the response, the current percent correct was presented on the monitor. There were 80 trials, in-

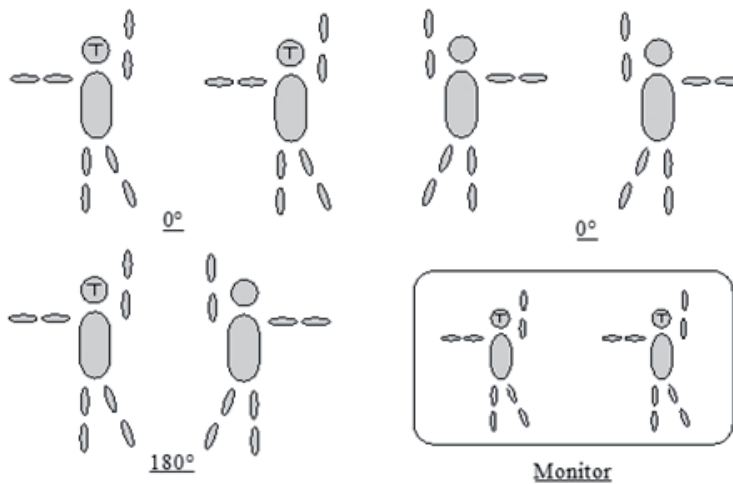


Figure 1. A sample of poses used in this experiment

cluding eight non-task related pictures used to obtain a baseline for analyzing the EEG data, which were presented in random order. The participants were free to look anywhere they wanted during the experiment.

### Data processing and dependent variables

The data were analyzed by conducting 256-point FFTs (Fast Fourier transforms) using ATAMAP II (Kissei Comtec, Inc., Japan). Raw data were analyzed at 1.95 Hz resolution; two 0.51-s units were averaged to yield a 1.02-s epoch for analysis.

The frequency band was  $\alpha$  (8–13 Hz). The data that included artifacts were excluded from analysis. We used content ( $\mu\text{V}$ ) to compare the transition of data, and determined the content ( $\mu\text{V}$ ) remainders for  $\alpha$  by comparing the task judgment data and the observations of non-task-related pictures (the landscape pictures). That is, the remainders were positive if the content ( $\mu\text{V}$ ) during the judgments was higher than those during the observations of non-task related pictures.

### Statistical analysis

A two-way analysis of variance (ANOVA) was used for the analysis of the reaction time and the percent correct responses. All significant effects are reported at  $p < .05$ , with effect sizes reported as  $\eta^2$ , and statistical power reported as  $\phi$ . Post hoc comparisons of the means were performed using the Tukey *HSD* test. A multiple stepwise regression was used to examine the relationship between the reaction time and the content ( $\mu\text{V}$ ) remainders of  $\alpha$  data. IBM SPSS Version 22 J (IBM SPSS Japan, Inc., Japan) statistical software was used for all statistical analyses.

## RESULTS

### Reaction times and correct responses

We used a two-way ANOVA to compare the reaction time between the angular differences ( $0^\circ$  and  $180^\circ$ ) and sex differences (male and female). Figure 2 shows the mean reaction time and standard deviation for each angular difference. The angle effect was significant,  $F(1, 10) = 37.12, p = .01, \eta^2 = .79, \phi = 1.00$ . The reaction time for  $0^\circ$  was faster than that for  $180^\circ$ . The effect of sex difference was not significant.

To compare the proportions of correct responses as a function of angles ( $0^\circ$  and  $180^\circ$ )  $\times$  sex (male and female), we used a similar two-way ANOVA. Figure 3 shows the mean proportion of correct responses and the standard deviation. The main effect of the proportions of correct responses was significant,  $F(1, 10) = 17.33, p = .01, \eta^2 = .63, \phi = .96$ . The percent correct at  $0^\circ$  was greater than the percent correct at  $180^\circ$ . The effect of sex difference was not significant.

