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The Possible Connection of Gamma Oscillation and 3-D Object Representation

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Abstract

We process and encode for different features of a particular object (shape, color, texture, etc.) in distinct areas of the brain. How we bind these attributes together into a unified perception of an object is unknown. Past research suggests that synchronized activity between brain areas, particularly induced gamma activity (~ 40 Hz), may account for this binding process and the basis of our conscious perceptual experience, specifically through object represenptation. In this study, participants were asked to look at a series of 2-D pictures of cars from distinctive rotations (0^0, 90^0, 180^0) and were asked to distinguish whether two pictures are of the same or different cars; meanwhile, electroencephalography (EEG) was used to measure electrical activity on participants' scalps. Our preliminary analysis showed a difference in gamma oscillation after the stimulus onset when comparing 180^0 rotations to no rotation in one participant. This suggests the possible relationship between induced gamma oscillation and 3-D object representation.

Keywords: induced gamma, object representation, binding problem, object recognition.

The Possible Connection of Gamma Oscillation and 3-D Object Representation

Experiencing objects, though seemed intuitive, contains one fundamental question in psychology and philosophy called “binding problem." The “binding problem” refers to the basic question of how conscious experiences come about. Specifically, studies of the human neurological system showed that distinct parts of the brain processes and codes for different features of an object, including those of visual, auditory, semantic and even emotional contents (Courtney & Ungerleider, 1997; Posner & Raichle, 1994). The problem arises when we actually experience objects as a whole and not discrete features. For example, disparate aspects of an apple (e.g., red skin, round shape, smooth texture, etc.) are processed by anatomically different areas of the brain, yet one experiences the apple as a whole and not separate apple characteristics. How we “bind” these distinct cues into a unified perception remains unknown and under much investigation.

A potential answer to the so-called “binding problem” is that this binding occurs through synchronization of neural activity across different areas of the brain (Malsburg & Schneider, 1986; Milner, 1974; Singer & Gray, 1995). For example, the areas of the brain processing the color, shape, and texture of an object would all activate concurrently to provide a unified percept of that object. Synchronized activity of a large number of neurons in this manner would cause macroscopic neural oscillations, which could be measured with the electroencephalogram (EEG), a method of recording electrical activities along the scalp.

EEG research suggests that there are two types of gamma responses, differing in their relation to the timing of a stimulus. The first type is the evoked response, characterized by precise phase-locking to the onset of a stimulus; the second is called an *induced* gamma response refer to that are not phase-locked to the onset of stimulus. Induced gamma responses appear at variable times after the stimulus has been shown, and it is this induced gamma activity, which appears to be related to conscious perception of the stimulus.

A growing body of EEG evidence suggests that induced gamma activity has important roles in high-level cognitive processes (Pulvermüller, Birbaumer, Lutzenberger, & Mohr, 1997), and perhaps conscious representation. For example, increase in induced gamma activity in response to coherent stimuli as opposed to incoherent stimuli in a discrimination task was observed. In one study, subjects were asked to look for an illusory triangle between three other stimuli: triangle (see figure to the right), a real triangle and "no-triangle". The results revealed induced gamma activity 280 ms after presentations of triangles, but not after the no-triangle stimulus. Importantly, the induced gamma was seen for even the *illusory* triangle suggesting that induced gamma activity was related to the *perception* of a triangle, and not simply the actual presence of a triangle in a stimuli (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1996). These results provide support for the hypothesis that when a coherent perception of a stimulus is formed; induced gamma activity is enhanced suggesting a connection between gamma activity and conscious unity.

The connection of induced gamma activity and binding of information was suggested but the mechanism behind this activity and that of binding remains a mystery. However, evidence from a recent study provides evidence that induced gamma activity is related to the internal, conscious representation of an object. In this study (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1997), subjects were asked to detect a hidden object in a blurry and seemingly arbitrary picture. Due to the disparate nature of the image, features cannot be bound together until an internal mental representation of the object is formed. Subjects who were naïve or did not get training in hidden object detection showed less induced gamma activity when viewing this image than those who were trained to see the object, suggesting that internal conscious representation correlates with induced gamma activity.

