The Social Brain in Action: The Human Mirror System Dynamically Expands to Include More People

Himani Manglik
Briarcliff High School

Table of Contents

List of Figures & Tables

Abstract

Mirror neurons are a class of audiovisual neurons, mostly in the premotor cortex, but found in other areas of the brain as well, that fire when an individual performs a specific goal-directed action as well as when that individual observes someone else performing a similar action. This assists in action recognition and understanding. The mirror system has been proposed to be involved with language comprehension and speech-associated gestures, which are goal-directed actions that individuals use to assist in more efficient communication. In the present study, electroencephalography (EEG) was used to monitor the mirror activity of participants who observed a show called *Are You Smarter Than a 5th Grader?* The two variables being tested are the synchrony, or mirror system activation, based on differences in the number of people on the screen, and thus actions, as well as gender. This is a novel study because all prior research on the human mirror system has only concentrated on the role of the mirror system in processing one person's action at a time. This research, however, looks at what happens with the mirror system when multiple people's actions are observed, as is the case in social interactions. In addition, previous work has not looked at the effects of gender on the firing of mirror neurons. Results have found that the mirror system expands to accommodate the observation of multiple people and their actions. Also, the present research has suggested that females are able to process multiple people's actions better than male's can process them. This study incorporates research on the mirror system into a real-world context and hopes to provide an explanation on how humans interact.

1.0 Review of Literature

1.1 The Properties of Mirror Neurons

Mirror neurons are a class of neurons mostly in the premotor cortex that fire when a monkey performs a goal-directed motor action. These neurons also fire when that monkey sees someone else performing that same action (Rizzolati et al., 2006). More importantly, mirror neurons are involved in action recognition and understanding. Depending on the goal intended specific neurons are discharged that correspond to that goal. If the neurons are activated by visual stimuli, they require an interaction between a biological effector, either a hand or mouth, and an object (Rizzolatti and Laila Craighero, 2004). The observer recognizes and processes another's actions because the induced motor representation coincides to that generated internally during action execution (Rizzolatti et al., 2001). These distinct neurons are also associated with imitation, or the copying of body movements that is observed (Brass and Heyes, 2005). Mirror neurons can be classified as audiovisual, meaning that they respond to the visual observation of actions accompanied by sounds, as well as with only sounds. These unique neurons may help bridge the interstice between humanities and science, and may also allow for the understanding of the evolution of language over time, empathy, imitational learning, "theories of other minds," and the "nature vs. nurture" debate, proving that learnability through the changes in one's environment has a greater effect on individuals than heredity does.

Giacomo Rizzolatti and his colleagues at the University of Parma, in Italy, first discovered mirror neurons in the 1980s, while studying macaque monkeys and their various motor activities. They learned that these neurons respond to audio, visual, and somatosensory stimuli (Winters, 2008). According to Rizzolatti and Craighero (2004), research into mirror neurons found that the goal and the ways of reaching that goal were both important. This led to the division of mirror neurons into two groups, which are “strictly congruent,” and “broadly congruent.” Mirror neurons are classified as “strictly congruent” if the effective observed and effective executed actions correspond in terms of goal and means for reaching the goal. On the other hand, mirror neurons are classified as “broadly congruent,” if in order to be triggered, they don’t require the observation of exactly the same action that they code motorically. Mirror neurons are involved in two main functional roles, which are imitation (Jeannerod, 1994) and action understanding (Rizzolatti et al., 2001). Simply put, the mirror system transforms visual information into knowledge (Rizzolatti et al., 2001). After an individual observes an action done by another individual, neurons that represent that motor action are triggered in the observer’s premotor cortex (Rizzolatti and Craighero, 2004).

1.2 Mirror Neurons and Language Comprehension

Mirror neurons have also been associated with language processing and comprehension. Skipper, Goldin-Meadow, Nusbaum, and Small (2007) reported that language comprehension is greatly influenced by speech-associated gestures. Speech-associated gestures are goal-directed actions that individuals use to assist in more efficient communication. In order to have a greater influence on the brain, these gestures have to be meaningful with the purpose of conveying a set goal and reducing ambiguity. It was shown that the human mirror system emphatically changes to accommodate the goal of comprehension to the observed actions that are available.

