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Empathy and the Mirror Neuron System: An Electroencephalographic Study

Specific Aims:

Empathy, the ability to feel and understand another's pain, pleasure, and feelings is vital to surviving the social circus of everyday life. The idea of putting yourself in someone else's shoes is at the core of human relationships. Empathy is why charity is possible, why people go out of their way to selflessly help others in need, or why people can connect with each other on an emotional level. The aim of this study is to investigate the role of the human Mirror Neuron System (hMNS) in empathy. The mirror neuron system is a group of brain areas that consist of unique neurons. These neurons were found to have "mirroring qualities", in that the neurons exhibited analogous activity when performing an action, or observing the same or similar action being performed. The human MNS has also been implicated in social functions, including empathy. This study will allow us to observe whether hMNS activity, as measured by changes in EEG rhythmic oscillations in the 8-13 Hz band over sensorimotor cortex, during an empathy task is correlated with empathic function. We will take normal-functioning UCSD students from each end of the empathizing-systemizing quotient (EQ-SQ) scale and observe their MNS activity during an emotional face-empathy task. Given that this difference in individual trait empathy may be reflected in differences 8-13 Hz rhythm, the two groups ought to show significant differences in the functional neuroanatomy of empathy. The specific aims of this study are to test the following hypotheses:

- The empathizing group will show differential activation compared to the systemizing group
- That the empathizers will exhibit increased MNS activation during the empathy tasks, reflected in the EEG data.

Background and Significance:

Empathy, the vicarious feeling of emotions in response to the perception of another person's emotional state, is based on the process of perceiving a person's psychological state occurring within a certain social constructs and contexts [13]. The empathetic process involves certain cognitive and social abilities and processes: the ability to maintain a self-other distinction, the ability to attribute an emotional state to a person (usually through their facial expressions), and the feeling of having something in common with the other person.

It has been theorized that the experience of sharing emotional feelings is modulated and controlled by a mirroring system in the brain [3]. Originally discovered in macaque monkeys, mirror neurons were found to respond to both the observation and execution of the same or similar action. These were found in frontal area F5 and parietal area PF of the macaques [12 for a review]. This study, and others confirming these findings have led to an emergence of a possible homologous mirror neuron system in humans. It has been proposed that this system is centered in the inferior frontal cortex and posterior parietal cortex [6,5].

Many researchers have used electroencephalography (EEG) to investigate the hMNS by non-invasively recording electrical brain activity that results from neuronal activity. Recording of this electrical activity uses electrodes placed on the scalp above specific parts of the brain. The EEG component assumed to reflect MNS activity is an 8-13 Hz oscillation recorded over sensorimotor corticies, which has been called the mu rhythm. The desynchronization of EEG frequencies below 30 Hz is considered to reflect activated cortical networks, while synchronous activity reflects the idling of these cortical networks [9]. Mu rhythm desynchronization and the resulting mu rhythm has been shown to occur when a person moves, observes specific movements, and imagines the same or similar movements [10]. This evidence suggests a functional connection between mu rhythm suppression and the MNS. Recently, Keuken et al (submitted) showed that inhibiting activity in frontal mirror neuron areas prevented expected suppression of mu rhythms to the observation of movement. Still, a more direct connection between the two is yet to be conclusively drawn due to the inability to identify, isolate, and test a single mirror neuron (except with the rare neurological disorder case, see Mukamel et al, 2010).

Recent research has investigated the connection between mu rhythm reactivity and MNS activation during hand actions. These groups found a strong correlation between the two, much like macaque mirror neuron firing [7,8]. There is also significant evidence showing mu suppression in premotor neurons in the primary motor areas in the absence of motor activity [4,8,9].

Studies have shown that the hMNS responds not only to motor actions, but during emotional processing and imitating as well. Pineda et al. puts forth that empathy is made possible by “mirroring mechanisms” that give humans the ability to infer and simulate the feelings, beliefs, and intentions of others [13]. Carr et al observed activation in the inferior frontal and posterior parietal cortex during the observation and imitation of facial expressions [1]. Schulte-Ruther et al specifically investigated the role of the MNS in empathy in normal subjects using static, emotional face stimuli and a paradigm very similar to the one in this study. They found activation in the MNS during all the tasks, concluding that the MNS plays a vital role in empathy [13]

So, given this evidence of the possible role of the MNS in empathy function, this study’s aim is to further investigate this theory using EEG and mu rhythm suppression during a static-face empathy task. By isolating two groups that are distinctly different in empathic function and running each through the same empathy task, we hope corresponding differential MNS activation will arise and help to illuminate MNS’s role in human empathic function and social behavior.

