Project Report: Testing Hypotheses of Mirror Neuron Function

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Abstract

Mirror neurons, discovered by Rizzolatti et al. in the 1990s [2], have been the subject of much debate. There are many theories regarding their possible function, both evolutionarily as well as in day to day life. It has been proposed that mirror neurons are the single neuron substrates of the Common Code [1], which links perceptual and action representations to allow the brain to predict of the outcomes of complex actions. Knoblich et al.[1] have proposed that if this is true, the motor mirror neurons should be better able to predict the outcomes of one's own actions, seen from a third-person perspective, than those of another person. In this study I have replicated their experiment which measures the accuracy with which humans can anticipate outcomes of their own actions, compared with those of others.

Introduction

A commonly held view in cognitive science thus far has been that the cognitive system, perception system and motor system are distinct entities which interact with one another in a hierarchical manner: the perception system provides input to the cognitive system; the cognitive system provides output to the motor system. This motor output id thought to be based on analysis of perceived information, and one's will and volitions.

The Common Coding Hypothesis proposes that motor and perception systems are inherently linked in our brains, and that their interaction is the basis for many cognitive processes. In particular, there exists a common representation for every stereotypical "action" that we see around us. This representation is both perceptual (what the action looks like) and motor (what commands trigger the action). By activating internal motor 'simulations' of the commands for an action, our brains can interpret actions that we observe and anticipate consequent actions or their outcomes.

The discovery of mirror neurons in the premotor cortex of macaques which fired both when a particular action was performed by the monkey and when the monkey observed the experimenter performing the same action is seen as physiological evidence for the Common Coding Theory. These neurons are activated by neurons in higher visual areas like superior temporal sulcus [4], which respond to visual scenes. The mirror neurons in turn activate motor programs for those actions.

Motivation

If this is correct, and our brains indeed carry out a mental simulation of observed actions, then to what extent do these simulations capture intricacies in the observed motions? In particular, if the same action is performed by two individuals, there is bound to be some disparity in the two visual scenes generated. Is this disparity also present in the mental simulations of the two observed actions?

If the motor representations activated by visuals of actions are actually accurate enough to preserve individual differences in performing the same action, then an interesting conclusion can be made.

fMRI studies of subjects viewing biological movements have shown that viewing an action produces activity in the same parts of the brain as performing the action. That is – the motor representation that constitutes the mental simulation of an action is actually the same motor representation activated to bring about the action.

Let us suppose that a person is viewing a scene of *themselves* performing an action – as in a video taken from third person perspective. Thus the motor representation activated by this visual is actually the *same motor representation that produced the action in the first place*. We can assume that if a particular system A (the motor system in this case) that performs an action is later used to analyse the action it produced, then this analysis will be more accurate than if system A is used to analyse an action produced by system B, which is similar, but not identical to system A. Thus we hypothesize that people will more accurately predict the consequences of actions performed by themselves than they will for actions performed by others. This hypothesis is tested using the following experimental procedure.

Method

I followed the methodology of the experiment conducted in [1], in which subjects performed a two-alternative choice task.

30 subjects did the experiment. They were female undergraduate students of IIT Kanpur.

In the first phase of the experiment, subjects were asked to throw darts at a dartboard which had been divided into two halves. They aimed either at the upper half or at the lower half. Each subject first practiced until they were able to hit the upper half of the board four or five times in a row, and then the lower half. After this the actual experimental trials started. Twelve successful trials were recorded for each subject, six of which were throws aimed at the upper half of the board.

The video clippings of the trial were then edited as follows. Each clip was cut off as soon as the dart left the hand of the thrower, such that only the thrower's movement and not the trajectory of the dart could be seen in the video. A total of 24 clippings were included in the final video of each subject, with each trial being used twice. The order of upper half throws and lower half throws was random. Between two clippings, the screen went blank for 7 seconds during which the subject gave her response. (See the sample video at **https://drive.google.com/file/d/0B5tFl7yJBEYENjBDNjRLdW1qcTg/view?usp=sharing.** The correct answers for the trials in the sample video are at the end of the report.**)**

Figure 1: An example last frame of a clipping.

The second phase was done one week after the recording of the trials. Subjects were arbitrarily divided into pairs and shown two videos: their own and their partner's. For each clipping, the subject predicted which half the dart had been aimed at. Importantly, the order in which the two videos were presented was the same for a subject and her partner. That is, if subject A viewed her own video and then her partner's video, the partner also viewed subject A's video before her own.

