

Event-Related Potential Study on Image-Symmetry Discrimination in the Human Brain

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Abstract—The human visual system seems to have a highly perceptual sensitivity to symmetry. However, where and when the discrimination of symmetrical properties begins in the context of visual information processing is largely unclear. This study investigates event-related potential (ERP) patterns in humans when perceiving symmetry-varied complex object images. ERP responses were derived from electroencephalography (EEG) data recorded from eight healthy subjects using 128-channel scalp electrodes. Visual stimulation was provided using gray-scaled photographs of a car with six different viewpoints, hence disrupting the vertical symmetry, where one of the stimuli was intentionally made symmetric by mirroring the image about its center vertical axis. The results show that discrimination of image symmetry is revealed by potential deflection in early ERP components recorded at occipito-temporal sites and can be significantly observed around 220 ms after stimulus onset.

I. INTRODUCTION

As the world we perceive is rich in symmetries, perhaps it is not surprising that humans show a remarkable sensitivity to visual symmetry [1]. Although the perceptual phenomenology of symmetry processing is well understood, little is known about the underlying neural mechanisms.

Any visual object being viewed casts a two-dimensional (2-D) retinal image and furthermore induces a cortical representation in the visual cortex. As has been conceptualized in [2], an object is said to have “image symmetry” when the projection received in the retina is a mirrored transform of two or more image components from one or more axes of transformation. The image symmetry is not concerned with the interpretation of the image as an object in space and therefore could be destroyed easily by shifting the observer’s viewpoint. Another type of symmetry is “object symmetry,” in which the object is interpreted as a three-dimensional (3-D) object in space and hence is tolerant to viewpoint shifts. Object symmetry is considered to be a high-level mechanism as it may involve the comparison of 3-D templates in the memory.

In the present work, we focused on revealing the discrimination of image symmetry from the early stages of visual information processing in the human brain. Our experiment was designed to isolate the sensitivity of image symmetry using an electrophysiological approach, by showing the area on the scalp that was strongly relevant to image-symmetry discrimination and reporting its temporal dynamics.

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An electrophysiological study on symmetry processing by Hfel and Jacobsen [3] showed symmetry-correlated modulation of a later negative ERP component at posterior sites during a 500–1000 ms period after stimulus onset. However, another result obtained by Norcia et al. [4] using 2-fold symmetry versus random patterns as stimuli showed a substantially earlier symmetry-sensitive response (around 200 ms). Our study was intended to clarify the temporal dynamics of image-symmetry processing and to investigate whether or not the conclusions of previous studies could be generalized to more varied and complex object stimuli.

Because vertical symmetry has been observed widely in many studies (as in [5]) as the most attractive to humans compared to other types of symmetry, we manipulated only vertical symmetry in the stimuli in our experiment.

II. METHODS

A. Subject and Stimuli

Eight healthy, right-handed, male subjects, aged 22–40 years, participated in this experiment. Six 8-bit 640 × 480 gray-scaled photographs of a car taken from 6 different viewpoints, hence disrupting the vertical symmetry, were used as stimuli (Fig. 1). The symmetry of a stimulus from the frontal viewpoint (0°) was controlled by mirroring the image components about the center vertical axis.

The percentage of symmetry in the images was obtained using (1), which computes the 2-D correlation (R) between the left and right halves of the image (matrix A and B respectively), where m and n are the indexes of the matrix and \bar{A} and \bar{B} are the means of the matrix. The vertical centerline was set as the bilateral symmetry axis.

$$R = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\left(\sum_m \sum_n (A_{mn} - \bar{A})^2\right) \left(\sum_m \sum_n (B_{mn} - \bar{B})^2\right)}} \quad (1)$$

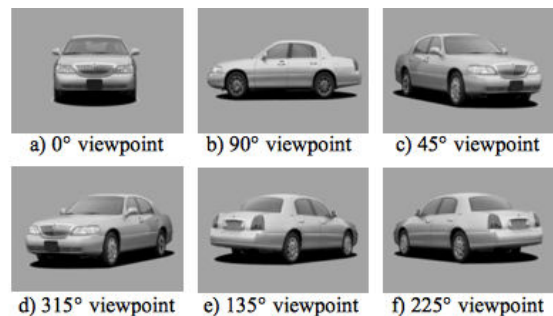


Figure 1. Stimuli.

