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THE MNS (mirror neuron system) in embodied semantics: Activation Patterns of the Mirror Neuron System in Visual Linguistic Processing

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Introduction

Investigations concerning the phenomena of implementing linguistic expressions via observation resulted in arbitrary conclusions prior to the use of neuroimaging and electrophysiological techniques. Recently, neuroscientists have discovered a potential neurological basis for how we understand the intent of others and translate perception to action. Numerous studies have established that neurons located in the ventral premotor cortex (area F5) of Macaque monkeys were activated both when executing and observing actions. Evaluating this special class of cells, known as 'mirror neurons,' can give us insight into a broad range of questions concerning its correspondence to social cognition as well as the development of language.

Comparative anatomical mappings of brain regions between Macaque monkeys and humans demonstrate that the ventrolateral prefrontal cortex (area F5) in monkeys is cytoarchitectonically homologous to BA44 (Rizzolati, Arbib, 1998; Petrides, 2002), a region generally assumed to control language in humans, which is also known as Broca's area. These premises form the basis for the hypothesis that area F5 serves as an anatomical precursor for a language area (Rizolatti, Arbib 1998). Neurophysiological evidence supporting the role of area F5 in controlling hand movements (Fogassi, 2001), in conjunction with theories proposing gestural origins for language (Arbib, 2008), inductively leads to the conclusion that area F5 also serves as the functional precursor of a language area in humans (Rizzolatti, Arbib, 1998).

Contrary to these proposals, a few researchers have expressed skepticism regarding these evolutionary claims attributing functional and anatomical homology between the Macaque rostral area of the ventral premotor cortices (F5c) and the human BA44 (Zubicaray, Postle, McMahon, Meredith, Ashton, 2008) due to the lack of evidence that "mirror neurons in a premotor region in any common ancestor of humans and macaques" exist (Toni, Lange, Noordzij, Haggort, 2008).

Based on empirical evidence, a sensorimotor schema in the F5/BA44 exhibits the transitive property of creating neural representations when processing action depicting phrases, such as “bite” and “grab”, which indicates that it might be involved in understanding actions semantically. Furthermore, observation of movement (i.e. specific hand gestures) led to the activation of motor evoked potentials within humans, suggesting that this neural network also functions in bridging perception to action between a sender and receiver via the process of “motor embodiment” (Rizzolatti, Arbib, 1998). To reiterate, when perceiving the action of a “sender” this causes the “receiver” to have a surrogate perceptual experience by preparing the same muscles needed to execute that observed action. In particular, measurements suggest that actions using effectors such as the hand, foot, and mouth were transferred as precise motor representations in the observer (Glenberg, 2008).

According to the embodied cognition framework, conceptual knowledge is implemented by “modality-specific input/output systems” (Kemmerer, Castillo, 2008). A linguistic analogy of this conceptualization, known as embodied semantics, suggests that comprehending verbal depictions of actions results in an internal simulation of that action (Fischer, Zwaan, 2008). The process of conceptualizing action verbs appears to integrate motor areas in the frontal lobe, particularly in the premotor cortex (Kemmerer, Castillo, 2008). Neuroimaging studies of the human cerebral cortex reveal that linguistic stimuli elicits mirror neuron activity in Brodmann’s area 44 (BA44), supporting the hypothesis that the MNS has a functional role in semantic representation (Kemmerer, Castillo, 2008; Glenberg, Sato, Cattaneo, Riggio, Palumbo, Buccino, 2008).

Opponents of embodied cognition argue for an alternate explanation; a disembodied theory comprised of amodal motor representations of verb meanings, devoid of activation in the frontal lobe (Toni, Lange, Noordzij, Hagoort, 2008). Contesting evidence such as the absence of preferential activation within the BA44 during presentation of words and non-words seems to infer that this region is unrelated to the processing of semantic or abstract information (Zubricaray, Postle, McMahon, Meredith, Ashton, 2008).

The legitimacy of this argument has been substantially outweighed by the mounting data endorsing the embodied cognition framework. Various experiments consistently confirm that semantic processing results in activation patterns of the frontal lobe, among other regions (Glenberg, 2008; Hauk, 2004; Kemmerer, Castillo, 2008; Aziz – Zadeh, 2006). According to the authors Kemmerer and Castillo (2008), simply viewing action-related words elicited the response of the motor homunculus.

It has been suggested that the level of mirror neuron activity can be measured quantitatively by utilizing electrophysiological methods. Mu rhythms, defined as EEG oscillations in the 8-13 Hz frequency band, are attributed as reflecting modulation of sensorimotor regions by mirror neuron activity in the premotor cortex (Pineda, 2005). Changes in the amplitude of the mu rhythm during goal-oriented actions suggest that these waves represent cognitive processing such as retrieval of motor representations. An inverse relationship is exhibited by mu rhythms in which synchronization during idle states results in higher amplitude, and desynchronization during increased cortical activity correlates with mu suppression (Pineda, 2005). Thus, greater mu suppression is attributed to a higher level of mirroring activity.

Given the various analyses and supporting evidence, conclusive inferences can be generated to predict that processing linguistic information, particularly lexicon forms, should cause mirror neurons to discharge. This raises a number of additional questions: would comprehension of initially nonsensical or abstract characters engage mirror neurons? If so, would reading action verbs subsequent to learning the meaning of the new characters elicit more activity, resulting in greater mu suppression than reading nouns? Based on embodied semantics, it will be hypothesized that the process of learning the meaning of foreign action-depicting lexicons will indeed engage the mirror neuron system. Moreover, attaching semantic significance to initially meaningless symbols or characters should elicit more mirror neuron activity for the verbal - action – related words than the nouns.