Research Design and Methods:

Participants:

All subjects were male and female UCSD undergraduate students ages 18-23. It has been found that there is notable differential fMRI activation and ability between men and women in emotion attribution and specifically empathy tasks (very similar to the one being used in this study) [13]. Although this study used both males and females we did not address the issue of gender differences. Instead, subjects’ were grouped by their individual empathic abilities, therefore avoiding this possible confounding factor. All subjects had normal or corrected-to-normal vision.

Prescreening Session Procedure:

The empathizing-systemizing (EQ-SQ) test was administered to assess each participant's trait empathy. The test, created by Simon Baron-Cohen, Sally Wheelwright, and their team at the University of Cambridge [2] tests each students empathetic and systemization abilities using two questionnaire tests that produces a score for each trait. Then, given these two scores, they are categorized as extreme empathizing, empathizing, balanced, systemizing, and extreme systemizing. We used a modified categorization method in which the two subject groups are chosen using a normative T-score and then a median split creates 4 distinct subject groups (empathizing, systemizing, and two balanced groups). The empathizing and systemizing groups are then used as the subject groups. The empathizing group consisted of subjects whose EQ score was in the top 50% of the population and SQ score was in the lower 50%. The systemizing group consisted of subjects whose SQ score was in the top 50% of the population and EQ score was in the lower 50%.

Pre-Task Procedure (beginning of EEG Session):

To allow us to help control for the possible confounding influence of the subjects' transient emotional state and state empathy fluctuations we administered the Interpersonal Reactivity (IRI) test. This assesses dispositional empathy by using four seven-item subscales of empathic function. [2,3] The IRI was administered immediately before every EEG session. This will help to factor out any effect transient factors might have on the EEG data and results.

Stimuli:

The MacBrain Face Stimulus set[1] was used for the empathy task. The stimuli consist of just the eye portion of faces that have been shown to reliably portray specific emotions. The approximate emotions presented were fearful, angry, sad, happy, and neutral. To control for variability of performance and activation due to stimulus ambiguity and gender-differences, there were multiple faces used for each emotion, including both genders.

Experimental Tasks:

The paradigm is a modification of one used by Schulte-Ruther et al (2007) for an fMRI study. The stimuli were presented on a computer screen using Presentation. There awere 3 blocks of trials, each consisting of 20 trials. In the first block, a single stimulus was presented and the subject was asked to focus on their own emotional feelings when viewing the stimuli (Self-condition). During the second block, the subject was asked to focus on the emotional state being expressed by the stimulus being presented (Other-condition). The third block was a gender /age discrimination task (Baseline condition), where the subjects were asked to identify whether the stimulus is male or female.

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[1] Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Contact Nim Tottenham at tott0006@tc.umn.edu for more information concerning the stimulus set.

Presentation of the individual stimuli was randomized within blocks, with each specific stimuli being shown the same number of times for each subject. Each stimulus will be presented for 5 seconds. During the first two blocks, the stimuli were accompanied by four adjectives (one at each corner of the image) describing four different emotions. In the Self condition, subjects were asked to ignore these words and focus on their internal emotions. In the Other condition, the subjects were asked to pick from these adjectives the one that best described the emotion. For the gender-discrimination, baseline condition, the words “male” and “female” appeared underneath the stimulus.

Subjects were asked to only focus on their answer. After the stimulus was shown a black screen with the word “respond” appeared in the middle and subject were asked to respond by pressing the space button on a keyboard to indicate they had focused on their answer and were ready to proceed to the next trial. When the subject hit the space key, the next trial appeared.

<u>EEG and Data Analysis (overview):</u>

We used electroencephalography (EEG) to measure the subject brain activity during the empathy task. An EEG cap was placed on the subject prior to the task. The areas of interest, as mentioned before, are the proposed MNS areas of the human brain, the inferior frontal cortex and posterior parietal cortex. The raw data was treated and cleaned up to allow for reliable analysis. This was done using a Neuroscan Synamp System.