### Reaction times versus EEG

We used stepwise multiple regression analysis to examine the relationship between the reaction times and the content ( $\mu\text{V}$ ) remainders of  $\alpha$  for each electrode. The result of the regression for  $180^\circ$  ( $F(1, 10) = 6.13, p = .03$ ) was significant. The standardized partial regression coefficient was significant for P4 at  $180^\circ$  (0.62). The regression analysis for  $0^\circ$  was not significant.

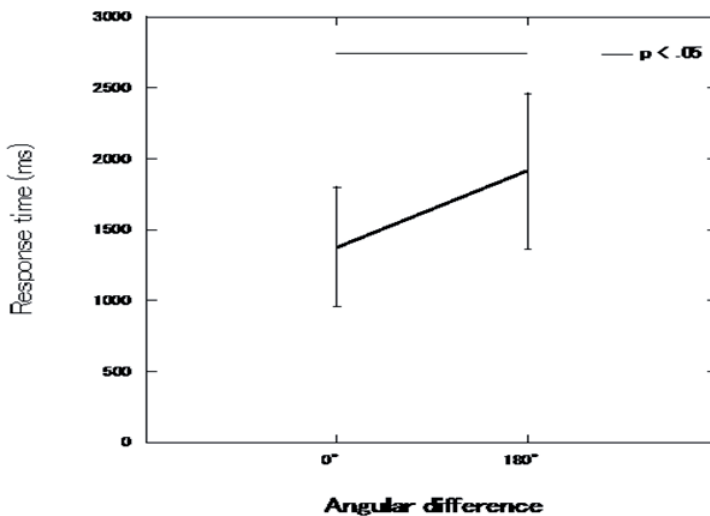


Figure 2. Reaction times for each angular difference

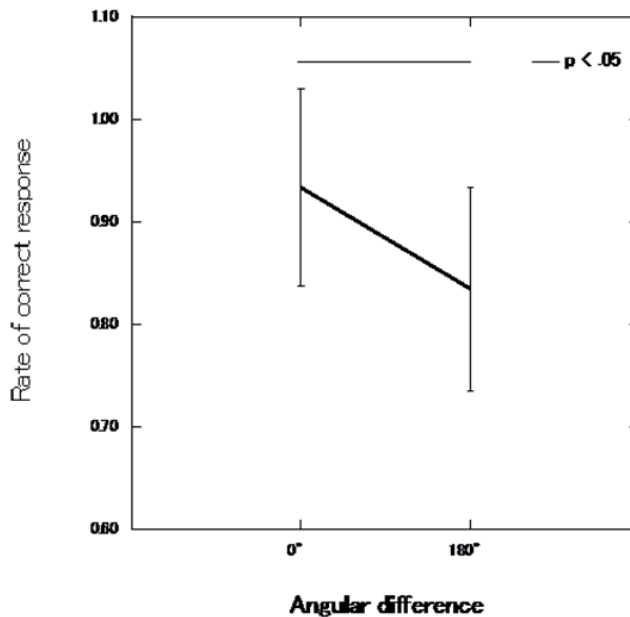


Figure 3. The proportion of correct answers for each angular difference

## DISCUSSION

This study examined the relationship between the reaction time in which the congruence judgment of the degree of rotation angle of the same visual stimulus occurs, and the cranial nerve activity, which induced the alpha attenuation of the index. The results suggest that the accuracy of the response time and the accuracy of response for mental rotation of 0° was faster and more accurate than that for 180°. These results supported the notion that the judgment reaction time increased as the degree of difference between the two objects increased in the mental rotation task (Shepard & Metzler, 1971). The hypothesis of this study was that the conditions that require rotation of visual imagery are reflected in the delay of the reaction time. In other words, the cognitive effort required in the 180° condition was compared with the 0° condition, which required no rotation. However, we found no difference between the performance of male and female participants on the three-dimensional mental rotation task, in contrast to the findings of Roberts and Bell (2003) Moreover, analysis of the response time and the alpha wave attenuation indicated that the content becomes smaller as the response time becomes quicker at P4 in the 180° condition. This result proves that the right parietal lobe (electrode P4) is activated when the response time is quick, thereby supporting our hypothesis that alpha wave attenuation is observed when the response time is quick. This finding is also consistent with the results of Roberts and Bell's study, which reported that the response amplitude in the right parietal lobe in both men and women was larger than that in other brain areas