B. EEG Recordings

EEG signals were recorded using a 128-channel Geodesic Sensor Net (Electrical Geodesic Inc., Eugene, Oregon [6]). EEG was sampled at 1000 Hz with the vertex electrode (Cz) as the reference lead during acquisition. An average reference was used in offline analysis.

During the EEG recording, each subject was asked to fixate at the center of a computer screen, placed at a 75-cm distance from the subject's eyes. The stimuli were shown one at a time with a duration of 300 ms, followed by a 1500-ms blank interval. The subject passively viewed each stimulus 300 times in random sequence with the same probability. Subjects were instructed to refrain from moving their eyes and bodies to minimize artifacts in the EEG recording.

C. Data Analyses

EEG data were averaged for each subject participant and then grand-averaged to obtain the overall across-subject ERP. The ERP data were computed using 1100 ms epoch and were baseline-corrected using the average amplitude in 100 ms prior to stimulus onset.

The mean potential analysis of the ERPs was focused to the early temporal evolution of ERPs, which is commonly associated with visual information processing [7], in the latency period at which three ERP components occurred:

- P1: The first positive peak in ERP elicited around 100 ms after stimulus onset,
- N1: The first negative peak in ERP elicited 150–200 ms after stimulus onset, and
- P2: The second positive peak in ERP elicited around 300 ms after stimulus onset.

To show the amplitude difference across stimuli in grand average ERPs, absolute difference ($D_{x,t}$) waves of each stimulus (x) were obtained by subtracting the amplitude value of a stimulus ERP ($A_{x,t}$) at each time (t) from the amplitude mean of six stimuli ERP values ($A_{all,t}$) at that particular time, as in (2).

$$D_{x,t} = \left| \frac{\sum A_{all} - A_{x,t}}{6} \right| \quad (2)$$

The latency of interest was defined as the time period at which the greatest difference occurred in the synoptic representation of the difference waves. Furthermore, topographic maps were constructed from the difference waves at the latency of interest to determine the best locations which potentially exhibit significant amplitude difference across-stimulus.

Statistical analysis of the ERP data was focused on the location and latency suggested by the difference waves. One-way analysis of variance (ANOVA) and post-hoc multiple comparison using Tukey Honestly Significant Difference (HSD) test were conducted to check the mean amplitude's significance. The level of significance was set to $\alpha = .05$. As the difference across subjects is not a concern in our experimental design, the normality in the data was corrected by subtracting the mean of across-stimulus amplitudes for each subject from each data point [8].

III. RESULTS

The percentage of symmetry in the stimulus that was obtained using (1) is shown in Fig. 2. This plot clearly shows some degree-of-symmetry variations in the stimulus images, with the 0°-viewpoint stimulus as the most symmetrical of all stimuli. The symmetry percentage of the 90°-viewpoint stimulus was less than that of the 0°-viewpoint stimulus but about 20–25% greater than the rest. A moderate percentage difference between the most symmetric and asymmetric stimuli was designed to identify whether the image-symmetry processing could be affected by the gradual changes.

The spatiotemporal dynamics of symmetry discrimination in the resulting ERPs is shown using synoptic plots (Fig. 3) of the absolute difference between the amplitude of each stimulus and the mean amplitude of all stimuli.

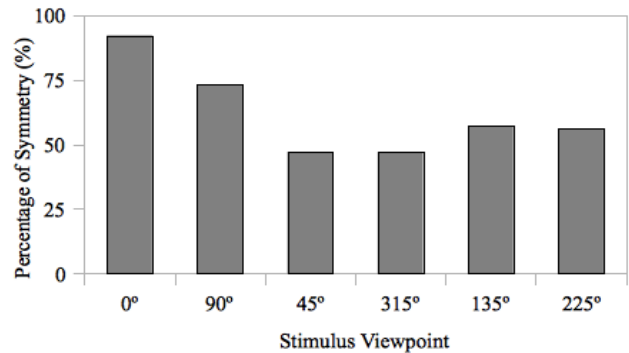


Figure 2. Percentage of symmetry.