Some changes were made from the protocol followed in [1]:

1) A **sample video** was shown before the actual experimental trials. This is because a significant improvement in accuracy was seen from the first set of videos to the second.

Sample (6 trials) Self and Partner's videos (24 trials each)

Figure 2: Order in which videos were shown.

2) It was explicitly stated that the order of videos was completely random and they could even be all up/all down. This is because the first few participants started counting the number of ups/downs that 'should' be there.

Calculation of Accuracy

Based on the responses of each subject to the videos, two hit rates were calculated: one each for upper half throws and lower half throws.

u = fraction of upper half throws guessed correctly

l = fraction of lower half throws guessed correctly

Correct Answer / Response	Upper Half Was Aimed	Lower Half Was Aimed
Upper Half Was Aimed	Correctly identified upper half	Incorrectly identified as lower half
Lower Half Was Aimed	Incorrectly identified as upper half	Correctly identified lower half

Based on these two hit rates, the accuracy of the subject was calculated as the sensitivity d', a standard psychophysics measure for accuracy.

$$d' = z(u) + z(l)$$ [3]

$$z(.) = \text{Inverse Normal Distribution}$$

So for each subject, there were two d' values; one for their own videos (referred to as 'self-accuracy' henceforth) and one for the videos of their partner (referred to as 'other-accuracy' henceforth).

Results

Figure 3: A plot of 'other-accuracy' versus 'self-accuracy' for all the subjects. Though the average self-accuracy was higher than the average other-accuracy (Figure 4), the points were broadly distributed. The blue points represent subjects who saw their partner's video first; and red points are subjects who saw their own video first.