2. Methods

2.1 Participants

The group of subjects who participated in this experiment included 15 undergraduate students from the University of California. Ten out of the fifteen subjects were native English speakers with no prior exposure to the Korean or Japanese language.

There were variances within this group for languages learned but all of them were highly competent in English.

Experimental Group data	Non – Koreans (N = 10)	Koreans (N = 5)
Mean Age	Mean = 21.3 years (σ = ± 5.62)	Mean = 20.8 (σ = ± 2.67)
Male to female ratio	1:1	2 to 3
Age range	18 to 24	20 to 23

Languages learned	English, Spanish, Vietnamese, Chinese, Czech, Malayalam, Hindi, Cantonese, ASL, Gujarati, Urdu	Korean, English

All subjects were right – handed and had no history of psychological disorders or traumatic brain injuries. Visual stimuli displaying Korean lexicons were presented to these English speakers. Subsequent to training they had to validate their comprehension of these foreign symbols. The control group consisted of five native Korean speakers whom regarded themselves as highly fluent in Korean. Initially these speakers were able to understand and distinguish the Korean words either as an action verb or noun so training was not necessary.

2.2 Experimental Procedure for English Speakers.

In general, the experimental
procedure differed for the English natives, as Korean speakers did not receive any training or post-EEG assessment. The procedure for the English native speakers was arranged in three segments: a pre-training EEG recording session, a training session, and post- training EEG recording session.

Visual stimuli consisted of four Korean words: two action verbs (e.g., “grab” and “bite”), two effector related nouns (e.g., “grape” and “scissor”), and a baseline condition of meaningless character strings (####) to account for any noisy input unrelated to the event.

2. 22 Experimental Procedure for Korean Speakers

This version of the experiment for native Korean speakers (control group) resembled the post-training EEG recording condition. Since participants in the control group are already able to comprehend the significance of the four words, reinforcement was not necessary. The EEG only recorded the activation during presentation of visual stimuli. Prior to the EEG recording, Korean subjects were also asked to complete the quiz to validate comprehension of the Korean words.

2.3 General Experimental procedure

An electroencephalogram (EEG) was used to examine the subject’s response. All together, we recorded from nineteen sites in the anterior, posterior, and medial region (F7, F8, F3, FZ, F4, FP1, FP2, T5, T6, O1, O2, T3, T4, C3, CZ, C4, P3, PZ, and P4). The mastoids were used as reference points.

Pre-Training EEG Recording

For the initial pre-training EEG recording session, English speakers were presented with a block of four Korean lexical items: two action-related words ("grab" and "bite"), two effector - related nouns ("grape" and "scissor"), along with a baseline condition of meaningless strings (####). Four images representing the two action verbs and two nouns were displayed in the training session. The Presentation program by Neurobehavioral Systems was used to present the visual stimuli on a computer screen approximately two feet away from the subjects. Each word was presented thirteen times each for three seconds. The baseline condition was presented six times during the entire presentation. The Korean words appeared briefly on the screen in succession, with variations in the order of words presented. There was a two second interval between each visual stimulus. In order to ensure that participants were actively observing the foreign words, they were instructed to count the number of baseline conditions in the entire presentation. All together a total of 57 visual stimuli were displayed on the screen during the pre-training.

Training of English Speakers

Following the initial recording of EEG, English speakers were trained to interpret the semantic meaning behind each Korean word. The Psyscope program was used for the training segment. A single Korean lexicon was presented simultaneously on the screen with four images depicting each word displayed on different corners. The baseline character was omitted. Subjects were instructed to click on the picture corresponding to the Korean lexicon in the center based on their inferences. Feedback was given after each input to aid subjects in deductively forming semantic representations for each word. Participants repeated several trials until they achieved a nearly perfect success rate and validated their comprehension of the four Korean lexicons. Altogether they completed three blocks of training. Each block of training had thirty trials. After training participants displayed their comprehension of the Korean words or symbols by writing the English definition for the Korean words that were presented to them.

Subjects finally took a comprehensive quiz post- training which consisted of eight questions. Each Korean word was displayed twice and the order of words presented varied for each subject. All subjects wrote the correct English definition of the Korean word all eight times for the quiz to proceed to the post-training.

Post – Training EEG Recording

Similar to the pre – training EEG recording session, subjects were presented with 13 blocks of 4 Korean words consisting of two action verbs and two nouns, along with 6 baseline conditions. Each word was presented for 3 seconds similar to the pre-training. Participants were asked to count the number of baseline conditions to ensure that they were paying attention to the presentation. There was a 2 second interval between each visual stimulus presentation. In contrast to pre – training, participants were now able to categorize and comprehend the foreign words as validated by the quiz. The quiz consisted of eight questions in which the subjects had to write the English definition of the Korean word presented to them. Each word was repeated twice and for every quiz the words were presented in random order. Each subject wrote the correct response for every word.