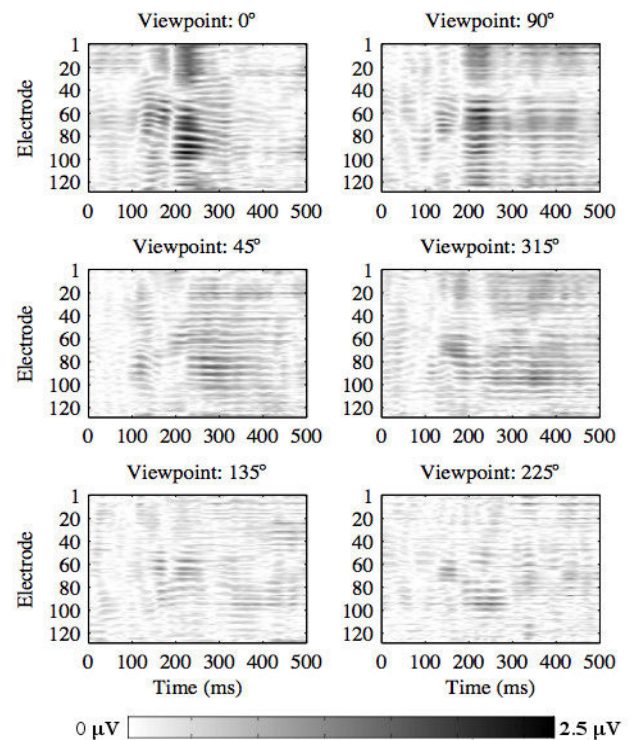


Figure 3. Synoptic plots. These plots represent the early temporal evolution of the absolute difference waves measured using 128-channels electrodes (y-axis).

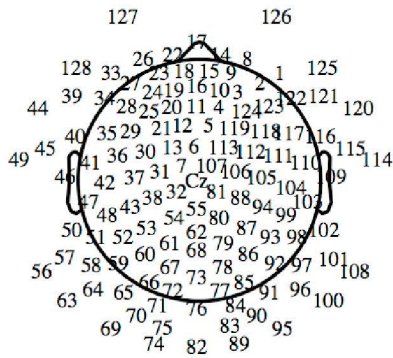


Figure 4. Schematic representation of 128-channel Geodesic Sensor Net which was used in the EEG recording.

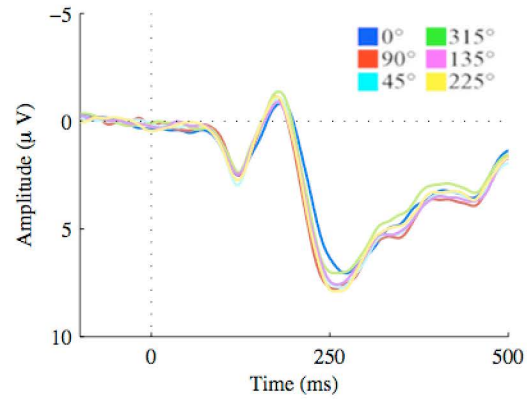


Figure 6. Mean ERP plot at the region of interest.

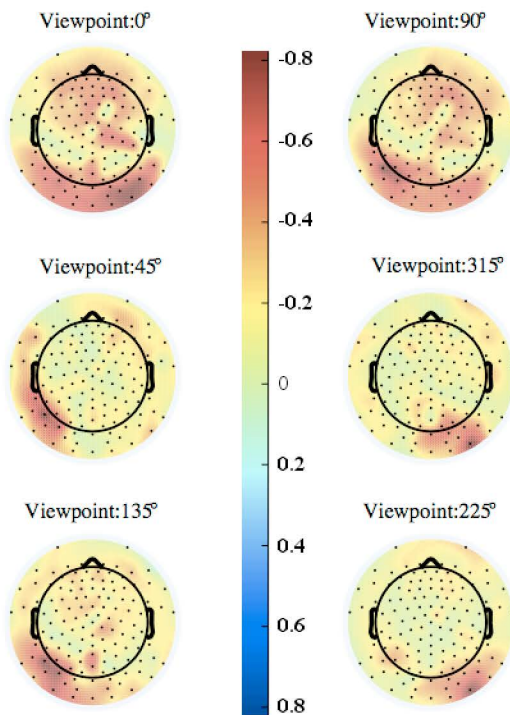


Figure 5. Topographic plots. These plots represent the spatial distribution of the absolute difference (in μV) between the amplitude of each stimulus and the mean amplitude of all stimuli, at 220 ms after stimulus onset.

