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DO PARTICIPANTS USE MENTAL ROTATION WHEN COMPARING TWO MODELS FROM DIFFERENT VIEWING ANGLES?

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SUMMARY

Background: This study aimed to examine the role of the viewing angle in determining whether two posed figures are the same or different, in terms of event-related potentials (ERPs) and cognitive load measured via response times. It was hypothesized that an angular difference between poses of 0° would be associated with the shortest reaction times and the largest ERP amplitudes before, and 350 ms after a stimulus presentation.

Material/ Methods: Fourteen healthy male university students (mean age = 22.4 years, SD = 1.4) participated. They were asked to judge whether two figures were posed in the same way or not. The difference in angular rotation between the two figures was 0º, 60º, 120º, or 180º.

Results: The angular differences of 0º received the fastest responses. The Pz scalp site had a larger amplitude from 250 ms to 500 ms after stimulus onset than from 500 ms to 600 ms, but there was no effect of the viewing angle. Similarly, the viewing angle was also not distinguished in the pre-response ERP components.

Conclusions: These results indicate that since there was no rotation-related negativity in the ERP data, individuals might judge whether two simultaneously presented figures are the same or different without mentally rotating the figures.

Keywords: mental rotation, event-related potentials (ERPs), rotation-related negativity (RRN)

BACKGROUND

During observational motor skill learning, the angle from which a demonstration is viewed affects the learning efficiency. For example, during a skill demonstration, participants who viewed a model from the back learned faster than those who viewed the model from the front (Ishikura & Inomata, 1995). The researchers proposed that the reason for their results was that the learners who observed the model from the front had to mentally rotate the model's image because there was a 180˚ difference between the physical position of the demonstrator and that of the learner. That is, the degree to which the spatial relationship between the model's body and the learner's body coincides affects the learner's cognitive load during visual information processing.

Shepard & Metzler (1971) reported that when participants judged the correspondence or non-correspondence of two, three-dimensional letters or digits, the response time was proportional to the angular difference between the letters or digits. It was assumed that the image of the object was rotated mentally: larger angular differences between the two objects determined the cognitive load, and thus slowed responses (e.g., Cooper, 1976; Cooper & Shepard, 1973; Mikicin 2016).

Heil (2002) measured event-related potentials (ERPs) during mental rotation, observing that larger rotation angles led to greater negative amplitudes for the P300 component. This phenomenon was called rotation-related negativity (RRN); the negative-polarity slow wave (NSW) showed the greatest amplitude over the parietal region of the cortex (Stuss, Sarazin, Leech, & Picton, 1983). RRN is observed about 350 ms after the presentation of the visual stimulus, and the subsequent late-positive components are correspondingly reduced in magnitude. RRN is the ERP aspect most sensitive to different rotation demands (Riečanský et al., 2013). Further, Riečanský & Jagla (2008) reported that RRN was observed in the pre-response period, from about 600 ms pre-stimulus, reaching a peak at 400 ms pre-stimulus.

Larger angular differences between two posed figures should be associated with slower reaction times when judging their correspondence, because of the cognitive load associated with the mental rotation of the figure. Accordingly, larger RTs are expected to be associated with higher-magnitude ERP components. That is, the larger the rotation angle, the greater the magnitude of the relevant ERPs (Heil, 2002), and the greater the magnitude of the ERP component peaking 400 ms pre-response (Riečanský & Jagla, 2008). The study reported here examined the role of the viewing angle in assessing whether two posed figures were the same, in terms of ERPs and the cognitive load measured via response times.

MATERIAL AND METHODS

Participants

This experiment was conducted after obtaining the approval of the Doshisha University Ethics Committee for Scientific Research Involving Human Subjects.

Fourteen healthy male university students (mean age = 22.4 years, *SD* = 1.4 years) participated in this experiment.

Task and procedure

Participants were required to judge whether two images of posed figures were of the same pose. The poses were presented on a 22-inch monitor. If the participant judged that the two poses were correspondent, they pressed the “1” key on a keyboard’s numeric keypad and the “3” key otherwise. The difference in angular rotation between the two figures was 0º, 60º, 120º, or 180º. The figures were posed in five different ways (Figure 1).

After explaining the experiment to the participant, we attached the EEG electrodes, after which the experiment began. After presenting a black screen for 1200 ms, two poses were simultaneously presented on the monitor. The screen changed back to the black background once the participant had responded. After a 3000 ms interval, accuracy feedback, the reaction time, and the current percentage of correct answers were presented for 2000 ms. This procedure was repeated for 60 trials × 4 sets (240 trials).

Dependent variables

EEG leads were placed according to the International 10–20 Electrode System. Signals were recorded from Fz, Cz, and Pz using silver-silver chloride electrodes. The reference electrodes were placed on each earlobe. EEGs were sampled at 500 Hz using an EEG-1200 system (Nihon Kohden, Inc., Japan). The electrical resistance of each EEG electrode was under 10 kΩ. The amplifier bandwidth was 0.1–60 Hz.