2. 4 Data Analysis

The EEG device was used to measure the mu wave (alpha band, 8-13Hz) and selectively depict the activation of mirror neurons. In order to complete the data analysis the SPSS program was used to do comparisons of conditions and electrodes. First, I analyzed three separate general linear models of the anterior, medial, and posterior region by doing repeated measures of two factors including five levels of conditions and six levels of electrodes. This was done for the pre and post-training data from the non-Koreans as well as for the control group of Koreans. The options were set to display descriptive statistics, more exactly the mean, for the two factors (conditions and electrodes) as well as conditions by electrodes. Also, for comparing main effects the confidence interval was adjusted to the Bonferroni setting in which the significance level was 0.05 or lower. In order to determine whether or not a factor showed significance, the Greenhouse – Geisser had to be less than the significance level for the tests of within – subjects effects.

2.5 Results

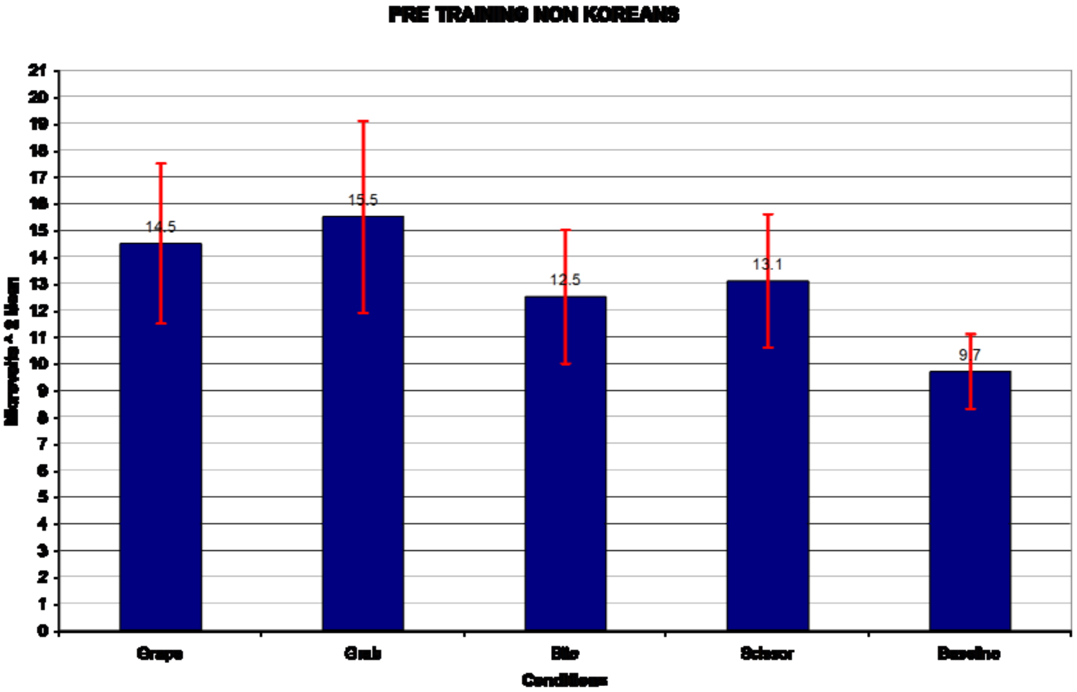

Figure 1. This bar graph represents the mean mu power for each condition from the non-Korean group prior to training. It encompasses the data from the electrode sites in the medial region (C3, CZ, C4, P3, PZ, & P4).

The mean mu power for each Korean word is roughly the same amount of enhancement relative to the baseline before training. There is no distinction between the verbs and the nouns at this point so it is expected that there is no relationship within categories.

