Final Project

Exploring the Differences in Mental Rotation of Letters and Faces: Comparing Reaction time

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Background

Mental rotation, the cognitive process of rotating mental representations of two-dimensional and three-dimensional objects, is a well-established area of research in cognitive psychology. Shepard first demonstrated the phenomenon in their seminal work, showing that the time it takes to decide whether two objects are the same increases linearly with the angular difference between their orientations, suggesting that objects are mentally rotated in an analogue fashion to align them(Cooper & Shepard, 1973). Subsequent research has expanded on these findings, exploring different types of stimuli such as letters, numbers, and human faces. While studies involving letters and geometric shapes are plentiful, they found that the time to recognize letters as the same, when presented in different orientations, also followed a linear trend with respect to the angle of rotation, confirming that mental rotation is not limited to objects but also extends to symbolic representations(Cooper & Shepard, 1973). The research on mental rotation of faces is comparatively less extensive but suggests a more complex cognitive process. Studies by Yin (1969) revealed that faces are recognized differently from objects, likely due to their bilateral symmetry and inherent emotional content(Yin, 1969). This complexity could potentially lead to differences in how mental rotation is performed on faces versus letters, where faces may not only be rotated but also processed through a filter of social and emotional recognition(Bruce & Young, 1986). Moreover, the reaction times (RT) associated with the mental rotation of letters and faces may differ due to the distinct cognitive strategies employed. For example, faces might be processed in a more holistic manner compared to the more feature-based analysis used for letters(H. Tanaka, 2020; Tanaka J. W. & Simonyi, 2016). This suggests that different cognitive and neural mechanisms are likely to be engaged depending on the type of stimulus, potentially leading to significant differences in RT for mental rotation tasks.(Bartlett et al., 2009)

Research Objectives

Exploring the Differences in Mental Rotation of Letters and Faces: Comparing Reaction Time. The objectives of this research are: To determine if there is a significant difference in reaction times (RT) for mental rotation tasks involving letters versus faces. To analyze the changes in reaction times as the rotation angle increases for both letters and faces, and whether these changes differ by material type.

Hypotheses

Exploring the Differences in Mental Rotation of Letters and Faces: Comparing Reaction Time. The objectives of this research are: To determine if there is a significant difference in reaction times (RT) for mental rotation tasks involving letters versus faces. To analyze the changes in reaction times as the rotation angle increases for both letters and faces, and whether these changes differ by material type.

Research significance

The study explores the differences in performance between letters and faces in a mental rotation task, which has far-reaching implications for cognitive psychology and related fields. First, by comparing the mental rotation reaction times of letters and faces, we can gain a deeper understanding of the differences in cognitive processing of visual stimuli. The processing of letters, a fundamental component of language, is often associated with linguistic cognition and visuospatial skills, whereas the recognition and processing of faces, as key visual information for social interactions, involves more complex affective and socio-cognitive functions.

In addition, this research highlights the value of the application of cognitive psychology research in understanding human intelligence and behavior. By exploring ways to better understand and enhance human spatial cognitive abilities, can develop new technologies and approaches for a variety of fields, including virtual reality, robotics, and augmented reality, among other high-tech areas that are highly dependent on effective spatial vision and cognitive processing.

Methods

Experiment Process

We improved upon the classical mental rotation paradigm introduced by Shepard and Metzler. As shown in Figure 1, for each trial, participants were first presented with a fixation cross for 5 seconds to ensure they were focused on the task. They were then shown two letters or two similar faces that had been rotated to varying degrees and were asked to determine whether the two letters or faces were mirror images of each other. Participants responded by pressing a button. The reaction times and accuracy rates of the participants were recorded. Each trial lasted 6 seconds; trials that exceeded this duration were skipped and recorded as no response.

The experiment consisted of five stages. Initially, the experimenter demonstrated the materials used during a training session to ensure that the participants understood the concepts of rotation and mirroring. The trials using letters as experimental materials were then conducted 60 times. After a 30-second interval, the same number of trials were performed using male faces, followed by female faces and another set of letter materials. Each set comprised 60 trials, with a 30-second rest between sets.