Visual inspection of the synoptic plots reveals that the deflections of ERP amplitude as the response of highly symmetrical stimuli (0° and 90° viewpoints) were clearly shown in a time window between 210 ms and 230 ms after stimulation.

To identify the region of interest, the difference wave of each stimulus at 220 ms post-stimulus, which was chosen as the center time point of the latencies of interest, were plotted in the topographic maps shown in Fig. 5. The distribution of the ERP amplitudes of the highly symmetrical stimuli (0° and 90° viewpoints) appeared to be different compared to others,

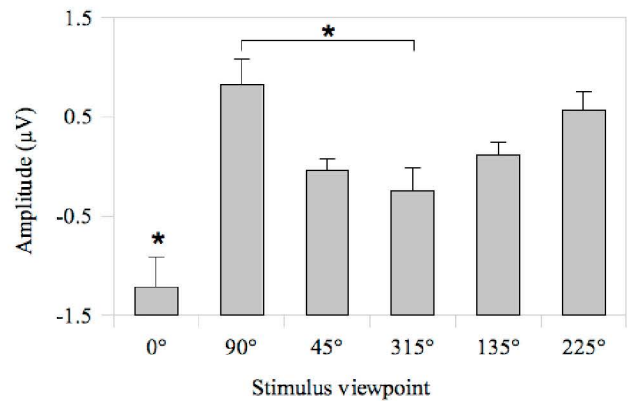


Figure 7. Mean of ERP amplitude of all subjects in 220 ± 10 ms latency window. Error bar is standard error of the means. The ERP amplitude of 0° viewpoint is significantly different from the others ($p < 0.05$).

especially at the electrodes around occipito-temporal region. In case of 0° -viewpoint, the greatest difference was revealed by some neighboring electrodes (89, 90 and 95) that approximately correspond to the O2 site according to International 10-20 system [9].

The grand average ERPs recorded from electrodes 89, 90 and 95 were averaged [8] and plotted in Fig. 6. The amplitudes of 0° viewpoint's ERP appeared to be more negative than the others at the period of 220 ± 10 ms post-stimulus onset, which was between the period of N1 and P2 components.

A one-way ANOVA was used to examine the means of the ERP amplitude from all subjects in 220 ± 10 ms latency window at the region of interest. The ANOVA test result showed that the amplitudes of the ERPs differed significantly across six stimuli, $F[5,42] = 10.95$, $p < 0.001$. A post-hoc multiple comparison using Tukey HSD was conducted to test each pair of stimulus' means. The results of post-hoc test, showed in Fig. 7, confirmed that the amplitude of the 0° -viewpoint stimulus was significantly different from all others at the region and latency of interest.

IV. DISCUSSION

As revealed by our results, deflections of ERP amplitude in response to perceiving a highly symmetrical stimulus (such as a 0°- or 90°-viewpoint stimulus) were clearly distinguishable, mainly at temporo-occipital locations, and the differences were statistically significant at some electrodes that correspond to O2 site [9]. Considering the affected locations, our finding is supportive of other studies that have suggested a significant role of the human extrastriate visual cortex in symmetry perception [5]. As the visual processing can be considered as a feed-forward activity that propagates from the posterior occipital cortex anteriorly along the ventral temporal lobe [10], the location at which our results showed the strongest differentiation suggests that image-symmetry discrimination occurs early during visual object processing.

In adults, visual symmetry has been shown to influence various perceptual processes, such as figure-ground segregation. As demonstrated in some electrophysiological studies, the figure-ground-specific signals appear in the visual cortex at various stages within a large time window spanning 50–300 ms [11]. The symmetry discrimination revealed in our results resided within this latency period.