The design of Tallon-Baudry et al.'s (1997) research has some major advantages in suggesting an answer to the question of interest, but it has some flaws that could be addressed. This paradigm addresses the subjectivity of object experience by requiring participants to perform a mental task that demands the existence of an internal mental representation. However, in the study, the differences in observed induced gamma intensity could be the result of the training itself rather than a conscious mental representation of an object. The use of only 2-D images has its own issue, in that each image contains limited features that could be remembered and utilized individually for the detection task. Thus, the mental task using 2-D images does not necessarily require participants to produce a full 3-D mental representation of the object when each feature could be stored and matched individually with the stimuli. For example, there are two separate main features of a red triangle: color and shape. To detect a red triangle within a blurry picture, we might not need to form a conscious perception of a red triangle, but we could look for a triangle that is red.

This present study investigates further the role of induced gamma activity with respect to the formation of a 3-D internal mental representation of an object. To accomplish this task, we are asking participants to different 2-D images at different rotations and requiring them to distinguish if consecutive 2-D images belong to the same or different object. In order to perform such task, they have to form a 3-D internal representation of an object; meanwhile, we would be monitoring their brain activity using EEG. EEG is used in this research due to its high temporal resolution that would be extremely useful to understanding an unconscious process of object recognition that normally occurs instantaneously the moment we see objects. We hypothesize that if induced gamma oscillations reflect the brain capacity to form 3-D object representation, gamma oscillations would be prevalent before participants made the response. In addition, we are exploring the differences in induced gamma oscillations depending on different contexts such as degrees of rotations, same or different objects, reaction time, etc.

Methods

Participants

20 undergraduate students were recruited from University of Puget Sound (n = 20, Male = 9, Female = 11) during summer of 2012 through email advertising and other forms of advertisement. People in the study received $15 as honorarium and were informed of the study's purpose, description, risks and benefits prior through email, written and verbal consent forms.

Stimuli

Stimuli consisted of different types of car images in distinct rotations of 0^0, 90^0, 180^0. All stimuli pairs were randomized from 80 sets of pictures of cars in different rotations. A white fixation-cross on a black screen was always present centrally on a computer monitor. Texts showed up occasionally to inform participants that they could take a break during these periods. After each break, a message and a tone of medium volume appeared indicating that participants should prepare for a subsequent trial. The pictures of cars were obtained from (Andresen, Vinberg, & Grill-Spector, 2009) and selected for their familiarity in shape and type. The presentation of stimuli was managed by Matlab code.

EEG

Brain's activity on the scalp was measured and recorded while participants performed a series of object rotation and discrimination tasks using an electroencephalograph (EEG). Specifically, a cap with 32 electrodes (Biosemi, Active Two system) were placed on the scalp and attached with conductive non-invasive Signa Gel to ensure robust measurement of weak electrical fields generated by neural cortical activity. Two electrodes were also placed behind the ears (i.e, the mastoids), one on the side of the left eye and one underneath the same eye for reference recording and accounts of electrical artifacts due to blinking. These facial electrodes were attached to small adhesive disks to allow adhesion without discomfort. Net impedance for each electrode was below 10 kΩ for all participants. All channels were recorded continuously throughout the session with approximately 60 minutes of data at a sampling rate of 500 Hz. All data, including temporal information of stimulus onset and electrical information from the scalp were collected by ActiView, a Biosemi acquisition software.

Task

Participants were seated approximately 35 cm away from the monitor screen during electrode application and task performance. Whenever participants were ready, the MATLAB code was started initiating the appearance of fixation cross. During a trial, an image of a car appeared, 500 ms of a blank black screen with the fixation cross, another image of the same or different car after, and finally, a blank screen for two seconds during which participants were asked to decide if the two pictures belong to the same object regardless of rotations. Participants were asked to use the left key to indicate if they thought the two images belong to two distinct objects and the right key to indicate if the two images are of the same object. After the response, participants were allowed to blink before the next trial began, and the process repeated. During each trial, from when the first stimulus appeared to the participants' responses, participants were asked to refrain from blinking but were free to do so if they must. In addition to the short amount of time after each response to blink, participants were given explicitly 30-second breaks every ten trials. It took participants approximately 60 minutes to complete 480 trials. (see Figure 1)