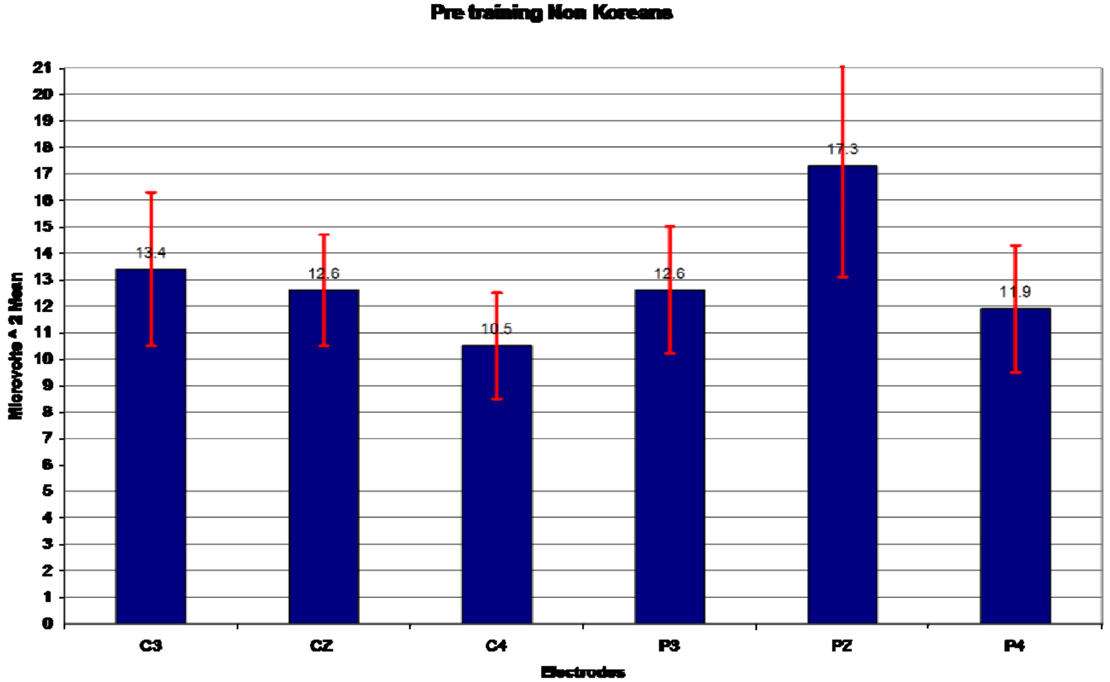

Figure 2. This bar graph represents the mean mu power for each electrode site from the medial region prior to training. In the analysis of the pre-training comparing conditions by electrodes from the medial region, there was a main effect found for conditions, F (4, 36) = 4.288, $p < 0.05$ as well as a marginal significance for the electrodes, F (5, 45) = 3.690, $p = 0.064$.

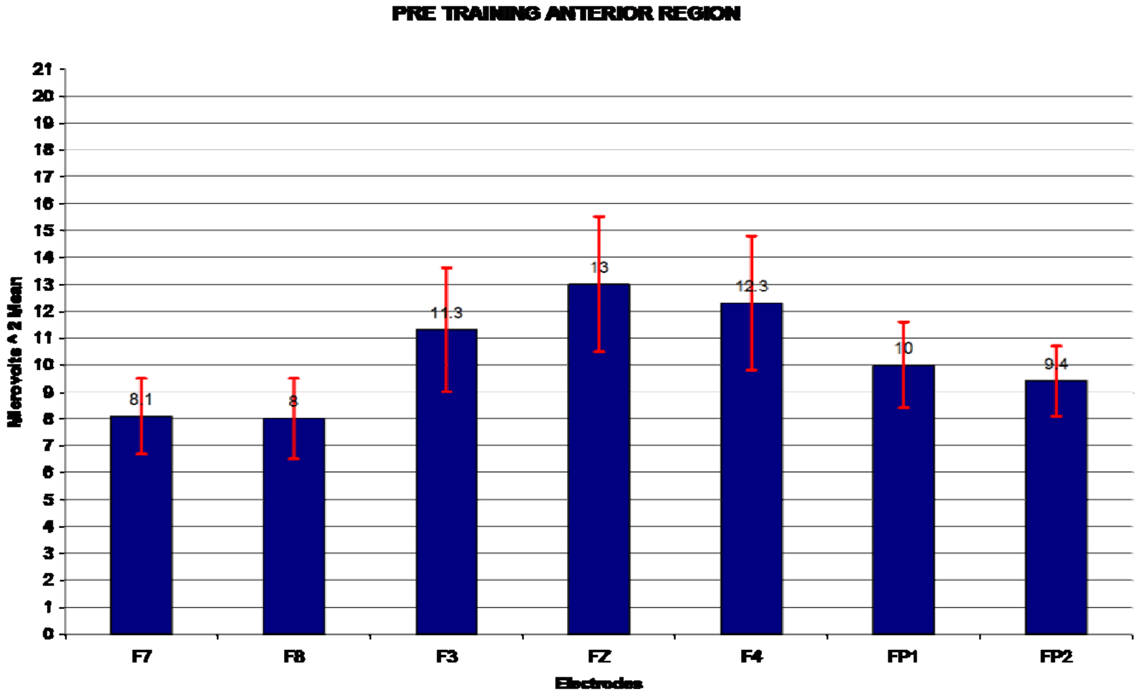

Figure 3. This bar graph represents the mean mu power for each electrode site from the anterior region (F7, F8, F3, FZ, F4, FP1, and FP2) before training.

There was a main effect for the electrodes from the anterior region, F (6, 54) = 6.898, $p < 0.05$ whereas there was no relationship or significance for the conditions.