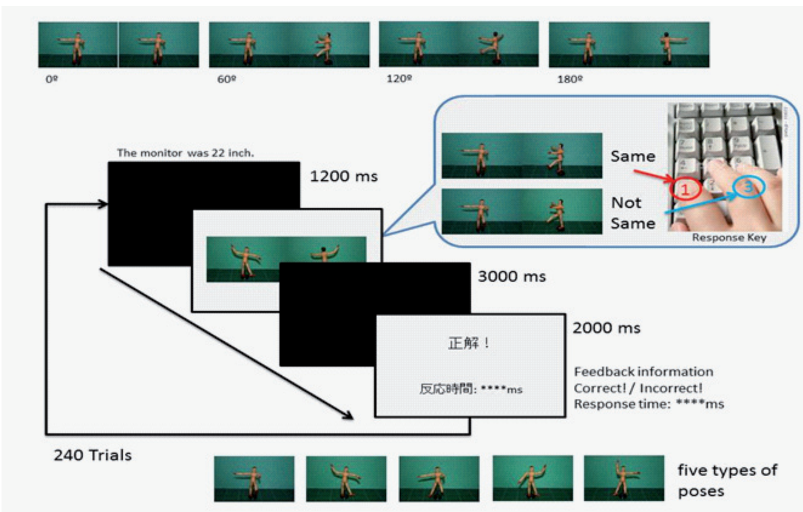

Figure 1. The experimental procedure. The participant was required to judge as quickly as possible whether two figures were posed in the same way. After a response key was pressed, the feedback information was presented on the monitor

The ERPs for each angular difference were analyzed within 50 ms windows, from 250 ms to 1000 ms from the stimulus onset, and from 700 ms pre-response to 100 ms post-response.

Statistical analysis

One- and two-way analyses of variance (ANOVAs) were used in this study. Significant effects were defined as $p < .05$. Post-hoc comparisons of the means were performed using Tukey's HSD. IBM SPSS Version 23 J statistical software (IBM SPSS Japan, Inc., Japan) was used for all statistical analyses.

RESULTS

Percent correct and response times

A one-way ANOVA showed there were no significant differences in the percentage correct according to the angular difference (0˚, 60˚, 120˚, and 180˚). The mean percentage correct was 91.0%. We used a one-way ANOVA to compare the reaction times at angular differences of 0˚, 60˚, 120˚, and 180˚. Figure 2 shows the mean and standard deviation of reaction time for each angular difference. The effect of the angle was significant ($F_{3,39} = 54.12$, $p = .001$); figures with an angular difference of 0º received the fastest responses.

Figure 2. Response times for judging whether two stimulus models had the same pose, for four angular differences between the models.

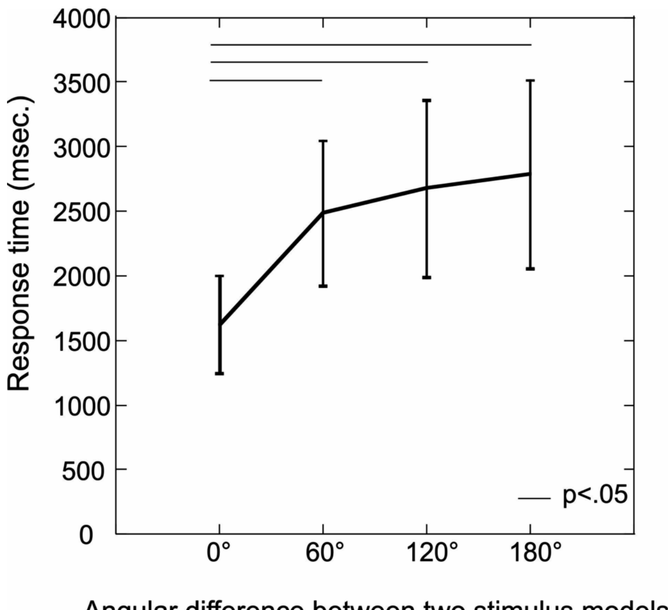

Figure 2. Response times for judging whether two stimulus models had the same pose, for four angular differences between the models.

Potential from 250 ms to 1000 ms from stimulus onset

To compare potentials from 250 ms to 1000 ms after stimulus onset among the angles, we used a two-way ANOVA with the factors angular difference (0˚, 60˚, 120˚, and 180˚) and time period (15 windows). Figure 3 shows the mean of the potential amplitudes of Fz, Cz, and Pz.

For Fz (see Figure 3, left), using the Greenhouse-Geisser correction, the main effect of the time period was significant ($F_{2.00, 25.91}$ = 19.01, p = .001). The potential amplitude between 250 ms and 459 ms was larger than between 850 ms and 1000 ms. The main effect of angular difference and the interaction were not significant.

For Cz (see Figure 3, center), using the Greenhouse-Geisser correction, the main effect of the time period was significant ($F_{2.15, 27.94}$ = 8.08, p = .001). The potential amplitude between 250 ms and 499 ms was larger than between 600 ms and 699 ms. The interaction was significant ($F_{6.63, 96.16}$ = 2.56, p = .021). Table 1 shows the results of multiple comparisons.