Preliminary Analysis

Data were processed and analyzed by EMSE Suite 5.4 by Source Signal. Data were processed with standard artifact rejection procedure. Specifically, EMSE was used to sample approximately five segments of EEG data that reflect artifacts and blinking. Then EMSE stripped the data of these similar instances of crossing the artifact threshold. A time-frequency-power spectrum for each participant at each electrode was developed to analyze the induced gamma oscillation of interest (prototypically ~40 Hz). This was achieved by a complex Morlet's and Garbor's wavelet transform (Sinkkonen, Tiitinen, & Näätänen, 1995). This analysis provided clearly identified power of gamma oscillations of interest compared to standard averaging techniques of analyses. Preliminary inspection of the spectrum of one participant at Pz was performed. In addition, topography maps of regions of interest on the spectra were constructed to estimate the source of activity on the scalp.

Results

Inspection of the time-frequency-power spectrum of one participant's Pz revealed that the participant had more gamma oscillation activity around 150ms and 200ms or after the second stimulus and before the response in the no rotation case compared to 180^0 rotation of stimulus. In addition, the peak gamma activities when compared the no rotation and 180^0 rotation showed a similar pattern of latency until the onset of the second stimulus. Specifically, high gamma activities of both cases of no rotation and 180^0 rotation appeared almost at the same occasions until the second stimulus's onset where gamma peaks appeared at approximately 10 ms apart. Topography maps of these regions of the spectra were similar in patterns of activation and depression of activity in different regions of the brain. (see Figure 2)

Discussion

Preliminary results showed a promising trend that could satisfy our hypothesis that induced gamma oscillations could be associated with a mental representation of a 3-D object. No comparative analysis was performed, and only spectra inspection was done; thus, no definite conclusion could be drawn. However, there is a noticeable difference in the amount of gamma oscillations after the second stimulus and before the response for 180^0 rotation compared to the no rotation. This difference might indicate that gamma oscillation is especially relevant in 180^0 rotation when participants were required to form a 3-D representation of the first image, manipulate the product to the right rotation, and discriminate if the two images are of the same object or not. In contrast, in no rotation, participants were only required to perform a discrimination task between two 2-D images of the same rotation; thus, no 3-D representation was needed.

In addition, the difference in latency of gamma peak at the onset of the second stimulus poses an interesting question to our hypothesis that induced gamma after the stimulus onset is associated with binding of information. The latency difference of gamma peak at the onset of second stimulus for no rotation and 180^0 rotation might indicate differences in underlying mechanisms that lead to later induced gamma oscillation for binding. This gamma oscillation might have a fundamental role in distinguishing whether or not the formation of 3-D representation of an object was needed; for 180^0 rotation 3-D representation was needed while in no rotation, no 3-D representation was needed to form. However, when topography maps were formed at these instances of gamma peak around the onset of second stimulus, the maps indicated that the two processes might be very similar in pattern of brain activity. Thus, the decision to form 3-D oscillation depending on cues might be of the same mechanism yet the latency might be indicative of whether or not the 3-D representation of an object was needed.

The study has some inherent limitations that need clarification for careful interpretation of the results. Firstly, EEG data provides mainly temporal information and electrical oscillation on the scalp from which information about induced gamma oscillation could be extracted from Morlet wavelet analysis; thus spatial information of where brain activity happens in the brain is unknown and at best, estimated. Topography maps were estimated as an attempt to chart pattern of activation, but they are not necessarily accurate or reflect the source of brain activity. Secondly, the preliminary conclusions were drawn through visual inspection of initial analyses of the data from only one participant at one location on the scalp, and thus should not be taken as accurate interpretation for the effect might not be statistically significant or the effect was entirely individualistic. Lastly, even though the results might support the representation hypothesis, meaning induced gamma might indicate the object representation for the discrimination task in 180^0 rotation case, it does not necessarily mean the brain use object representation to be discriminate if two images are of the same or different objects. A completely different strategy could be used but unidentifiable to our consciousness due to the intrinsic unconscious nature of object recognition. And thus, EEG provides a set of information that is useful to support or disprove our hypothesis of the mechanism, but it does not necessarily mean that the underlying process could be elucidated.