1.3 The Social Nature of Mirror Neurons

Mirror neurons have also been found to process emotional states. Body movements and facial expressions have been shown to aid in the recognition of another’s emotions. Emotions motivate the way individuals move (Winters, 2008). Emotions can be detected by subtle details of body posture, musculoskeletal changes, shaping of body movement, speed and contour of movement, minimal changes in the amount and speed of eye movements, and the degree and contraction of facial muscles (Damasio, 1999). It has been suggested that individuals automatically read nonverbal cues and naturally know when emotional expression is "off." (Winters, 2008). A key component of mirror neurons are their ability to convey empathy as a mental state. Mirror neurons allow two individuals to physically and emphatically attune to each other, bringing meaning to the bodily-felt experiences.

1.4 Techniques for Monitoring Neural Activity

There are many techniques for monitoring neural activity. Electroencephalography (EEG) measures the electrical activity of the brain by the recordings from electrodes placed on the scalp. It can be used in the diagnosis of tumors, comas, head injuries, sleep disorders, Alzheimer's, and other brain diseases. EEG can also be used to investigate periods of unconsciousness. Functional magnetic resonance (fMRI) measures the change in blood flow related to neural activity in the brain or spinal cord. It is often used for brain mapping because of its low invasiveness, lack of radioactive exposure, and the convenience with which it can be found and used.

2.0 Methods

2.1 Participants

Participants were recruited from Hamilton College in Clinton, NY. Participants were notified via word of mouth and posters around campus. Participants had to meet certain criteria, including being right-handed and also a native English speaker with no earlier exposure to a second language. The purpose of these qualifications was to build a homogenous participant data set. Participants were told not to wear any sort of make-up and eyeglasses because that would interfere with the eye tracker. Additionally, participants were told to have clean, dry hair with no gels or products because it could result in high EEG impedances. There were a total of 65 participants, with 40 females and 25 males. After the prescreening, participants' names were replaced with participant ID numbers to maintain anonymity. All work was conducted with Hamilton College IRB approval.

2.2 Study Design and Procedures

When the participants arrived for the prescreening, they were required to sign a participant protection consent form. They were given the Handedness Inventory and Language Questionnaire, which asked questions about the participant's first language and dominant hand. Participants were also given the Participant Payment form, which formally addressed how much payment a participant would receive. Then, necessary measurements of the participant's heads were taken and the respective EEG caps were allocated. The EEG cap was placed on the participant's head with the vertex electrode in the net placed right over the vertex point on the scalp. The participants were then seated in the Faraday cage, a soundproof EEG room. They were told to limit movement and blinking during the experiment as it interferes with the EEG system. The participants were then monitored as they watched a full episode of the show called *Are You Smarter Than a 5th Grader?* The episode was divided into six runs, which were about six minutes each. Participants were allowed breaks between each video and a longer five-minute break after the third video to stretch. After the videos were completed, the Are You Smarter Than a 5th Grader questionnaire was given to participants. In the questionnaire, participants had to write the answers to all the questions in the video and were asked if they knew the answers prior to watching the show. Participants were given the Post EEG general survey that asked questions about their EEG experience, including their comfort level during the EEG, and feelings of drowsiness. Lastly, participants were given their payment, which was 10 dollars per hour.

2.3 EEG Programs

The participants were monitored using 3 computers. The first computer used a program called Net Station, which measures impedances and collects the EEG data. The second computer used Smart Eye Pro 5.6, which tracks the eye movements. The third computer used E-prime to record the stimulus presentation. Before the EEG began, the experimenter used a plastic pipette to apply a small amount of the electrolyte to the electrodes with impedances above threshold (50 kOhm). Impedances below the threshold were displayed as green and impedances above the threshold were displayed as red on the E-prime computer. Once all or most of the electrodes were green, the experimenter wrote down the electrodes that still had high impedances for future reference of data inaccuracies. Then, the experimenter began the videos. After the participants watched the videos, they were escorted out of the Faraday cage and their EEG caps were removed.