<u>Methods of Analysis:</u>

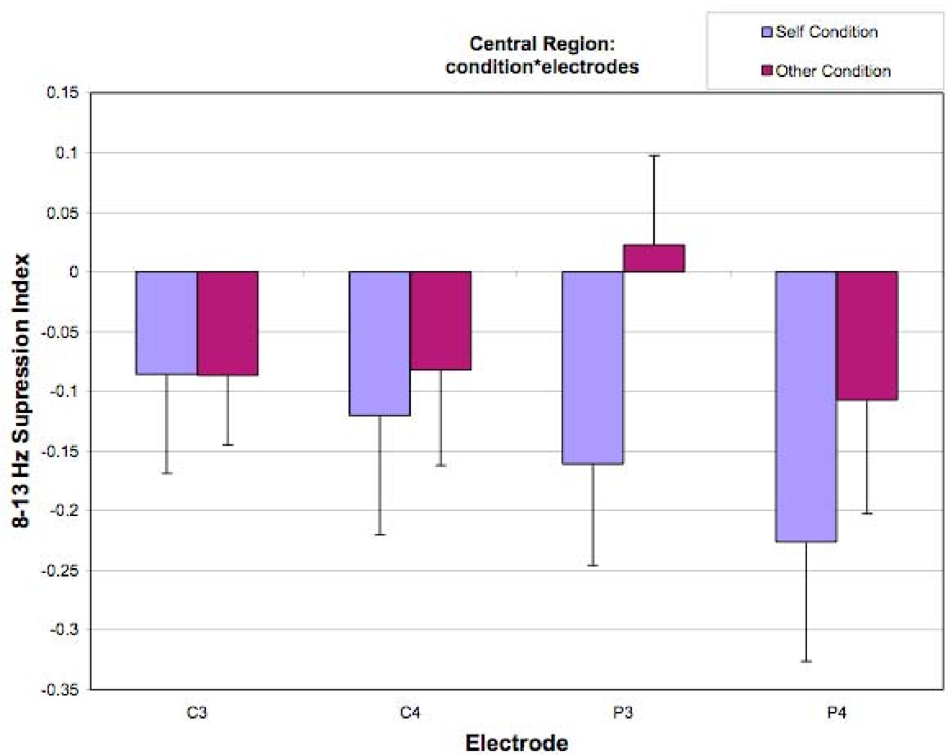
Each subject’s EEG data was first analyzed independently. First, each 5-second trial for every task is taken and put through artifact rejection. Eye blink artifacts were taken out using the 100mV threshold. Next, manual rejection was used to take out any other artifacts NeuroScan did not automatically reject. The remaining reliable data was then taken and separated into 5-second epochs to allow for averaging. Average EEG activation for each electrode per task was calculated, yielding task-specific averages (of the 20 trials per task) for each electrode for each subject. Given this data, the power of each electrode average was found using Fast Fourier Transform (FFT) in the frequency domain (8-13 Hz). Then, using the FFT data for each electrode, the 8-13 Hz Suppression Index for each electrode was calculated. For each subject, their power in the 8-13 Hz frequency in each electrode in the self (block 1) and other (block 2) was divided by the 8-13 Hz activity in the 3^{rd}, baseline block. Dividing the Self condition trials and Other condition trials by the baseline in the 8-13 Hz frequency calculated the significant suppression during trails in each condition, controlling for individual variances in the EEG data and isolating the EEG activations that resulted solely from our tasks and not from variations in the individual.

Given subjects’ Suppression Index for each electrode for the self and other tasks, the data was run through the SPSS 14.0 program for statistical analysis and comparison. To simplify our analysis we grouped the electrodes into 5 major regions: the frontal (FP1, FP2, F3, F4, F7, F8), central (C3, C4, P3, P4), lateral (T3, T4, T5, T6), occipital (O1, O2), and the midline (FZ, CZ, PZ). For each region, the EEG activation was compared between populations (empathizing vs. systemizing), between tasks (self vs. other), between electrodes, and for every combination of these factors. We used a .05 level of significance to determine significant main effects for each of these comparisons.