Due to the time-consuming nature of data collection and the complexity of analysis, we have not been able to complete a comprehensive series of analyses of the collected data. Specifically, we are planning to perform the same analyses to all participants at different location on the scalp depending on different rotations, objects' identities as same or different, and the interaction between rotation and objects' identities. Moreover, after individual analyses for each participant are done, we would like to compile the results to compare groups using standard analyses for more definite answers to our question. In addition, the behavioral information such as response speed and accuracy could be incorporated into the EEG data to elucidate the role of gamma oscillation in fast and accurate 3-D representation.

Conclusions

Overall, the preliminary results indicate promising trends to our hypothesis that induced gamma oscillations are associated with 3-D object representation. However, in order to confirm and understand this phenomenon, more comprehensive approach to analyses should be done in the near future.

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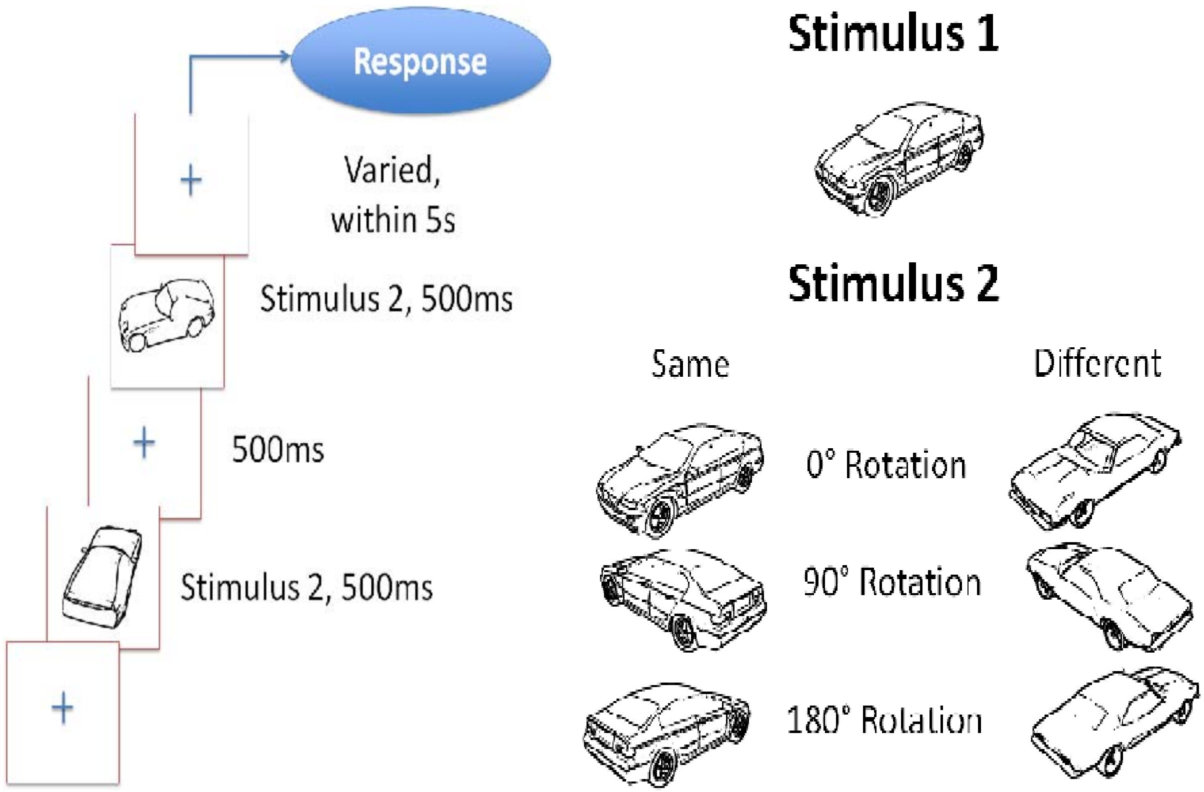

Figure 1. Object discrimination task procedure. Participants performed a series of randomized trials of object discrimination tasks. Each trial consists of two stimuli showing subsequently to each other of the same or different objects from different rotations of 0^0, 90^0, 180^0. After seeing the two stimuli, participants were asked to distinguish whether the two images belong to the same or different objects. Figure 1 also includes samples of stimuli.

