**Appendix**

**The Mirroring of Symbols: An EEG Study on the Role of Mirroring in the Formation of Symbolic Communication Systems**

**Guanhong Li, Takashi Hashimoto, Takeshi Konno, Jiro Okuda, Kazuyuki Samejima, Masayuki Fujiwara, Junya Morita**

***Letters on Evolutionary Behavioral Science***

**A1. Tasks in the single-player game (SG)**

The SG was designed to share the visual stimuli with the communicative coordination game (CCG) while involving a memory demand similar to that in the CCG without cognitive demands specifically related to communication. In the SG, to prevent the development of communication systems, participants played a single-player game with a computer program. The participants were told the truth that they were playing with a computer program that always selects figures and takes moves randomly. To involve a memory demand similar to that in the CCG, the participants were engaged in two non-communicative tasks: a *matching task* and an *identification task*.

The matching task is similar to the situation in the CCG when a participant firstly received a message and then replied. Instead of interpreting the communicative meaning of a message, the participant in the matching task would need to memorize the received figure and reply with the same figure. In each round, the computer program firstly selected a figure randomly from four alternatives and sent it to the participant. The figure would be shown on the participant’s screen for at least three seconds. The participant had been told that the received figure was randomly selected, and he would need to memorize that figure. The figure disappeared when the participant pressed a button. The participant would then need to select a figure from a pool of four alternatives to match the received one.

On the other hand, the identification task is similar to the situation in the CCG when a participant firstly sent a message and then received a message as a reply. Instead of interpreting the communicative meaning of a message, the participant in the identification task would need to recall the figure that he sent earlier in the same round and identify whether the received figure was the same or not. In each round, the participant would need to firstly select a random figure and send it to the computer program. A random figure would be selected by the computer program as a reply, which would be shown on the participant’s screen for at least three seconds. The participant had been told that the received figure was randomly selected, and he would need to recall the figure he sent previously and indicate that the received figure was the same/different by pressing a blue/green button, respectively.

Participants performed one of the two tasks in a sequence of six rounds and then switched to the other one. At the beginning of each round, the round number was shown, whose color indicated the type of task in the current round: a yellow number represented the matching task, while a green number represented the identification task. Eventually, a participant performed each task for 24 rounds, yielding a total of 48 rounds in the SG.

Similar to the flow in the CCG, after exchanging messages, the players in the SG would need to take a move to choose an ending room for their avatars. To prevent a consistent messages-rooms mapping from emerging, the computer player always chose a random room except for the diagonal one. The participants were told that the moves of the computer player were randomly chosen and instructed to take random moves as well. We instructed the participants to focus only on the matching/identification tasks instead of bringing their avatars to the same room with the computer player.

Participants performed well in the two tasks. The accuracy rate for most participants had been near perfect in both of matching task (M = 97.60%, SD = 6.11%) and identification task (M = 93.02%, SD = 16.60%), showing that the participants were well-involved in the memory demanding tasks. Meanwhile, the met-rate in the SG was at chance level (M = 24.58%, SD = 6.71%; chance level = 22.22%), showing that accidental symbolic communication systems were unlikely to exist.

**A2. Role-division in the CCG**

In the CCG, paired participants need to develop symbolic communication systems to communicate with each other. Better performance was achievable by successful communication of both denotative and connotative meanings, the latter of which refers to the implied meaning of a message related to the sending order. Critically, an optimal solution to the CCG is to send one’s own starting location when acting as the first sender, while sending the intended meeting location when acting as the second sender. With such role-division, even the same figure would imply different connotative meanings.

Different from the SG, the sending order was not predefined but determined by the participants in each round. The participant who sent the figure faster became the first sender, and then the other participant became the second sender, whose message-composing process would be interrupted by the display of the first sender’s message. It was impossible for both participants to send at the same time, since the computer server processed data from one side at a time. After a role-division, one expected to play the first sender role had to send figure as fast as possible. However, since the participant on the other side could just be faster, the expected role could not be guaranteed except that both sides reached some kind of agreement on that point, which was only observed in very limited cases.