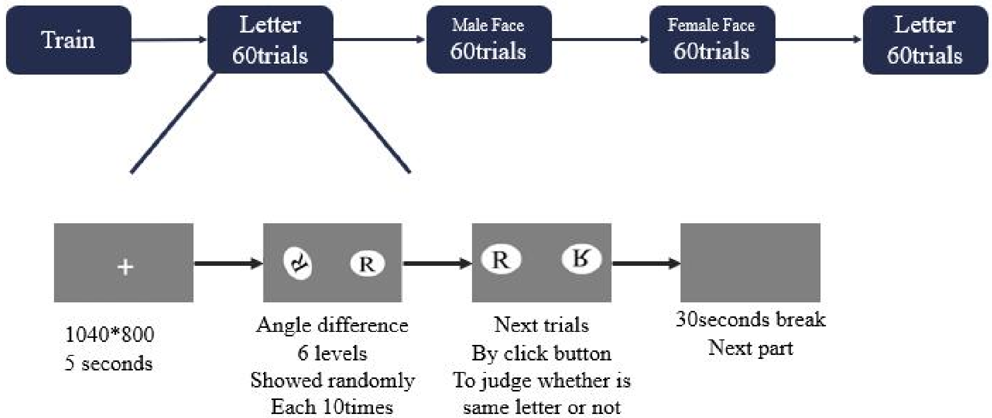

Figure 1 *Flowchart of experiment*

Materials

Regarding the experimental materials, as shown in Figure 2, we mirrored the letter R and then rotated two letters clockwise at 60°, 120°, 180°, 240°, and 300°, creating 12 different angular orientations of the letter materials. These were then randomly paired. In total, there are 144 kinds of stimuli. Congruent and incongruent stimuli are equally represented, with each level of angular difference having 24 kinds of stimuli.

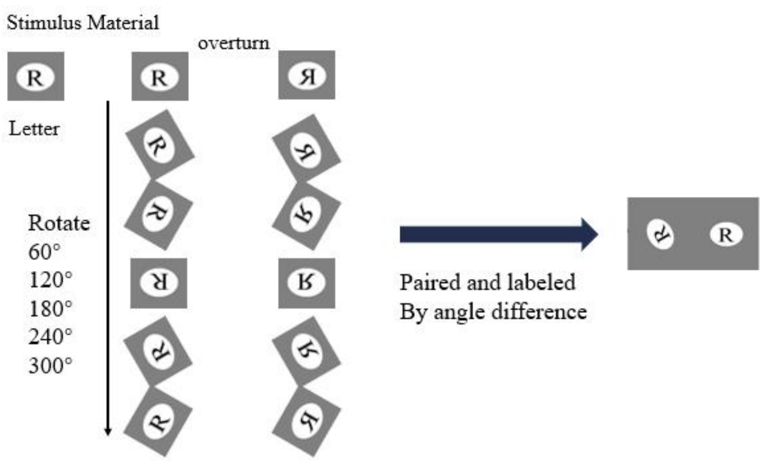

Figure 2 *Flowchart of rotate and overturn*

Figure 3 *Faces used in experiment*

For the face materials, we initially used the GAN method to generate the required faces. The process began with pretraining the GAN on the CelebA-HQ dataset, focusing on 30,000 high-resolution images of celebrity faces. We developed a 512-dimensional latent space that captures the key features and variations from the CelebA-HQ dataset. We randomly sampled points from the latent space using a multivariate normal distribution to generate initial source images. From each source image, we generated new images by adjusting specific distances in the latent space, creating a series of images that progressively differed from the original. We manually inspected the generated images, removed any with visual artifacts, and randomly selected 18 images as source faces for the experiment. We applied a gray, ellipsoid mask to each image to reduce visual variance not related to facial features. Two of the 18 were selected with asymmetric features, as shown in Figure 3. These two faces underwent a similar process as the letters.(De La Torre-Ortiz et al., 2023)

Variables and statical methods

The study employed a mixed ANOVA design. There are three independent variables: Within-subject Variable A is Stimulus type, with 2 levels, Face & Letter; Within-subject Variable B is Angle difference, with 6 levels, 0°, 60°, 120°, 180°, 240°, 300°; Between-subject

Variable C is Participant gender, with 2 levels, Male & Female. The Dependent Variable is the reaction time to judge whether paired stimuli are mirrored or not. Before analyzing, we removed incorrect trials and those whose reaction time exceeded 6000 ms. We then averaged the reaction times of the same type of trials with the same angle before applying mixed ANOVA analysis.

Results

As shown in Table 1, for the main effects, the main effect of gender on the dependent variable was not statistically significant ($F(1, 227) = 3.226$, $p = 0.074$), suggesting that there were no overall differences between genders across the conditions tested. There was a significant main effect of type ($F(1, 227) = 8.046$, $p = 0.005$). The angle factor had a notably large effect size (Partial $\eta^2 = 0.759$), highlighting its substantial impact. This indicates that the dependent variable differed significantly between the types studied. The effect of angle was highly significant ($F(5, 227) = 40.721$, $p < 0.001$), showing that changes in angle had a strong effect.