For Pz (see Figure 3, right), the main effect of the time period was significant ($F_{14, 182}$ = 6.85, p = .001). The potential amplitude between 250 ms and 499 ms was larger than between 500 ms and 599 ms. The interaction was also significant ($F_{42, 546}$ = 1.46, p = .034). Table 1 shows the results of multiple comparisons.

Potential from 700 ms pre-response to 100 ms post-response

To compare the potential amplitude from the 700 ms pre-response to the 100 ms post-response, we used an angular difference (0˚, 60˚, 120˚, and 180˚) × time period (16 windows) two-way ANOVA. There were no significant differences for each main effect and the interaction, that is, the viewing angle did not influence the pre-response ERP components.

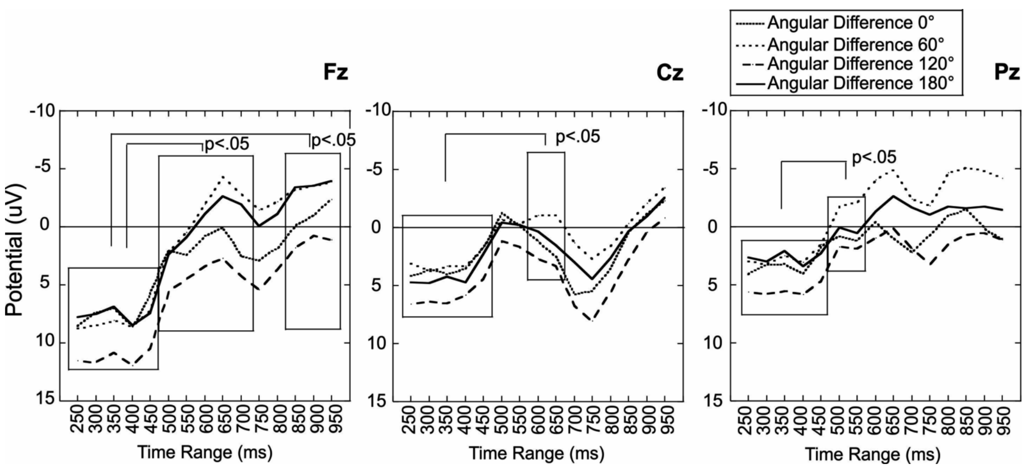

Figure 3. Potential from 250 ms to 1000 ms from stimulus onset for Fz (left), Cz (center), and Pz (right).

Table 1. Multiple pair-wise comparisons of potentials at each electrode site

Electrode	Condition	Comparison
All angles of Fz		250 ms – 459 ms > 850 ms – 1000 ms
All angles of Cz		250 ms – 499 ms > 600 ms – 699 ms
	650 ms – 1000 ms	120˚ > 60˚
	60˚	250 ms – 499 ms > 600 ms – 749 ms
	120˚	300 ms – 499 ms > 550 ms – 699 ms
	180˚	400 ms – 499 ms > 650 ms – 699 ms
All angles of Pz		250 ms – 499 ms > 500 ms – 599 ms
	700 ms – 849 ms	120˚ > 60˚, 180˚
	0˚	250 ms – 449 ms > 500 ms – 549 ms
	60˚	250 ms – 499 ms > 950 ms – 1000 ms
	120˚	250 ms – 399 ms > 500 ms – 549 ms
	120˚	700 ms – 849 ms > 650 ms – 699 ms
	180˚	300 ms – 449 ms > 550 ms – 599 ms

DISCUSSION

The results showed that the angular difference of 0º received faster responses than the other conditions. Although most mental rotation studies have reported that response times increase as angular differences become larger, the results of the current study did not replicate this finding. However, our results indicated that visually processing conditions other than 0º required more cognitive load.

Rotation-related negativity (RRN) has been reported as a feature of event-related potentials (ERPs) during mental rotation, whereby the highest potentials occur over the parietal region 350 ms after the visual stimulus presentation, and ERPs become increasingly negative as the angle of mental rotation becomes larger (Stuss, Sarazin, Leech, & Picton, 1983). Although the current study showed that the potential magnitude at Pz between 250 ms to 499 ms was larger than between 500 ms and 599 ms, no relationship between angular difference and amplitude was observed. It has also been reported that RRN is observed from about 600 ms before the response and that the peak of amplitude of RRN occurs about 400 ms pre-response (Riečanský & Jagla, 2008). Our results did not show these features. Therefore, since there was no rotation-related negativity in the ERP data, individuals might have judged whether the two simultaneously presented figures were the same without using mental rotation. It seems that the task used in this study did not require the participants to engage in the mental rotation of the posed models. The mental rotation studies using letters or digits typically present one visual stimulus to the participant, from a certain viewpoint. The participant is then required to compare a subsequently displayed visual stimulus with their mental image of the previous stimulus. To judge correspondence requires recall of the initial stimulus. The current study did not require recall because the participant compared two simultaneously presented posed figures. Consequently, RRN was not observed . Therefore, to examine RRN in a similar task might require participants to reproduce the model's gestures (Bianchi et al., 2014) using egocentric (from the model's back) and allocentric viewing angles (from the model's front).

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