記号コミュニケーションシステムの形成過程におけるヒトのミラーニューロンシステムの役割を明らかにする脳波計測実験

EEG experiment for examining the role of human mirror system in the formation of symbolic communication systems

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Abstract

Regarding the role that mirror neuron system plays in the perception process of language or any communication systems, there are two competing views available: the *byproduct* view and the *causation* view. Though these two hypotheses suggest very different mechanisms, they are indissociable in traditional before–after experiment design. In this paper, a new experiment paradigm is proposed. By combining the EEG measurement of human mirror system activities and experimental semiotics approach, the competing two views become dissociable. This will not only help us to clarify the role of mirror system in the message perception process, but also enable us to learn more about the neural mechanisms for understanding each other, especially when we need to develop novel communication systems together.

Keywords — Experimental semiotics, Mirror neuron system, Mu rhythm suppression, Symbolic communication

1. Introduction

There is little doubt that the mirror neurons play an important role in both action production and understanding [22], and the overlap between intentional action perception and production in the human brain has been used to explain many aspects of social behaviour relate to intention understanding of others [23, 11]. Since this ability is closely related to pantomimic communications, the theory of human mirror system had also been linked to the evolution of language comprehension [4, 21]. Moreover, empirical evidence has been found for the relationship between the activation of this system and different levels of language comprehension, including the understanding of the words without somatotopic mapping [1]. However, concerning the role that mirror neuron system plays in the perception process of languages or any kinds of communication systems, there are two competing views that either suggest a *byproduct* role or a *causation* role, which are difficult to dissociate in traditional experiment paradigms.

In this paper, we propose a new experiment paradigm that provides an empirical approach to clarify the role of mirror system in the message perception process, by directly examining the formation process of symbolic communication systems.

2. Two hypotheses

According to *associative hypothesis*, the mirror neuron system should be considered as a *byproduct* of associative learning involved in social interaction, rather than an adaptation for action understanding [9]. This account regards sensorimotor experience as crucial to facilitate the development of mirror neurons, and is supported by data showing that, mirror activities are not fixed but can be developed by sensorimotor learning [2]. Accordingly, some suggest mirror system is involved in, but could not be necessary for speech and language perception [10].

On the other hand, *motor cognition hypothesis* claims that the ability to understand others' intentional behaviour relies primarily on the motor cognition that underpins one's own capacity to act [7]. This account is able to explain neonatal imitation when little sensorimotor experience could be gained [14], and gained support from evidences showing the correlation between autism disorder and dysfunction of mirror system [17]. Hence, human mirror system should be considered *causally* contribute to language processing and understanding, as suggested by Gallese and Iacoboni in [8].

These two hypotheses are indissociable in a traditional before–after experiment (i.e., to contrast the message perception induced mirror activities before the development of communication systems with those after that), since both view predict a low–high tendency while suggesting very different mechanisms. According to *byproduct* view, this tendency is predictable simply because the motor neurons gain the *mirror* property throughout the learning process. In contrast, while *causation* view suggests overall high mirror activities during communication due to their *necessity*, low activities are also predictable at the earlier stage which involves mainly *theorizing*, i.e., before the perception process becomes automatically and subconsciously such that *simulating* gets involved in [20].

Therefore, to clarify the role of mirror system of this process, new experiment paradigm is needed.

3. Coordination game

In order to dissociate the above two views, a possible approach is to look into the whole formation process rather than only two stages, since they expect different results concerning the dynamics of the mirror activities and the correlation with behavioral performance throughout the whole process. The problem is, however, that direct observation of the formation process of communication systems is rather difficult, if even possible. While language development takes a long time span, the typical learning process of symbol–meaning mapping is too short to be studied closely.

The experimental semiotics approach proposed by Galantucci [6] provides a practical solution for the above problem. A typical experiment paradigm conform to this approach is to employ pairs of participants to play a coordination game, in which the two players are required to act cooperatively to win the game. Meanwhile, the players are physically separated and only allowed to exchange messages in terms of drawings without predefined meanings. Since the use of common graphic symbols (e.g., letters, numbers, etc.) is prohibited, the players have to develop novel symbolic communication systems together from scratch by trial and error, which could be achieved in tens of trials. In this way, laboratory studies on the formation process of symbolic communication systems become possible.

Based on the same approach, Konno et al. [13] introduced a simplified version of coordination game. In this version, instead of freely drawing, the players have to pick up figures from a limited set. Though these figures have no predefined meanings, the players have to infer each other's intentions from them, i.e., to interpret messages composed of these meaningless figures as representations of abstract *movements* or *positions*. As a result, the resulted symbol systems could be analyzed quantitatively, enabling a clearer understanding of the dynamics of symbol usage in the formation process.

Nevertheless, to adapt this paradigm to a neurocognitive study, we suggest following alterations in order to dissociate the various types of cognitive processes involved in this game.