2.4 Research Questions

1) Is there greater mirror system activation or synchrony between the observer and the people of the game show, when two people are viewed rather than one person?

2) Is there greater synchrony when the genders of the observer and the people of the game show correspond?

2.5 Hypotheses

H_a: There is greater synchrony between the observer and the people of the game show, when two people are viewed rather than a single person.

H_b: There is greater synchrony when the genders of the observer and the people of the game show correspond.

$H_0 1$: There is no greater synchrony between the observer and the people of the game show, when two people are viewed rather than a single person.

$H_0 2$: There is no greater synchrony when the genders of the observer and the people on the game show correspond.

3. 0 Data Analyses

3.1 ELAN

The experimenter used a program called ELAN to annotate the data. A specific coding formula was used and was represented as digits in the form xxx_xxx. The first set of three digits represents the visibility of the people on the game show to the observers. The first digit indicates if the contestant of the game show, Meghan, was visible. Zero was recorded when she was not visible and 1 was recorded when she was visible. The second digit indicates if the game show host, Jeff, is visible. Again, 0 indicates not visible and 1 indicates when he was visible. The third digit represents the number of audience/class members that are visible. The next set of three digits represents the kind of movement that each person on the game show performs, as seen in Data Table 1. This coding for the type of movement that people of the game show perform was done on a subjective basis. The first digit represents the movement of Meghan, the second digit represents the movement of Jeff, and the last digit represents the movement of the audience/class members of the game show.

Data Table 1: Coding for the Movements of the People on the Game Show

Coding	Movement
0	No movement
1	Very small movement; very small head movement/body movement; just visible
2	Small movement; visible
3	Medium movement; fuller movements of face/body; 2 different movements
4	Large movements of face/body that require a lot of muscle movements; completed actions; visible; 3 different movements
5	Very large movements; a lot of muscle movements in face/body; 4 or more different movements

3.2 Pre-processing

The experimenter used a program called Net Station to filter the data. The processed data was first dragged into waveform tools. Then the experimenter went to Script: Default 256 Processing. The first step was to segment the data and remove any activity that was not associated with the television show. Following this, the data was filtered at .1 Hz lowpass and 100 Hz highpass filter. An alternative to throwing out data is to regress it by removing blinks of the eyes, which leaves the underlying data intact. The first in a series of artifact detection programs, which is used if the regression doesn't work properly or missed some eye blinks, is the bad channel detection, which excludes any channels with impedances above 200 kOhm from the data set. The second in the series is eye blinks, which excludes any eye blinks from the data. The third is the eye movement, which excludes eye movement data according to a different threshold and a different set of electrodes. The removal of eye blinks and eye movements is called ocular artificial removal. Next, the experimenter used the averaging tool to average all of the segments left by condition. Averaging gets rid of variance from the data so the underlying structure is left with the central trend. Then, the experimenter used montage operations to get rid of the distance between the VREF electrode, or the vertex electrode, and the other channels. It averages the distance of the channels in comparison to that reference point. The last step of preprocessing is baseline correction, which changes data to a percent signal change. The experimenter then exported the file in the appropriate format.

3.3 Imaging Analysis

The imaging analysis was performed with Brainstorm through Matlab. First, a forward model was used, which provides a model of the head, the skin on the head, the hair on the head, the dura, the skull, the brain tissue, and the fluid in the brain and their conductivity. Then, the Inverse Model was performed which shows how electricity looks in the brain given the distribution we measured on the scalp. The model of the head and where the dipole is located is used to find the activity in the brain for any given condition.