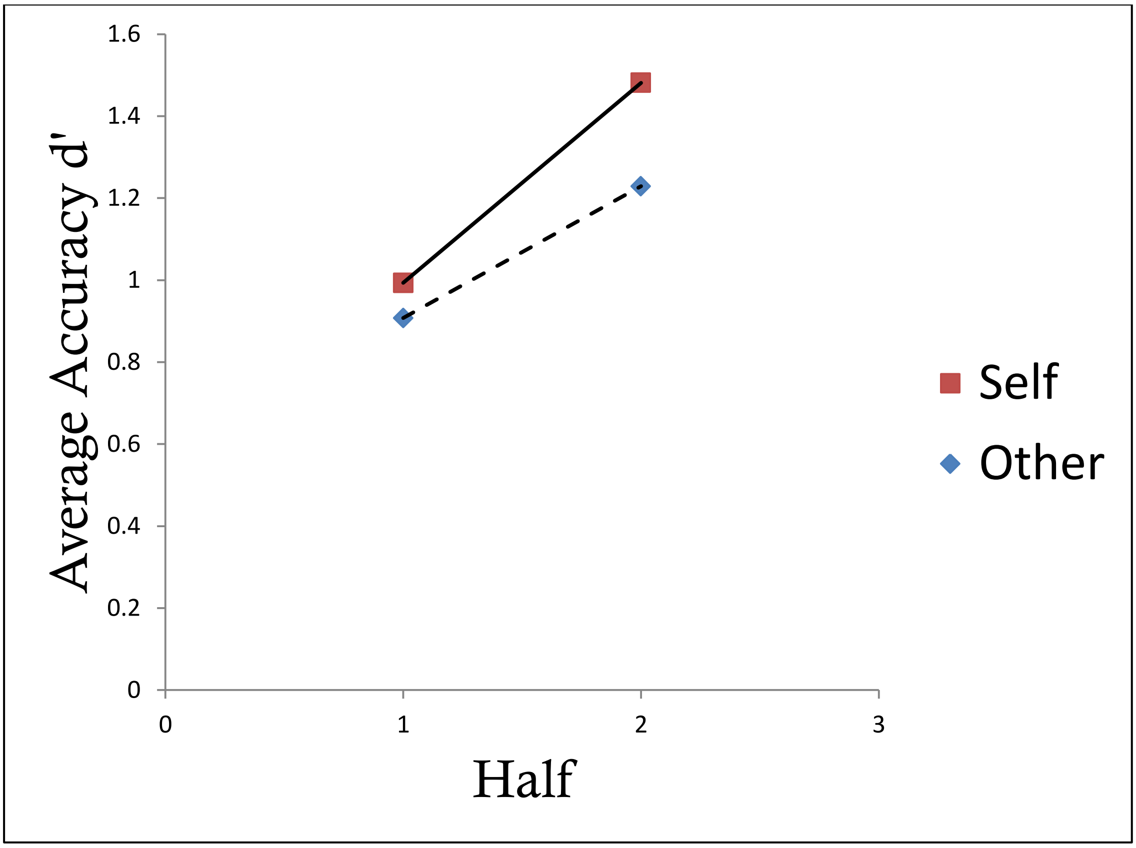

Figure 4: Average values of self-accuracy and other-accuracy for first half (i.e. first video seen) and second half (i.e. second video seen). In both halves, the self-accuracy is higher than the other accuracy. Further the increase in the self-accuracy between the two halves is 49.3%, while the increase in other-accuracy in the two halves is only 35%. Also for both sets of subjects, the accuracy in the second video seen is higher than that in the first video. However subjects who saw their own videos first showed a much smaller increase in accuracy in their partners videos (23%) than did subjects who saw their partner's video first (63%). This suggests that integration of perception representations with ones' inner motor representations takes time and improves with practice.

Discussion

The results are consistent with those of Knoblich et al.[1]. The difference between self-accuracy and other-accuracy is higher in the second half, i.e. in the second video seen (Figure 4). This suggests that integration of perception representations with ones' inner motor representations takes time and improves with practice. As the subjects watch the first video, they get accustomed to the task and accuracy increases in the second video (self- as well as other- accuracy). In the first video, subjects are mostly relying on third-person information (i.e. perceptual information they are getting from the third person view of the thrower). When watching the second video, the subjects begin to use integration of perceptual (third person) information and simulated motor commands (first person information). This integration is easier for self-videos as the system that generated the action is the same one being used to analyse it. Hence, the difference between self- and other-accuracy is more in the second video.

Note: In my experiment (unlike in [1]), each subject initially viewed a short sample video consisting of six trials, during which they were told to familiarise themselves with the task. It was anticipated that this would reduce the dramatic difference in accuracy seen in the second video, and the difference would be wholly accounted for by greater ease of interpreting ones' own actions by combining motor and perceptual information. However this was not the case; subjects still did better on average for the second video than the first.

Conclusions and Further Work

The basic hypothesis stands validated. Despite not being used to seeing themselves from a third-person perspective, people are better at judging their own actions than those of others.

Several points merit some thought. First, it is possible that along with the basic mirror system for judging the outcome of a movement or set of movements, there may be another system which predicts ones' *intention.* For example, a mechanism may be involved in which the subject's attention is coupled with that of the thrower based on the gaze of the thrower. Two subjects reported that they would actually follow the gaze of the person in the video and determine from this which half of the board she was aiming at.

Second, it is not clear whether the conscious and sub-conscious prediction of action outcomes employ the same system. Examples cited by various authors everyday judgements of perceived actions are often judgements that we make subconsciously, almost without being able to help it. For example, while watching a game of football, any viewer will spontaneously predict where a particular kick will land the ball. In contrast, this experiment and other similar experiments[5] explicitly ask the subject to *try* to make such a judgement. Perhaps the recruitment of the motor system to make perceptual judgements is slower (or does not occur) when mediated by conscious, top-down commands.

Lastly, it would be interesting to perform this experiment with subjects who routinely watch themselves from a 3D perspective, like actors or sportspeople. Perhaps there the difference between self-and other-accuracy would be sharpened.

References

[1] Knoblich, Günther, and Rüdiger Flach. "Predicting the effects of actions: Interactions of perception and action." *Psychological Science* 12.6 (2001): 467-472.

[2] Rizzolatti, Giacomo, et al. "Premotor cortex and the recognition of motor actions." Cognitive brain research 3.2 (1996): 131-141.

[3] Macmillan, Neil A., and C. Douglas Creelman. *Detection theory: A user's guide*. Psychology press, 2004

[4] Keysers, Christian, and Valeria Gazzola. "Hebbian learning and predictive mirror neurons for actions, sensations and emotions." Philosophical Transactions of the Royal Society B: Biological Sciences 369.1644 (2014): 20130175.

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Correct order of clippings in sample video: up, down, down, up, up, up