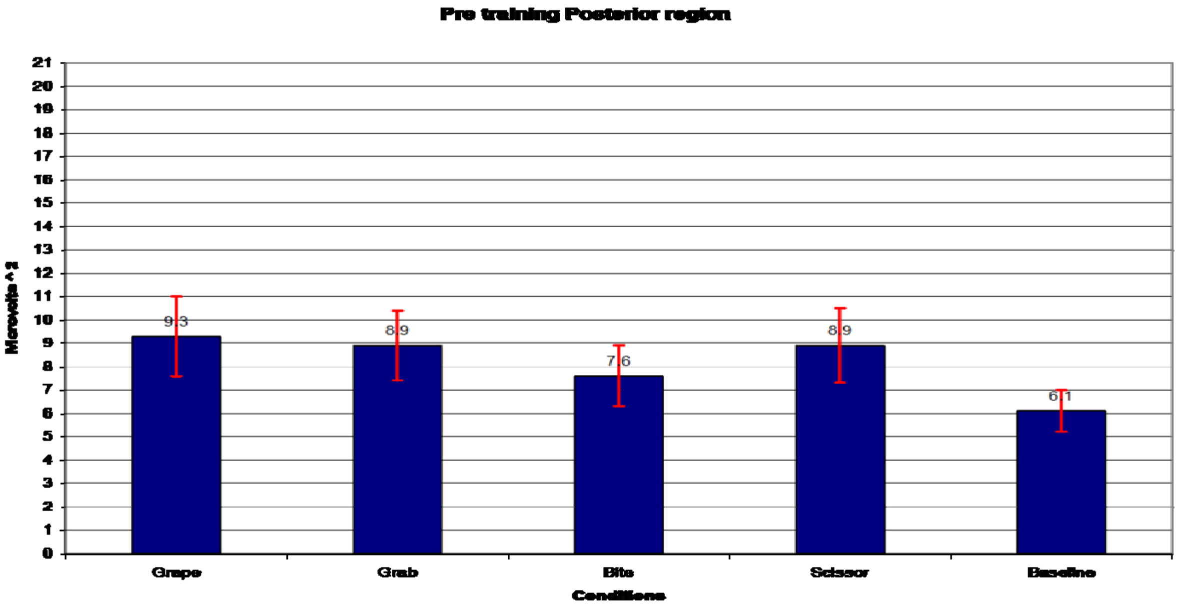

Figure 4. This bar graph represents the mean mu power for each condition from the electrode sites in the posterior region (T5, T6, O1, O2, T3, T4).

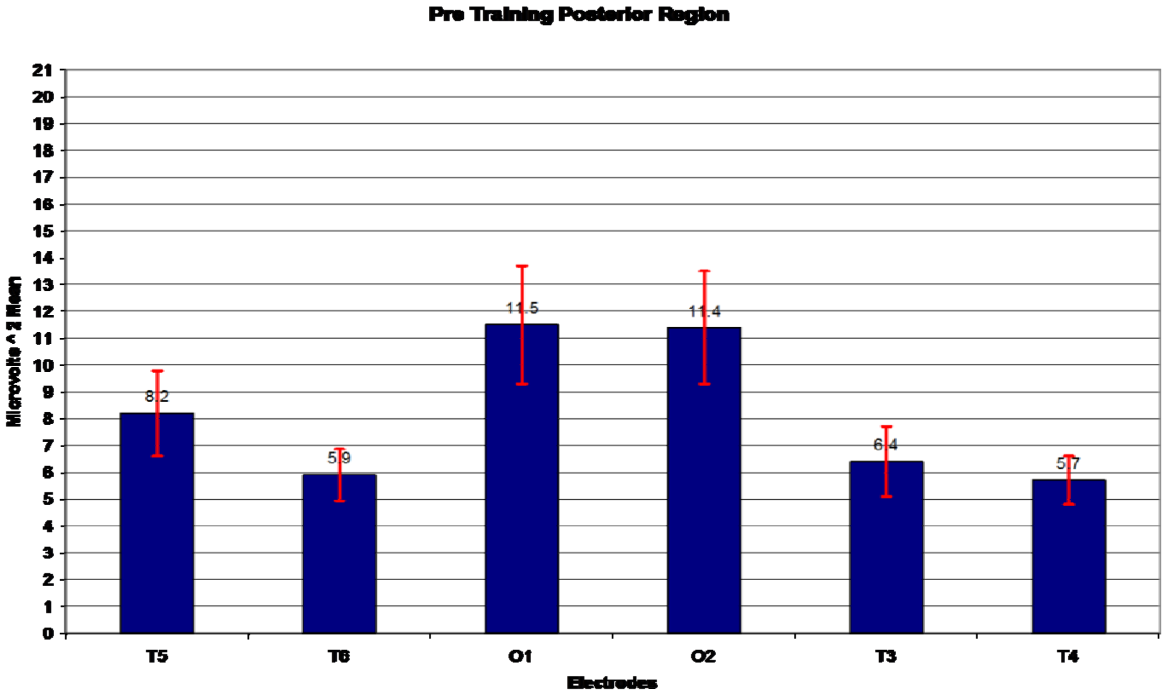

Figure 5. This bar graph represents the mean mu power for each electrode site in the posterior region.

The ANOVA of the data from the posterior region revealed that there was a main effect for both the conditions, F (4, 36) = 4.861, $p < 0.05$, as well as electrodes, F (5, 45) = 7.575, $p < 0.05$. Once again there was no significance found for the conditions by electrodes.