during the performance of a complex three-dimensional block design mental rotation task (Roberts and Bell, 2003). According to Overney, et al (2005), Overney and Blanke (2009), and Dhindsa, et al (2014), the left posterior parietal lobe is strongly activated during mental rotation and mental transmission involving the body part of another person compared to the observer's own body part. Consequently, in the current study, the results obtained in the mental rotation task involving wooden dolls suggested that the participants' judgments did not involve their own body image.

### **Statement of informed consent**

All procedures followed the ethical standards of the relevant committees on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 (5). Informed consent was obtained from all patients included in the study.

## **REFERENCES**

- Boiten, F., Sergeant, J., & Geuze, R. (1992). Event-related desynchronization: The effects of energetic and computational demands. *Electroencephalography and Clinical Neurophysiology*, 82, 302–309.
- Cooper, L. A. (1976). Demonstration of a mental analog of an external rotation. *Perception and Psychophysics*, 19, 296–302.
- Cooper, L. A., & Shepard, R. N. (1973). Chronometric studies of the rotation of mental images. In W. G. Chase (Ed.), *Visual information processing* (pp. 75–176). New York: Academic Press.
- Dhindsa, K., Drobinin, V., King, J., Hall, G.B., Burgess, N. & Becker, S. (2014) Examining the role of the temporo-parietal network in memory, imagery, and viewpoint transformations. *Frontiers in Human Neuroscience*, 8, 1–13.
- Gevens, A., & Smith, M. E. (2000). Neurophysiological measures of working memory and individual differences in cognitive ability and cognitive style. *Cerebral Cortex*, 10, 829–839.
- Heil, M. (2002). The functional significance of ERP effects during mental rotation. *Psychophysiology*, 39, 535–545.
- Koscik, T., O'Leary, D., Moser, D.J., Andreasen, N.C., & Nopoulos, P. (2009) Sex differences in parietal lobe morphology: Relationship to mental rotation performance. *Brain and Cognition*, 69, 451–459.
- Mikicin M., Kowalczyk M. (2015) Improvement in peak performance as a result of the inhibition of beta 2 bands (EEG) in neurofeedback-EEG training in motion. *Acta Neuropsychologica* 13(4):265-276.
- Overney, L.S., & Blanke, O. (2009) Impaired imagery for upper limbs. *Brain Topography*, 22, 27–43.
- Overney, L.S., Michel, C.M., Harris, I.M., & Pegna, A.J. (2005) Cerebral processes in mental transformations of body parts: Recognition prior to rotation. *Cognitive Brain Research*, 25, 722–734.
- Roberts, J. E., & Bell, M. A. (2003). Two- and three-dimensional mental rotation tasks lead to different parietal laterality for men and women. *International Journal of Psychophysiology*, 50, 235–246.
- Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171, 701–703.
- Stipacek, A., Grabner, R. H., Neuper, C., Fink, A., & Neubauer, A. C. (2003). Sensitivity of human EEG alpha band desynchronization to different working memory components and increasing levels of memory load. *Neuroscience Letters*, 353, 193–193.
- Thomas, M., Dalecki, M., and Abeln, V. (2013) EEG coherence during mental rotation of letters, hands and scenes. *International Journal of Psychophysiology*, 89, 128–135.

Zacks, J., Rypma, B., Gabrieli, J. D. E., Tversky, B., & Glover, G. H. (1999). Imagined transformations of bodies: An fMRI investigation. *Neuropsychologia*, *37*, 1029–1040.

**Address for correspondence:**

Tadao Ishikura  
Faculty of Health and Sports Science,  
Doshisha University, 1-3 Tatara Miyakodani,  
Kyotanabe-shi 610-0394, Japan  
mail: tishikur@mail.doshisha.ac.jp