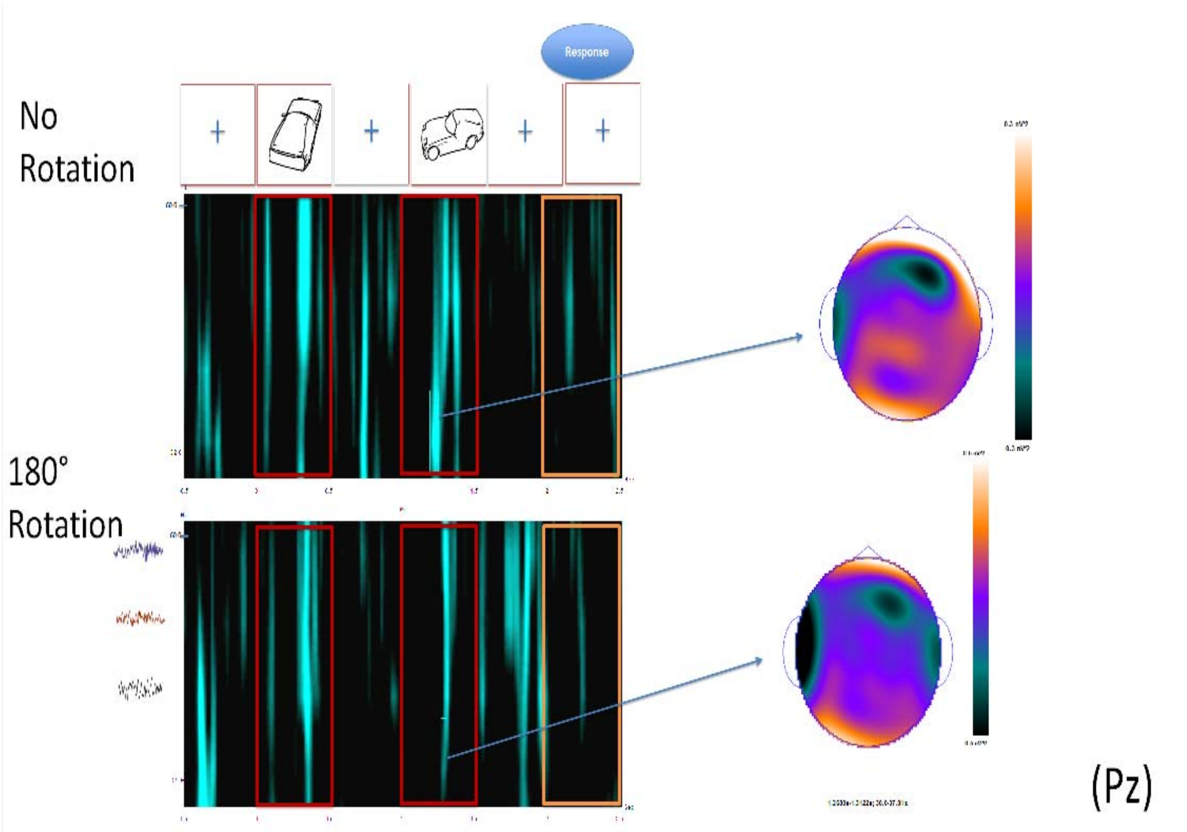

Figure 2. Time-frequency-power spectra results of No Rotation and 180^0 Rotation. Prior to the analysis, artifact rejection method was applied to remove unreliable information from blinking by EMSE Suite. Morlet wavelet and Gabor's method of analysis (Sinkkonen et al., 1995) was applied to the remaining data to form time-frequency-power spectra. The vertical axis signifies the variability of oscillations frequencies from 30 to 60 Hz while horizontal axis represents the time course. The power of oscillations is implied in the intensity of the blue lines on the spectra. Topography maps for the gamma oscillation peak around 120 ms and 131 ms were formed to estimate the pattern of brain activity. More gamma activity in the segment of 150ms to 200ms was found in 180^0 rotation than in no rotation.