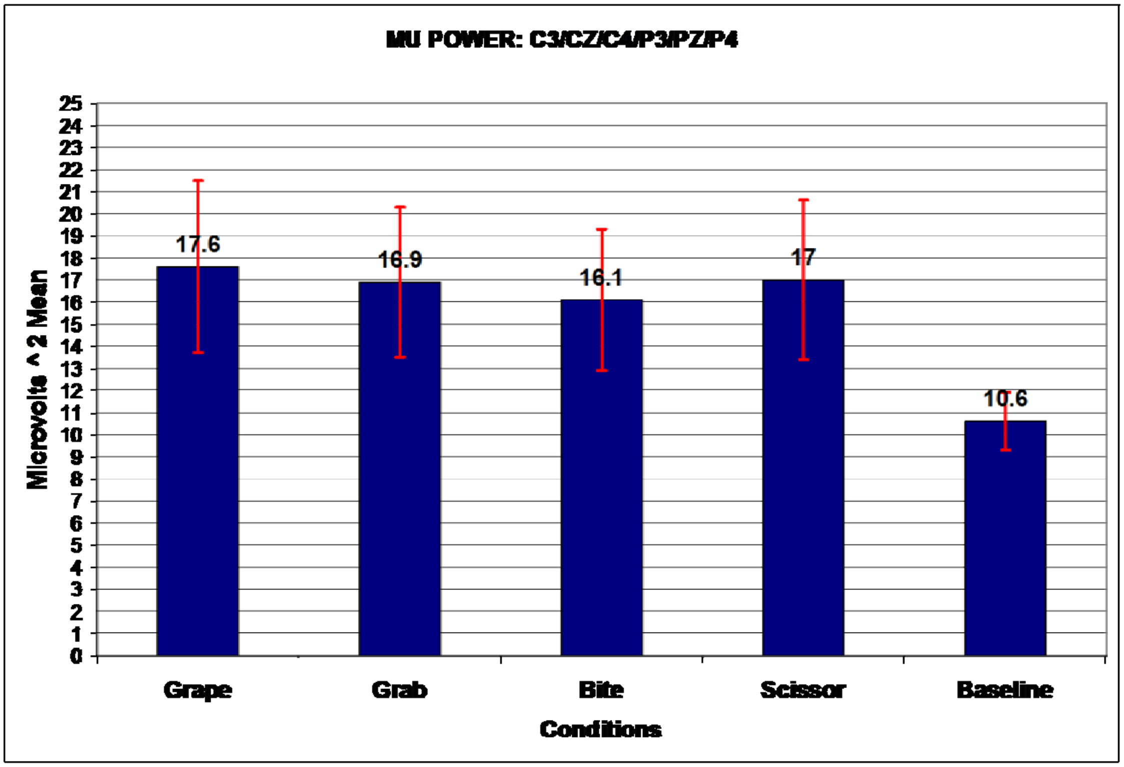

Figure 6. This bar graph represents the mean mu power of the conditions for the electrode sites from the medial region after training.

The analysis of post training data from the medial region revealed that there was a main effect for the conditions, F (4, 36) = 4.678, $p < 0.05$, but not for the electrodes. Subsequent to training, the mean mu powers for the conditions are still relatively the same, which is contrary to our predictions of there being a distinction between the verbs and nouns. Also, there is an enhancement in mu power from the pre-training graph for the conditions relative to the baseline, when it was expected that the graph would reflect a decrease after training.

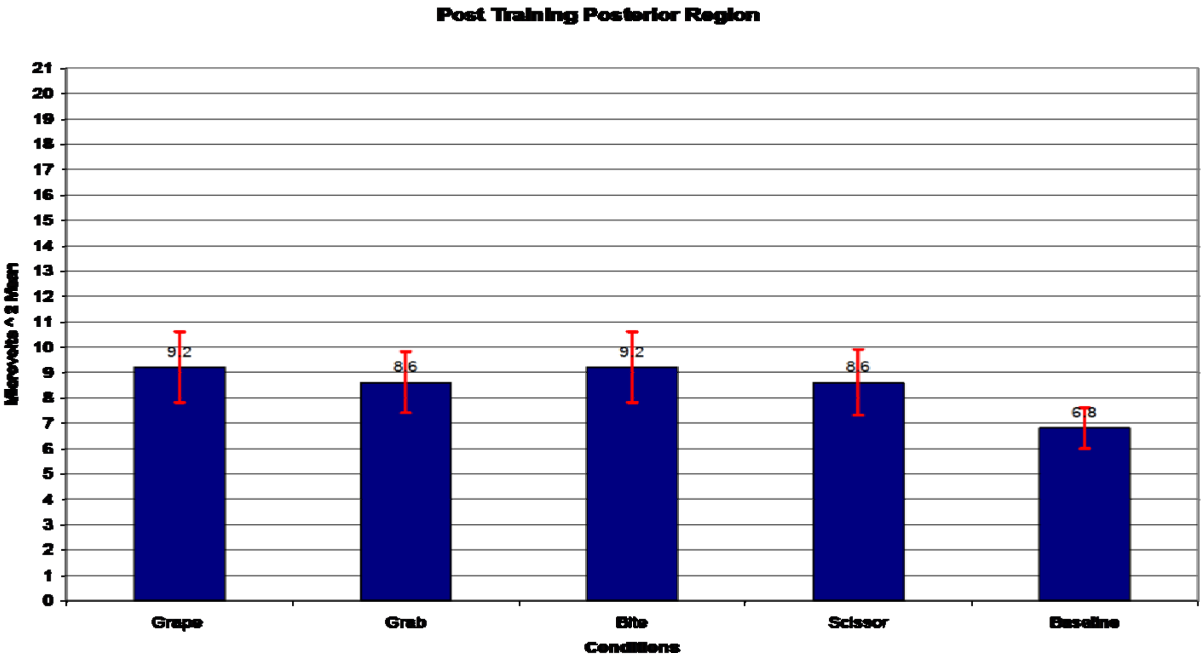

Figure 7. This bar graph represents the mean mu power for the conditions from the electrode sites from the posterior region subsequent to training.