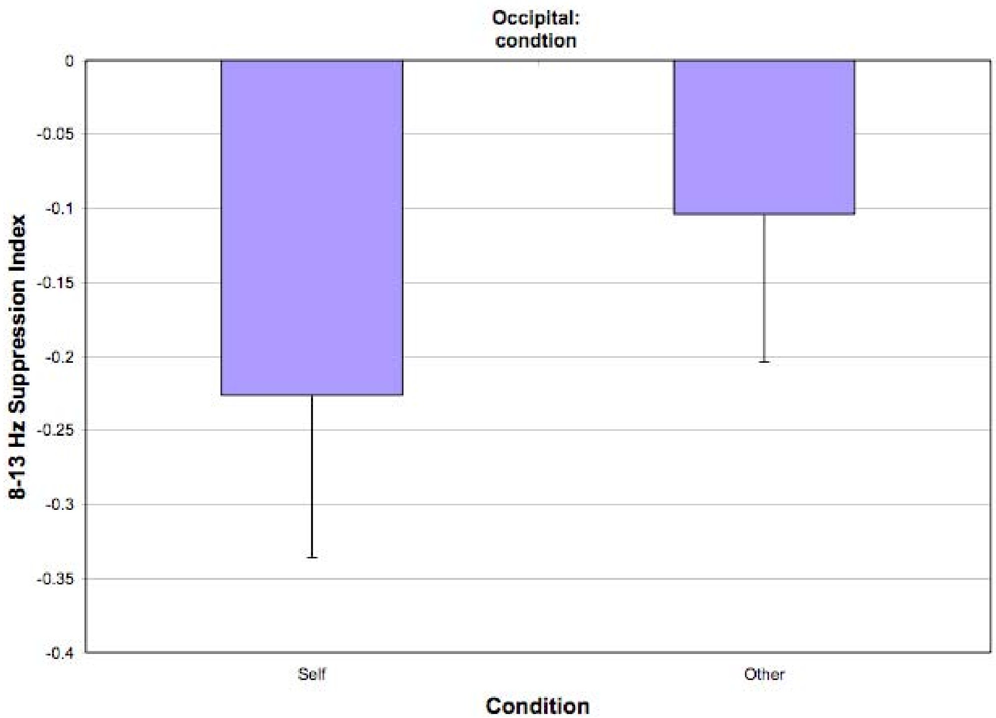
Results:

After statistical analysis, three regions (central, occipital, and midline) exhibited significant main effects in at least one comparison:

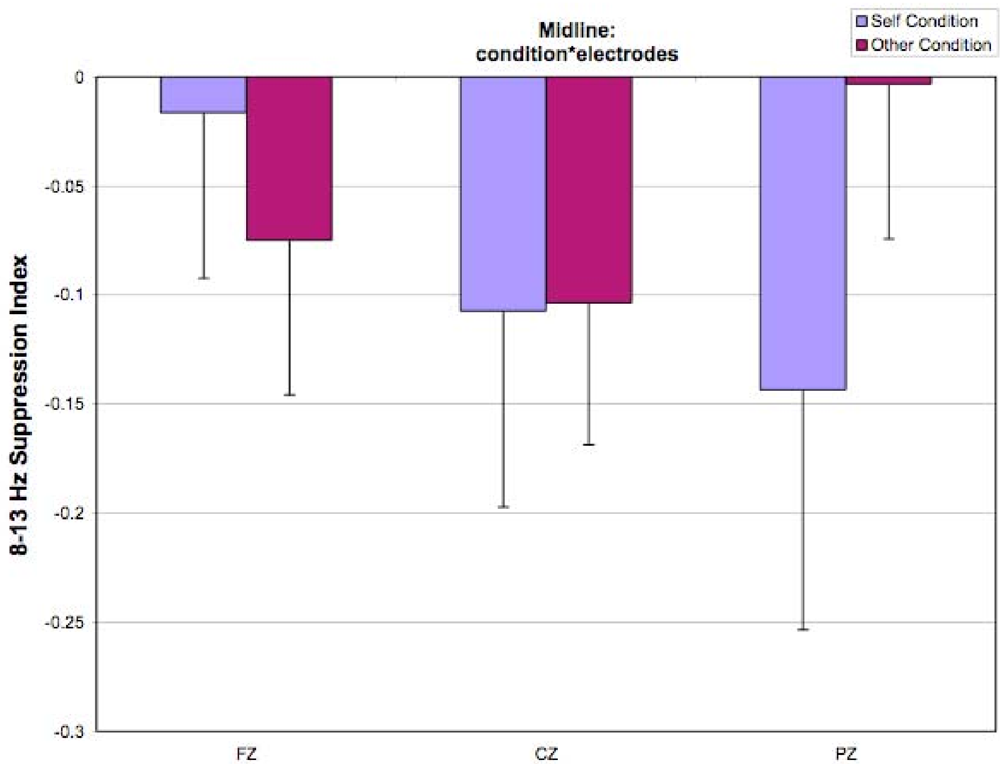
For the central region, we found one statistically significant main effect in the condition by electrodes comparison. This comparison yielded a Greenhouse-Geisser significance statistic of .01, well below our significance level of .05. The effect exhibited in this region was occipitally- centered increase in 8-13 Hz suppression index in the Self condition (increased suppression in Self condition as we moved towards the back of the head) as well as a trend of more suppression for the Self condition compared to the Other condition that is also occipitally- centered.