**A3. Measuring mu-suppression**

We analyzed EEG data in MATLAB R2016a. The raw data were preprocessed with EEGLAB toolbox[[1]](#footnote-1), including 1-Hz high-pass and 70-Hz low-pass filtering, common average re-referencing, and independent-component-analysis (ICA)-based artifact removal via SASICA (Chaumon, Bishop, & Busch, 2015). We selected 4-s epochs (-1.5–2.5 s corresponding to all events) and performed time-frequency analysis with five-cycle wavelets in FieldTrip toolbox[[2]](#footnote-2).

In the present study, we used mu-suppression as an EEG index of the mirroring activity. Mu-suppression refers to the event-related desynchronizations (ERD) related to body movements or the motor imagery of movements, typically identified as the power suppression of alpha band (8–13 Hz) recorded from central electrodes covering the sensorimotor area (Pineda, 2005). Instead of applying the general setting, we measured the mirroring activity using a more specific setting with a narrower band and a more restricted area to focus on the mirroring specifically related to our task.

Firstly, we measured mu-suppression at the 10–12 Hz band instead of the broader 8–13 Hz band. Previous studies had found that power suppression of the lower alpha band (8–10 Hz) and the upper alpha band (10–12 Hz) are functionally dissociable: the former probably reflects general task demands and attentional processes, while the latter develops during sensory-semantic information processing and is task-specific (Klimesch, 1999; Pfurtscheller, Neuper, & Krausz, 2000). Since this study focuses on the information processing specifically related to the communicative task rather than general task demands and attention, the frequency band for measuring mu-suppression was set to the upper alpha band (10–12 Hz).

Secondly, we measured mu-suppression at the left central electrode site C3 instead of all central electrode sites. This is due to the hemispheric asymmetry found in the power suppression of the upper alpha band. Specifically, Pfurtscheller et al. (2000) found a contra-lateral upper alpha band power suppression during the preparation of body movements. In our study, all participants were right-handed and instructed to press button always with the right hand. Therefore, we expected the related mu-suppression to be left-dominant and should be measured at the left central electrode site C3.

**A4. Participants without significant mu-suppression in both games**

In the present study, the participants who showed no significant mu-suppression in both the SG and the CCG (Group-N, n = 5) were excluded from subsequent statistical analysis. Ideally, the Group-N could provide another baseline alternative to those who showed significant mu-suppression in both games (i.e., the Group-B). That is, to evaluate the direct and indirect effects of the mirroring, we could compare the performance of the Group-N against those who showed significant mu-suppression in either game only, namely, the Group-S and the Group-C, respectively.

However, such comparisons were inapplicable to our study. In fact, mirroring related mu-suppression had been found varied in healthy subjects (Höller et al., 2013). Accordingly, a lack of significant mu-suppression in both games is more likely to reflect the individual difference in mu-suppression rather than a lack of mirroring. Therefore, the Group-N could not be used as a reliable baseline for comparing with other groups to evaluate the mirroring effects.

**References**

﻿Chaumon, M., Bishop, D. V. M., & Busch, N. A. (2015). A practical guide to the selection of independent components of the electroencephalogram for artifact correction. Journal of Neuroscience Methods, 250, 47–63. (doi: 10.1016/j.jneumeth.2015.02.025)

Höller, Y., Bergmann, J., Kronbichler, M., Crone, J. S., Schmid, E. V., Thomschewski, A., Butz, K., Schütze, V., Höller, P., & Trinka, E. (2013). Real movement vs. motor imagery in healthy subjects. International Journal of Psychophysiology, 87, 35–41. (doi: 10.1016/j.ijpsycho.2012.10.015)

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. Brain Research Reviews, 29, 169–195. (doi: 10.1016/S0165-0173(98)00056-3)

Pfurtscheller, G., Neuper, C., & Krausz, G. (2000). Functional dissociation of lower and upper frequency mu rhythms in relation to voluntary limb movement. Clinical Neurophysiology, 111, 1873–1879. (doi: 10.1016/S1388-2457(00)00428-4)

﻿Pineda, J. A. (2005). The functional significance of mu rhythms: translating “seeing” and “hearing” into “doing.” Brain Research Reviews, 50, 57–68. (doi: 10.1016/j.brainresrev.2005.04.005)

1. <https://sccn.ucsd.edu/eeglab/> (last accessed on 13 November 2019) [↑](#footnote-ref-1)
2. <http://www.fieldtriptoolbox.org/> (last accessed on 13 November 2019) [↑](#footnote-ref-2)