Regarding interaction effects, there was a significant interaction between type and angle ($F(5, 227) = 12.656$, $p < 0.001$), suggesting that the effect of type on the dependent variable varies depending on the angle. The significant interaction of type * angle also had a relatively large effect size (Partial $\eta^2 = 0.721$), which reinforces the importance of considering these factors together in further analyses. When Type interacts with Gender and Angle interacts with Gender, these interactions were not statistically significant ($p = 0.158$ and $p = 0.534$, respectively), indicating that the effects of type and angle do not vary significantly by gender. The three-way interaction was also not significant ($F(5, 227) = 0.276$, $p = 0.926$), suggesting that the combined effects of type, angle, and gender on the dependent variable do not significantly differ.

As shown in Figure 4, further simple effects tests found that at a rotation angle difference of 0°, women's reaction times to faces were significantly lower than to letters, while this difference was not detected in the male group. For men, at an angle difference of 60°, their reaction time was the shortest, and there were significant differences compared to the 0° and 120° groups. However, for women, whether letters or faces, the reaction times were consistent within the 0° to 120° range. At an angle difference of 180°, when participants needed to rotate the paired materials to the same angle, there was a peak in reaction time for all participants to faces, although this effect was not observed in their responses to letters. As the angle difference increased, meaning the rotation to the same level angle progressively decreased, the required reaction times sharply declined, regardless of gender or material type.

Table 1 *Mixed ANOVA Analyze Table*

Source	DF	SS	MS	*F* value	*p* value	Partial η^2
Between-subjects	1	484880				
Gender	1	484880	484880	3.226	0.074	0.048
Within-subjects	6	31814394				
Type	1	1209394	1209394	8.046	0.005	0.437
Angle	5	30605000	6120995	40.721	<0.001	0.759
Interaction	16	10639419				
Type * Angle	5	9512261	1902452	12.656	<0.001	0.721
Type * Gender	1	301133	301133	2.003	0.158	
Angle * Gender	5	618910	123782	0.823	0.534	0.008
Type * Angle * Gender	5	207115	41423	0.276	0.926	0.078
Error	187	30664600				
Total	227	76765300				