Norcia et al. [4] investigated the effect of transition between random and symmetric dot-patterns and reported a deflection in the evoked potential that occurs at 220 ms. A similar result was also observed in our experiment, in which the most noticeable discrimination of the ERP of a symmetrical stimulus from that of others seemed to occur along the P3 period (peaking at around 220 ms). However, because we employed a more complex type of visual stimulus than the simple dot-pattern stimulus used in [4] and yet achieved a similar result, we tentatively suggest that symmetry discrimination is sufficiently robust across the complexity of stimulation. Furthermore, in addition to [4], which only compared symmetric versus random stimuli, our stimuli involved some degree of symmetry variation. Interestingly, a discrimination that was similar to, yet smaller than, that shown by the symmetrical stimulus (0° viewpoint) was shown in difference waves of 90°-viewpoint stimulus' ERP and appeared to conform to the level of stimulus symmetry shown in Fig. 2. Although the ERP amplitudes of 90°-viewpoint stimulus did not reach the statistical level of significance at the region of interest, but the distribution of the difference waves around temporo-occipital locations suggests that sensitivity to image symmetry is not brittle and could involve a gradual degree of response.

In summary, in the present work we report evidence for image-symmetry discrimination that was strongly observed at temporo-occipital locations around 220-ms latency after stimulus onset. This study paves the way for a deeper understanding of the relationship between symmetry perception and its underlying neural basis. Future work will cover the following: (a) observation of other types of symmetry such as horizontal and radial symmetry, and (b) redesigning the experimental setup to investigate the spatiotemporal dynamics of the transition from image symmetry to object symmetry.

V. REFERENCES

- [1] J. Wagemans, "Characteristics and models of human symmetry detection," *Trends in Cognitive Sciences*, vol. 1, no. 9 (1997), pp. 346–352.
- [2] C.-C. Chen, K.-L. C. Kao, and C. W. Tyler, "Face configuration processing in the human brain: the role of symmetry," *Cerebral cortex*, vol. 17 (2007), pp. 1423–1432.
- [3] L. Hfel and T. Jacobsen, "Electrophysiological indices of processing aesthetics, spontaneous or intentional processes?" *International Journal of Psychophysiology*, vol. 65 (2007), pp. 20–31.
- [4] A. M. Norcia, T. R. Candy, M. W. Pettet, V. Y. Vildavski, and C. W. Tyler, "Temporal dynamics of the human response to symmetry," *Journal of Vision*, vol. 2, no. 2 (2002), pp. 132–139.
- [5] Z. Cattaneo, G. Mattavelli, C. Papagno, A. Herbert, and J. Silvanto, "The role of the human extrastriate visual cortex in mirror symmetry discrimination: a TMS-adaptation study," *Brain and Cognition*, vol. 77, no. 1 (2011), pp. 120–127.
- [6] D. M. Tucker, "Spatial sampling of head electrical fields: the geodesic sensor net," *Electroencephalography and Clinical Neurophysiology*, vol. 87, no. 3 (1993), pp. 154–163.
- [7] J. Wagemans, "Detection of visual symmetries," *Spatial Vision*, vol. 9, (1995), pp. 9–32.
- [8] T. W. Picton, S. Bentin, P. Berg, E. Donchin, S. a Hillyard, R. Johnson, G. a Miller, W. Ritter, D. S. Ruchkin, M. D. Rugg, and M. J. Taylor, "Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria," *Psychophysiology*, vol. 37, no. 2, (2000), pp. 127–152.
- [9] H. A. Jasper, "The ten-twenty system of the international federation," *Electroencephalography and Clinical Neurophysiology*, vol. 10, (1958), pp. 371–375.
- [10] A. Clarke, K. I. Taylor, and L. K. Tyler, "The evolution of meaning: spatio-temporal dynamics of visual object recognition," *Journal of Cognitive Neuroscience*, vol. 23, no. 8 (2001), pp. 1887–1899.
- [11] P. Neri and D. M. Levi, "Temporal dynamics of figure-ground segregation in human vision," *Journal of Neurophysiology*, vol. 97, no. 1 (2007), pp. 951–957.