3.4 Statistical Analyses

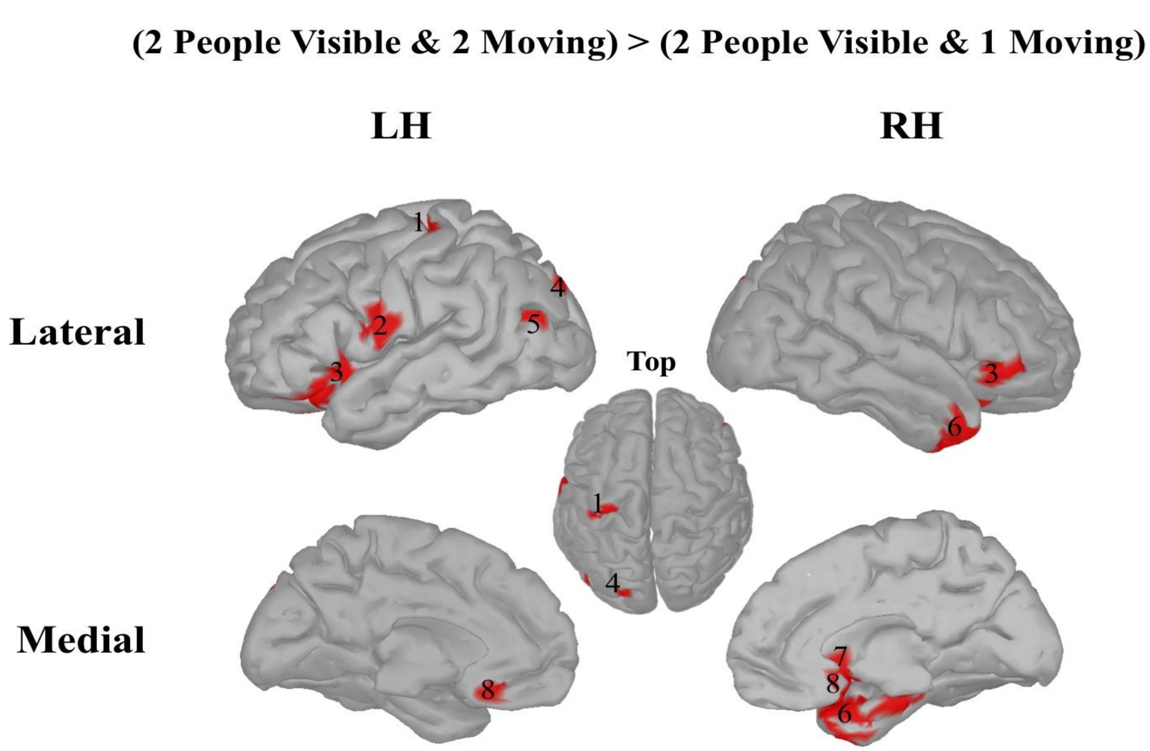
The annotations were used to import the data for at least two people visible and 2 people moving, as well as for at least 2 people visible and 1 person moving. 250 ms chunks were imported and source localization was performed at each sample. The sampling rate was 250 Hz, which is every 4 ms. Then the mirror activity of at least 2 people visible and 1 moving was subtracted from the mirror activity of at least 2 people visible and 2 people moving. There were only 515 segments per conditions because 2 people visible and 1 person moving occur rarely, only a little over 2 minutes. Therefore, 515 segments were randomly chosen for at least 2 people visible and 2 people moving despite there bring a lot more segments (N=2214). The file was then z-transformed. The group analysis was a t-test of the file compared to a resting baseline, or the null hypothesis of no activity. To address the second hypothesis of gender differences, the data for at least 2 people visible and 2 people moving was divided by gender. Subsequently, an unequal variance t-test was performed because there were more female participants (N=40) than male participants (N=25). However, even when the data for 15 females was randomly thrown out, the results looked similar.

4.0 Results

4.1 Two People Visible & 2 People Moving vs. 2 People Visible & 1 Person Moving

A paired t-test was performed for 2 people visible and 2 people moving versus 2 people visible and 1 person moving. Visibility served as a visual control because 2 people were visible in both cases. Since multiple t-tests were performed, the individual voxel probability actually had to be $p < .001$ in a cluster size of 10 voxels. It was corrected for multiple comparisons to $p < .05$ Results were found to be statistically significant ($p < .001$). Image 1 shows the different regions of the brain that are activated, as indicated by the red. Data table 2 outlines the names of the regions of the brain that are numbered in Image 1.