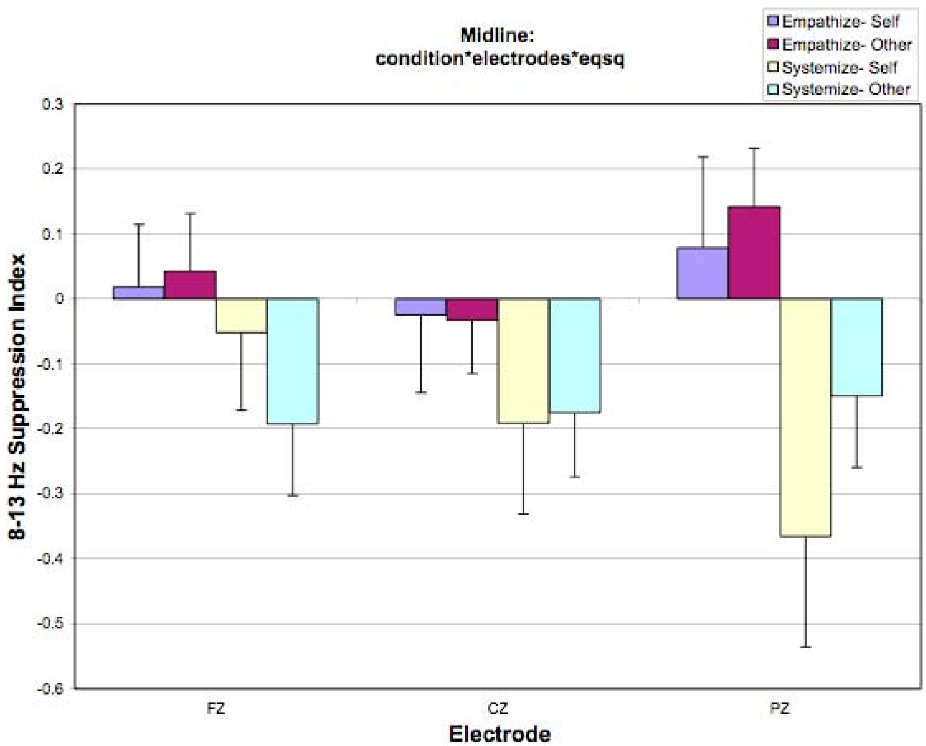
For the occipital region, we found one statistically significant main effect between conditions. The comparison between conditions yielded a Greenhouse-Geisser significance statistic of .03, below our significance level of .05. The effect exhibited in this region was a larger 8-13 Hz suppression index for the Self condition compared to the Other condition, in agreement with the trend seen in the central region.



Lastly, the midline region exhibited two statistically significant main effects. The first effect was found in the condition by electrodes comparison that yielded a Greenhouse-Geisser significance statistic of .004, again well below our significance level of .05. The effect exhibited is an occipitally- centered increase in the suppression index in the Self condition (results not applicable to Other condition due to abnormal suppression index in PZ electrode for other task).



The second effect in the midline region was found in the condition by electrode by populations comparison that yielded a Greenhouse-Geisser significance statistic of .019, well below our significance level 0f .05. There were two trends in this set of data. The first was an overall larger suppression index for the sytemizer population than empathizer population for both the self and other tasks. The second was an occipitally-centered increase in overall suppression in the systemizer population.



Discussion:

Human MNS activity is considered to be exhibited by suppression of the 8-13 Hz EEG rhythm [9]. In this study, we set out to study hMNS activity during an empathy task for two opposing populations, empathizers and systemizers. The original hypothesis was that we would find more of this 8-13 Hz suppression in the empathizing population than in the systemizing population and that this suppression would be centrally- centered. This would support the theory that empathy function recruits the mirror neuron system.

The results of our study, however exhibited some very different, but intriguing trends. Analysis of the EEG data showed one main overarching significant effect: an occipitally- centered increase in the 8-13 Hz suppression index for both tasks. Other main effects found included a larger suppression index for the self task as opposed to the other task in both the central and occipital regions as well as more 8-13 Hz suppression for the systemizing population in the midline region.

These significant results bring to light a few questions and possible explanations. The larger suppression index found for the systemizing population in the occipital region is counterintuitive to some degree, but its location and the overall trend of the EEG activation might help to tease apart the meaning and significance of our results. The fact that this difference was found in the occipital region and not the central, the region considered to be most indicative of MNS activation is an interesting point that fits well with the overall trend. The overall occipitally- centered suppression suggests a possible role of the alpha rhythm in the EEG activity and suppression index.

Another point to consider is the studies small sample size, and how this could lead to findings that might not be applicable to the population as a whole. Due to this constraint as well as time constraints, further analysis needs to be done. We are extended the study in two ways this summer. First, we are going to gather more subjects to put through this task. Second we are going to further analyze the data. Specifically we are planning on running a source separation analysis on the data which might help to illuminate the specific roles of the different EEG rhythms (mu and alpha) in our results.

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