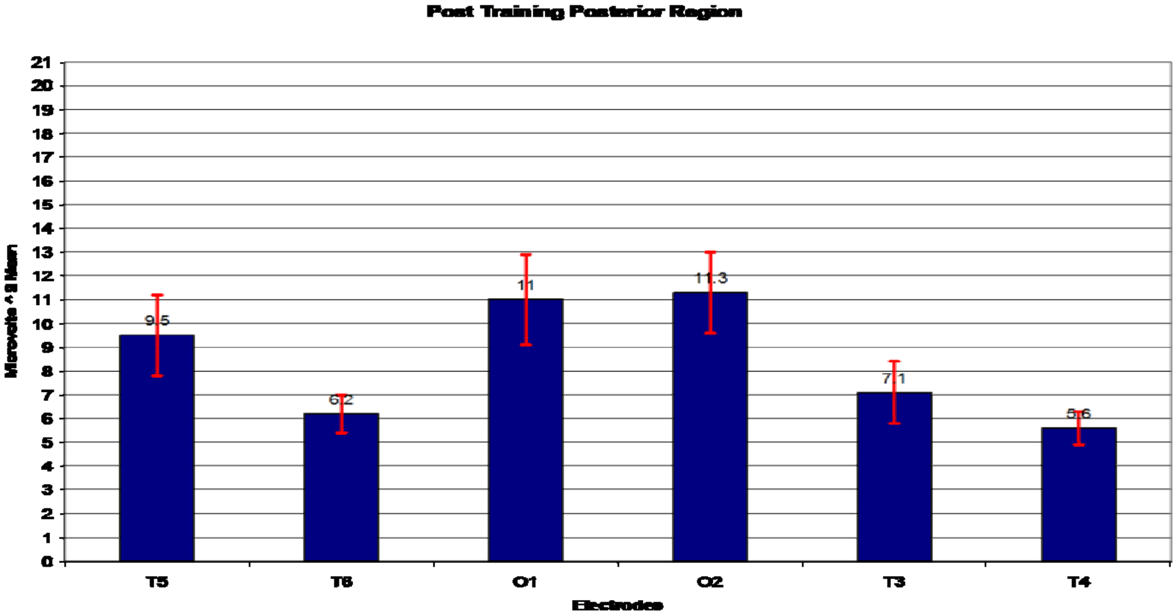

Figure 8. This bar graph represents the mean mu power for the electrodes from the posterior region after training.

The ANOVA for the post-training data from the posterior region revealed that there were main effects for both the conditions, F (4, 36) = 5.757, $p < 0.05$, and electrodes, F (5, 45) = 8.515, $p < 0.05$. A comparison of the graphs in figure 4 and figure 7 shows that there is a slight reduction in mean mu power for the conditions grape, grab, and scissor relative to the baseline whereas there is an increase for bite. In the graphs of the electrodes for the posterior region (Figure 5, Figure 8), the mean mu power remains generally consistent for both pre and post – training.

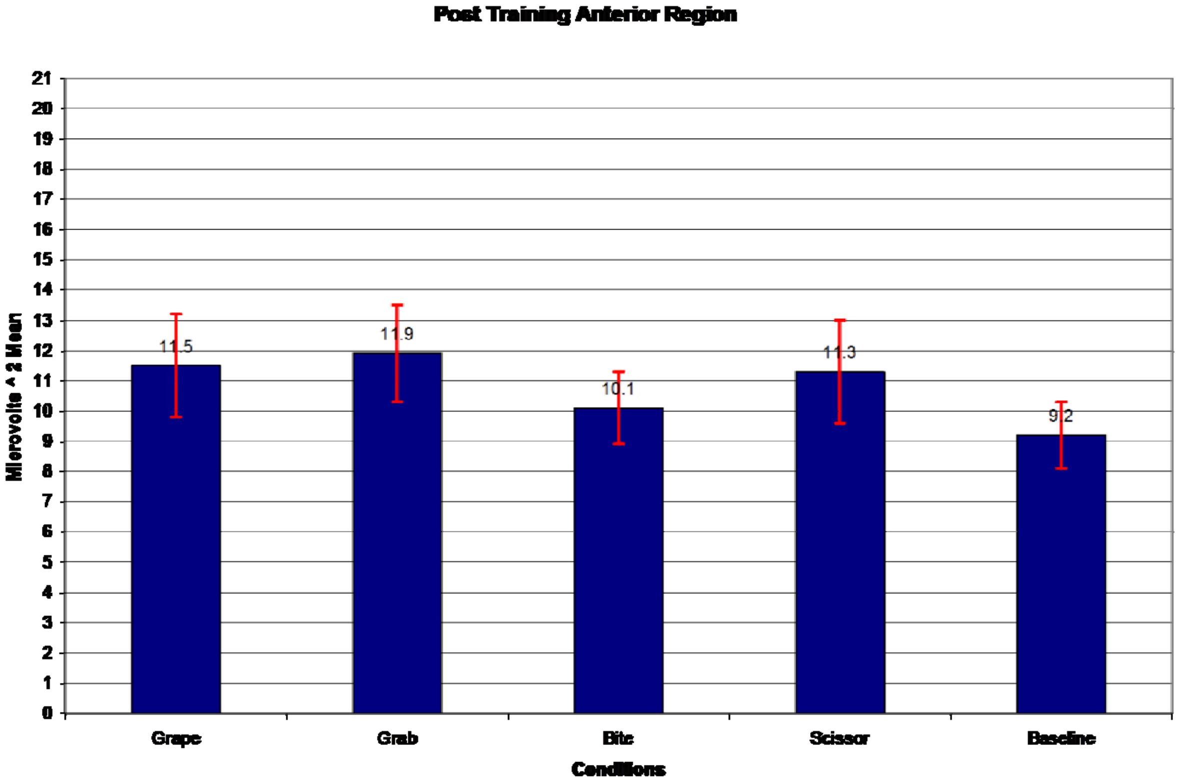

Figure 9. This bar graph represents the mean mu power for the conditions from the electrode sites in the anterior region (F7, F8, F3, FZ, F4, FP1, FP2) after training.