Image 1: Two People Visible & 2 People Moving Have Greater Mirror System Activation Than 2 People Visible & 1 Person Moving Do



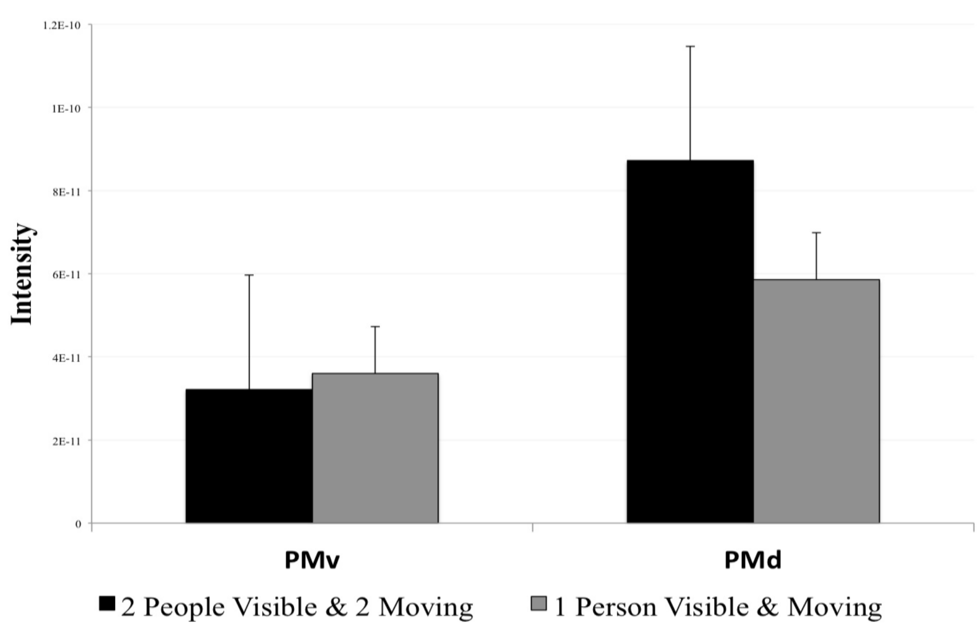
Data Table 2: Names of The Activated Regions of The Brain Shown in Image 1

1	Dorsal pre-and primary motor cortex and dorsal somatosensory cortex (will call PMd)
2	Pars opercularis and ventral pre-and primary motor cortex and somatosensory cortex (will call PMv)
3	Pars obitalis and the insula
4	Dorsal visual stream
5	Middle Temporal (will call MT/V5)
6	Anterior lateral and medial temporal cortex
7	Caudate
8	Ventromedial prefrontal cortex- Orbital frontal cortex

4.2 Two People Visible & 2 People Moving vs. 1 Person Visible & 1 Moving

A large region of interest (ROI) was drawn that encompassed PMd regions. Also, another large ROI was drawn that encompassed PMv regions. Then the time series data in these ROIs was averaged. The maximal response was found for 2 people visible and 2 people moving versus 1 person visible and 1 person moving. The bar plot graph below confirms that PMv is similarly active for 2 people or for 1 person moving. However, it confirms that PMd activity actually increases significantly in the presence of a second person.