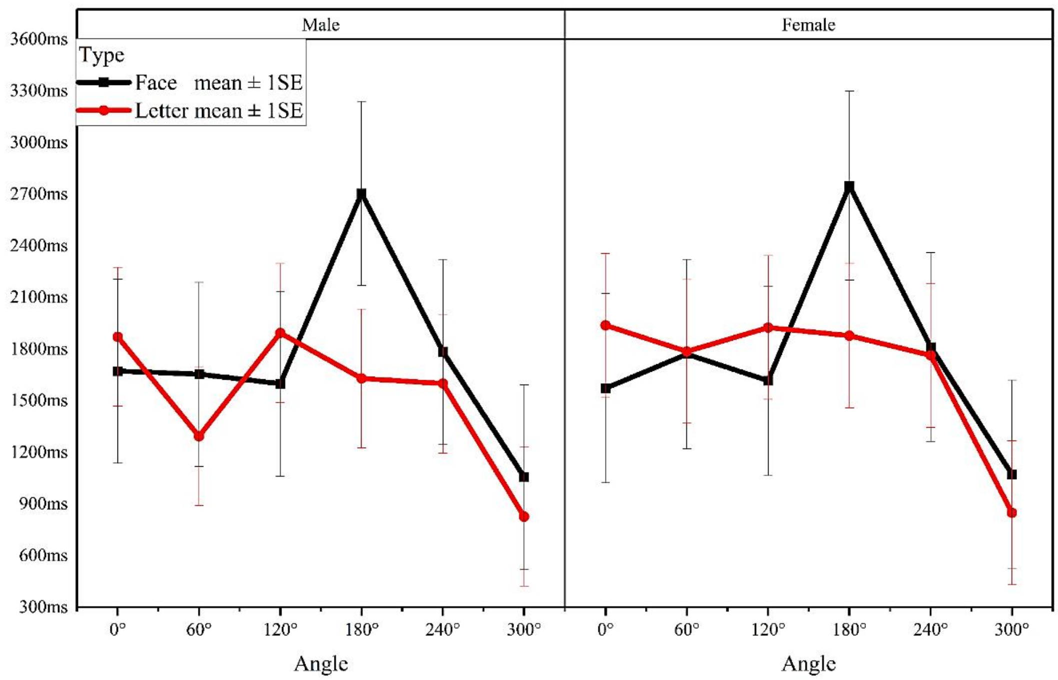

Figure 4 *Three-Way Interaction Effects of Gender, Type, and Angle on RT*

Discussion

Our study systematically confirms previous findings that reaction time increases with rotation angle, thus identifying angle as a critical factor in the performance of a mental rotation task. The increase in reaction time can be attributed to the intrinsic requirement of the recognition task, i.e., the necessity to mentally transform the rotating object, which supports the theoretical models(Cooper & Shepard, 1973; Shepard & Metzler, 1971). This suggests that the cognitive load increases as the angle of rotation increases, which may be due to the need to employ different cognitive strategies to accommodate the increased complexity.

When stimulus types were examined, significant differences were observed between the face and letter rotation tasks. Response times to faces were consistently longer than response times to letters, which is consistent with the hypothesis that face recognition requires more complex cognitive processes. Part of the reason for this complexity is that faces have richer and more varied features than the more uniform and familiar letter features(Bruce & Young, 1986). It is likely that the intricate nature of facial features demands more extensive cognitive engagement, reflecting deeper processing needs.

Furthermore, our study extends the neural basis of these tasks. The different neural circuits activated during face and letter rotation suggest a specialization of the brain's visual and recognition systems. The patterns of activation of the occipital and temporal lobes for faces, as well as of the posterior parietal cortex for both stimuli, emphasize different processing pathways(Zacks, 2008). Particularly, the stronger N170 component associated with face rotations highlights the initial visual processing challenges unique to this type of stimulus(H. Tanaka, 2020)

However, our findings call into question some of the existing literature, such as that of Tanaka (2020), whose study did not observe significant behavioral differences between face rotation and letter rotation. Such differences may be due to methodological differences or differences in sample characteristics, and further research is necessary to elucidate these aspects(Tanaka J. W. & Simonyi, 2016).

Interestingly, the phenomenon observed at 300 degrees rotation where reaction times significantly decreased can be explained through the principle of the shortest path. In this scenario, stimuli presented include one image upright and the other at 300 degrees. Here, participants have an upright image as a reference, requiring only a 60-degree mental rotation to align the images. In contrast, at 0 degrees where both images might be rotated to 60 degrees, there is no upright image to serve as a reference. This absence seems to require more cognitive processing compared to the 300-degree condition, where the cognitive load is lessened by the presence of an intuitive reference.

Conclusion and limitations

Theoretical Implications and Practical Applications

Our findings distinguish themselves by identifying the heightened cognitive and emotional demands faced during mental rotation tasks involving faces compared to letters. This research extends spatial cognition studies by demonstrating how highly specialized visual stimuli, like faces, require complex cognitive resources beyond basic spatial transformations. The implications of this research are significant for cognitive rehabilitation. For instance, developing training programs that use progressively complex rotations of facial images could significantly improve recognition abilities in individuals with brain injuries or prosopagnosia. Such methodologies can also be adapted to improve attention and processing speeds in patients with ADHD, utilizing tasks that increase in complexity and demand.

Limitations and Future Directions

The primary limitations of our study include the lack of neurophysiological data and a sample size that may limit the generalizability of our findings. Future research should incorporate advanced neuroimaging techniques such as EEG and fNIRS to explore underlying neural mechanisms, particularly focusing on components like N170, which are crucial for face recognition. Additionally, including a more diverse participant pool would enhance the robustness and applicability of our findings across different demographics. Integrating Virtual Reality (VR) technology could also provide more immersive and realistic scenarios for mental rotation tasks, potentially offering new insights into how these cognitive processes function in more dynamic, real-world settings. This combination of methodological enhancements would not only address the current study's limitations but also broaden the scope and impact of the research in cognitive psychology and neurorehabilitation.

Conclusion

Our results show that rotation angle has a significant effect on reaction time, highlighting that task difficulty increases with angle. Specifically, the face rotation task elicited longer reaction times compared to the letter rotation task, suggesting that face recognition involves more complex cognitive processing. In addition, we observed that face and letter stimuli differed in their sensitivity to rotation angle. Notably, the sensitivity to face recognition increased as the rotation angle increased, suggesting a greater perceptual challenge in recognizing rotated face images. This differential effect emphasizes the different cognitive mechanisms involved in face rotation versus letter rotation.

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