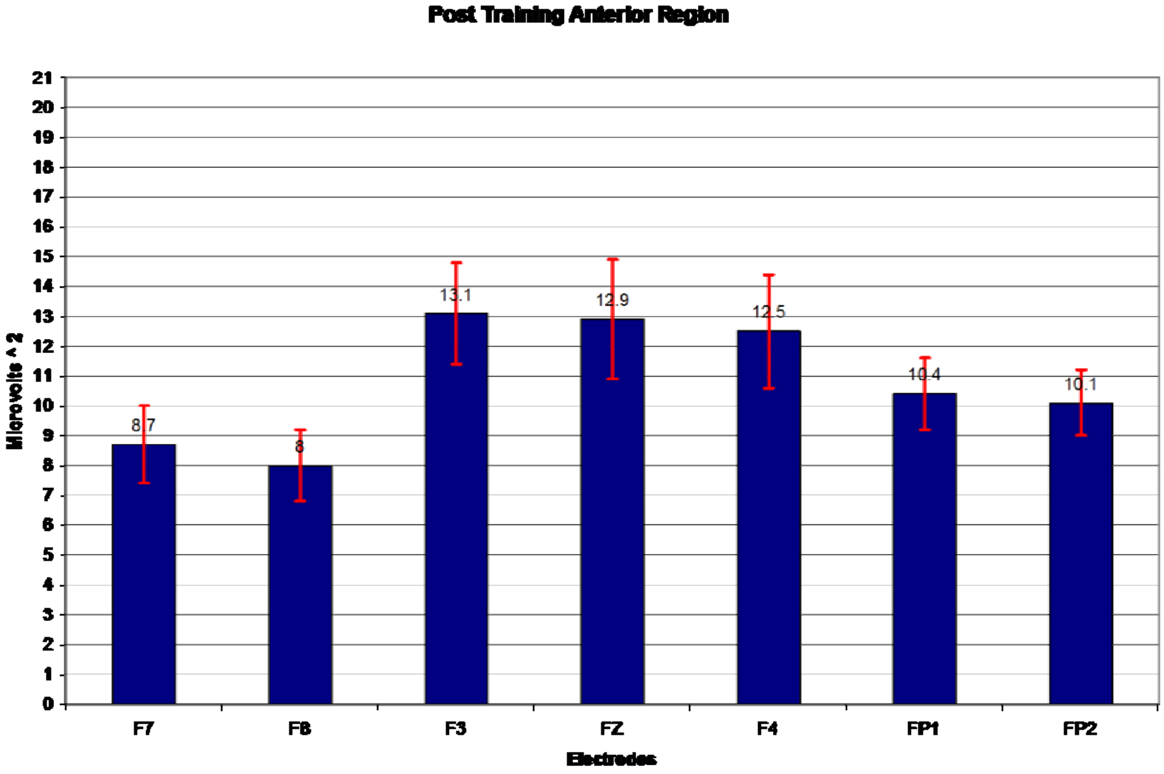

Figure 10. This bar graph represent the mean mu power for the electrode sites from the anterior region after training.

The ANOVA for the post-training data from the anterior region revealed that there were main effects from both the conditions, F (4, 36) = 3.198, $p < 0.05$, and electrodes, F (6, 54) = 9.122, $p < 0.05$. Compared to pre-training, there is a main effect for conditions after training and an increase in mu power for the electrodes.

There were no main effects found from the analysis of general linear models comparing mu suppression to electrodes. This was also the case when comparing the factors of verbs and nouns to electrodes. Similarly, the data analysis from Korean speakers did not show any significant findings.

3. DISCUSSION

Results from the present study showed that there was a main effect for conditions and for electrodes in the three regions but not for conditions by electrodes. Also, when analyzing the mu power data, no main effect was to be found.

Overall, the data results were inconsistent with our predictions that English speakers who learned the meaning of Korean symbols would engage mirror neuron activity, especially for action verbs, and this would produce a decrease in mu power relative to the baseline, signifying an increase in mu suppression. Analyses of mu power also failed to reveal a main effect for conditions and electrodes or for the categories of verbs verses nouns which is contrary to the emphasis placed on increased mu suppression as stated in the hypotheses. A possible reason for the failure to find main effects in mu suppression might be due to the small subject pool, a lack of thorough training, or the attention given to counting the symbol used in the baseline condition.

In order to obtain more accurate results we plan on replicating this study by reinforcing the training so subjects are not simply learning via visual recognition. Also, we will have subjects construct the words themselves by choosing from a pile of cards with Korean lexicons. In order to account for the importance given to the baseline, for the presentation of stimuli we will have subjects count the original symbol (####) while including (but not counting) an additional insignificant symbol to use as the baseline.

For future research it would be beneficial to replicate this study using the same paradigm with a larger subject pool. Also, it might be useful to implement training with a different language; one that uses the same alphabet, rather than an unfamiliar alphabet.

After replicating this study with a more difficult training session, if the data results were to reflect our hypotheses it would imply that mirroring activity mainly had a role in the semantic acquisition of this set of Korean words. Supporting evidence for this inference could lead to further research investigating motor resonance in language acquisition, specifically in action depicting words.

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