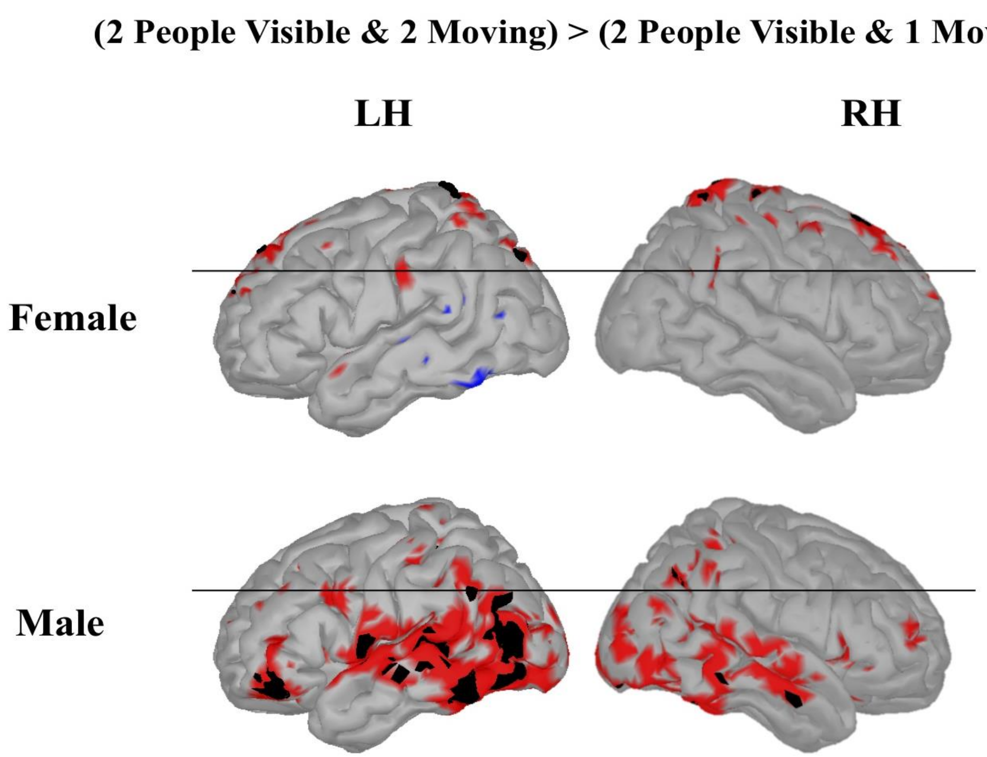
Image 2: PMd Activity Increases Significantly With a Second Person



4.3 Synchrony Based on Gender Differences

An unequal variance t-test was performed because there were more female participants than male participants. The data for 15 female participants was discarded, leaving data only for an equal number of male and female participants (N=25 male, N=25 female). Image 3 shows the regions of activity in the right and left hemispheres of the brain for both males and females. The corrected for multiple comparisons to p < .05 is shown in black. The uncorrected for multiple comparisons to p < .05 is shown in red. The blue shows where the female's had less activity than the males did. The black line, defined as an imaginary extension of the Inferior Frontal Sulcus, is a line that experimenters use to divide the PMd and PMv. The results show that there is no greater mirror activity when males and females observe people of their own gender.

Image 3: Females Can Process Multiple People's Actions Better Than Males Can



5.0 Discussion

The results confirm the first hypothesis that observing two people increases engagement of areas of the brain traditionally included in the mirror system, than when just observing one person. In addition, observing two people engages many other motor and somatosensory areas. This indicates that the mirror system expands to encompass the observed movements of all visible people on the show. As shown in image 1, classical areas of the mirror system were activated, such as the PMv. All the other areas besides the PMv are regions where mirror system activation isn't usually produced. The PMd was activated, which represents the exact location of the finger and the hand. The pars obitalis and the insula were activated, as well the anterior lateral and medial temporal cortex, which have been shown to be involved in action observation. The dorsal visual stream was activated, which is perhaps how information gets to the PMd. Even the MT/V5 was activated, which is the exact location of an area specialized for perception of motion, and is also considered part of the dorsal visual stream. The caudate was activated which is classically thought to be part of the motor control circuitry. Lastly, the ventromedial prefrontal cortex- orbital frontal cortex was activated which is involved in social cognition. Intriguingly, seeing a second person engages an area that has received a lot of attention for being involved in social cognition and social decision-making. This suggests that the mirror system expands to encompass multiple people not only for the purpose of action understanding, but rather, action understanding for the purpose of social evaluation.

The results show that though both male and female observers produce activity in the PMd as seen in Image 3, females tend to drive these areas more than males do as they have greater PMv activity than males do. By lowering the threshold, we see that this isn't just a statistical artifact. This might suggest that females pay more attention to multiple people in our sample.