1. The mapping between messages and rooms should be reduced, preferably, to a one–to–one style, in which case a message can be considered as the representation of a *position*. To achieve this, a message should consist of only one figure, with only four options available, to encourage a direct mapping to one of the four rooms. Meanwhile, the options should be symmetric and abstract to avoid cognitive and linguistic bias. An example of the message set and a possible mapping with rooms is shown in figure 1.
2. We need to exclude the trials in which the message is thought not understandable for either receiver or sender. To find out the understandability of a message, the participants are expected to express their opinion through explicit feedback. While the feedback from a receiver represents the understandability for him/herself, that from a sender represents the *supposed* understandability for the receiver.
3. Due to the fact that mirror system could also be triggered by body actions and possibly by indefinite visual stimuli, the experiment should be designed in such a way that body actions and unnecessary visual information are prevented when interpreting received messages. For example, the received message could be separately shown for seconds before moving on to next step, while participants are required to keep still during this step.

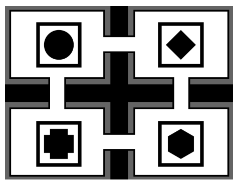

Figure 1 A possible mapping between messages and rooms

On the whole, the suggesting experiment paradigm provides a practical approach to examine the dynamics of behavioral performance in the formation process of communication systems in terms of symbols usage and successful rate, enabling the correlation evaluation against the activities of mirror neurons.

4. Mu rhythm suppression

We suggest to use the mu rhythm suppression to index the intensity of mirror neuron activities, since electroencephalogram (EEG) measuring of mu rhythm suppression has been conventionally used as an indirect but practical and reliable index [16, 17, 19, 5, 3], supported by both the comparison with functional magnetic resonance imaging (fMRI) studies [18], and also the empirical evidences from repetitive trans-cranial magnetic stimulation (rTMS) study [12].

Typically, the mu rhythm suppression is calculated as narrow-band (usually 8–13 Hz) event-related desynchronization (ERD) of signals collected from three electrodes covering sensorimotor cortices ($C3$, $C4$, and Cz) [17, 20]. However, due to the different sensitivity of suppressions in different bandwidths [5], the procedure suggested in [15] could also be applied as supplement, which provides time-frequency decomposition covering a wide range of frequency domain by employing event-related spectral perturbation (ERSP) analysis.

5. Prediction

Taking above together, we can then clarify the role of mirror system in the message perception process. Both indices of mirror activities upon message interpretation and behavioral performance are to be calculated in a moving average manner, which produces series of time-related values denoting the dynamics of the indices in the formation process. Besides, the correlation between these two indices can be evaluated to verify the hypotheses.

A possible results could be hypothesized as following. Firstly, the mirror activities should stay at a low level at first, as predicted both by *byproduct* view and *causation* view. Secondly, during the later *learning* stage, i.e., when the behavioral performance climbing up, the *byproduct* view suggests a same trend for mirror activities, while the *causation* view suggests a consistently high mirror activities after involving *simulation* (figure 2). Thirdly, *byproduct* view predicts a strong correlation between mirror activities and behavioral performance during this stage, while *causation* view predicts no such correlation since mirror system is always necessary for communication regardless of the learning outcome (figure 3). Finally, the mirror activities should get to a high level and stay still after the players can always win the game, as predicted by both views.

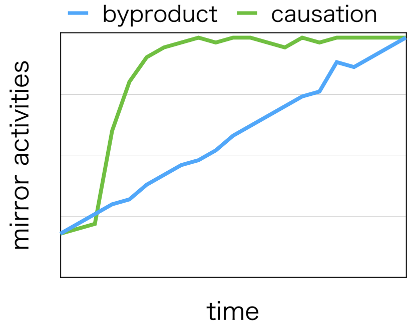

Figure 2 Hypothesized time-related mirror activities

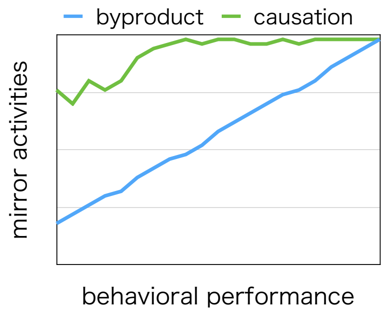

Figure 3 Hypothesized correlation between mirror activities and behavioral performance

Therefore, even though both *byproduct* view and *causation* view predict the same increase in the intensity of mirror system activities in a before–after experiment, they become dissociable in the present experiment paradigm.

In addition, the analysis results can not only dissociate the hypothesized two roles, but also reveal more details about the changes of mirror system activities according to behavioral performance. Chances are that unpredicted patterns of mirror activities would be discovered, which enable us to understand more about the features of mirror system and the relationship with learning and communication. Moreover, the results come from one participant can be compared against the other one of the same pair, allowing us to learn about the strategies they used *implicitly* when developing novel communication systems.

6. Summary

In summary, combining the EEG measurement of human mirror activities and experimental semiotics approach, the present study proposes a new experiment paradigm, in which the competing *byproduct* view and *causation* view are dissociable. Hence, the role of human mirror system in the message interpretation process can be clarified by evaluating the dynamics of mu rhythm suppression and the correlation with behavioral performance in the formation process of novel communication systems. This will allow us to understand more clearly about the neural mechanism for understanding each other when common communication systems are unavailable, which may be utilized to drive the development of more advanced artificial intelligence. Furthermore, the proposing experiment paradigm could possibly be used for examining other neuron systems related with learning and communication in addition to mirror system, serving as a practical approach to dissociate the neurocognitive elements that are indissociable in a traditional before–after experiment.

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