The second hypothesis that the male observers will have more synchrony with the male host and that female observers will have more synchrony with the female contestant, was shown to be invalid. Female observers just have a greater ability of processing multiple people's actions than male observers do. Male observers are only able to process one person's actions at a time. This finding confirms prior research done by Yawei Cheng, when she showed that females have stronger mu wave suppression than males do when watching hand motions (Cheng et al., 2008).

6.0 Limitations & Future Research

One limitation of this research could be that high impedances were recorded, which can result in data inaccuracies. Another limitation could be that the participants could have been moving or blinking greatly, which interferes with the EEG system and results in potential data being discarded. Future research will look to extend these findings by looking at a more diverse population, not just college students. Future research can also be done to look more in-depth at the workings of mirror neurons and how they are fired according to the characteristics of the people that are observed. Another, interesting question that researchers in the future can study is what effect goal congruence has on mirror system activation. For example, in the present research, it could be examined whether the observers and the contestant will have greater synchrony because both have the same goal of answering questions.

7.0 Acknowledgments

I would like to thank my mentor, Dr. Jeremy Skipper, for guiding me and putting in so much time and effort to help me conduct the research and write my research paper. I would also like to thank Ms. Carnahan and Ms. O'Brien for their support and encouragement.

8.0 Bibliography

Arbib, M. (2005). From monkey-like action recognition to human language: An evolutionary framework for neurologistics. *Behavioral and Brain Sciences*. 28, 105-167.

Brass, M., Heyes, C. (2005). Imitation: is cognitive neuroscience solving the problem? *Trends in Cognitive Science*. Vol. 9

Craighero, L., Metta, G., Sandini, G., Fadiga, L. (2007). The mirror-neurons system: data and models. *Progress in Brain Research*. Vol. 164

Cheng, Y., Lee, P., Yang, C., Lin, C., Hung, D., Decety, J. (2008) Gender Differences in the Mu Rhythm of the Human Mirror-Neuron System. *US National Library of Medicine National Institutes of Health*.

Damasio A, R. (1999). *The feeling of what happens: Body and emotion in the making of consciousness*. Orlando, FL: Harcourt Brace

Gog, T., Paas, F., Marcus, N., Ayres, P., Sweller, J. (2008). The Mirror Neuron System and Observational Learning: Implications for the Effectiveness of Dynamic Visualizations. *Educational Psychology Review*. 21: 21-30

Jeannerod M. 1994. The representing brain. Neural correlates of motor intention and imagery. *Behav. Brain Sci*. 17:187–245

Kohler, E., Keysers, C., Umilta, A., Fogassi, L., Gallese, V., Rizzolatti, G. (2002). Hearing Sounds, Understanding Actions: Action Representation in Mirror Neurons. *American Association for the Advancement of Sceince*. Vol. 297 issue 5592, p846

Molenberghs, P., Cunnington, R., Mattingley, J. (2009). Is the mirror neuron system involved in imitation? A short review and meta-analysis. *Neuroscience and Biobehavioral Reveiws*, 975-980.

Ramachandran, V.S. (2006). Mirror Neurons and the Brain in a Vat. *Edge The Third Culture,* 1-9.

Ramachandran, V.S., Oberman, L. (2006). Broken Mirrors. *Scientific American*. p62-69

Ramachandran, V.S., Altschuler, E. (2009). The use of visual feedback, in particular mirror visual feedback, in restoring brain function. *Brain*. 132: 1693-1710

Rizzolatti, G., Fogassi, L., Gallese, V. (2006). *Mirrors in the Mind*, 1-6.

Rizzolatti, G., Craighero L. (2004). The Mirror-Neuron System. *Annual Reviews Neuroscience*. 27: 169-92

Skipper, J., Goldin-Meadow, S., Nusbaum, H., Small, S. (2007). Speech-associated gestures, Broca's area, and the human mirror system. *Brain and Language*.

Winters, Allison F. (2008). Emotion Embodiment in Dance/Movement Therapy: A Connection Across Disciplines. *American Dance Therapy Association*.