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

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The underlying mechanism of communicative behavior in both humans and other animals was proposed to be “mirroring,” which refers to the similar neural pattern during action production and action observation. Nevertheless, the role of mirroring in human communication remains a puzzle, since human communication systems can take a symbolic form not relying directly on body action. We hypothesized that mirroring contributes to the formation of implied meaning, i.e., connotation, in symbolic communication. We used electroencephalography to study human brain mirroring activity, indexed by mu-suppression measured in the 10–12 Hz band over the left-central area, firstly in a non-communicative single-player game then in a communicative coordination game. We evaluated the effect of the mirroring activity in each game upon the performance of symbolic communication in the communicative game. We found that the participants showed significant mirroring in both games performed better on connotation-forming than those who showed significant mirroring in the communicative game only. Our results suggest that imagining signaling action in both communicative and non-communicative contexts could be a key to connotation-forming in symbolic communication.

Keywords
communicative coordination game, electroencephalography, mirroring, mu-suppression, symbolic communication

Introduction

In the brain of humans and other primates, mirroring activity refers to the similar neural activity during action production and action observation (Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010; Rizzolatti & Arbib, 1998). Mirroring was supposed to be the core of the neural mechanism that underlies communicative behavior in humans and other animals (Arbib, 2005; Rizzolatti & Arbib, 1998). However, does mirroring also play a role in human symbolic communication, where the forms of symbols are not bound to body action? The potential involvement of mirroring in the formation of symbolic communication systems was suggested by Li, Konno, Okuda, & Hashimoto (2016), but the role of mirroring in that process has not been well understood.

According to Tomasello (2003), the meaning of any symbols must base on their use in social interaction. Therefore, even though a symbol’s denotation (i.e., the literal meaning) could lie beyond the physical world, its connotation (i.e., the implied meaning inferred from context) could only be formed through social interaction, where intention-reading of body action plays a key role. As intention-reading of body action is proposed as being based on mirroring (Iacoboni et al., 2005), we hypothesized that mirroring contributes to the formation of connotation, which should be closely related to the intention of sending a message, in symbolic communication in two ways. Firstly, upon receiving a symbolic message in a communicative context, imagining the signaling action for sending that message may directly benefit the understanding of the sender’s intention. We call this direct effect. Secondly, the tendency to automatically simulate others’ actions has been related to social alignment, which provides a foundation for intention-sharing (Hasson & Frith, 2016). Upon receiving a symbol in a non-communicative context, a tendency towards imagining the signaling action may fundamentally benefit intention-sharing in the future symbolic communication. We call this bias effect. Using mu-suppression of electroencephalography (EEG) power as an index, this study examined mirroring activity in communicative and non-communicative contexts employing a communicative coordination game (Li et al., 2016). We measured the performance on the formation of denotation and connotation in the communicative context. We predicted that mirroring in both contexts yields better connotation-forming performance than non-communicative-only and communicative-only mirroring, demonstrating the direct and bias effects, respectively.

Methods

The communicative coordination game (CCG)

We used a simplified CCG, an experimental paradigm to

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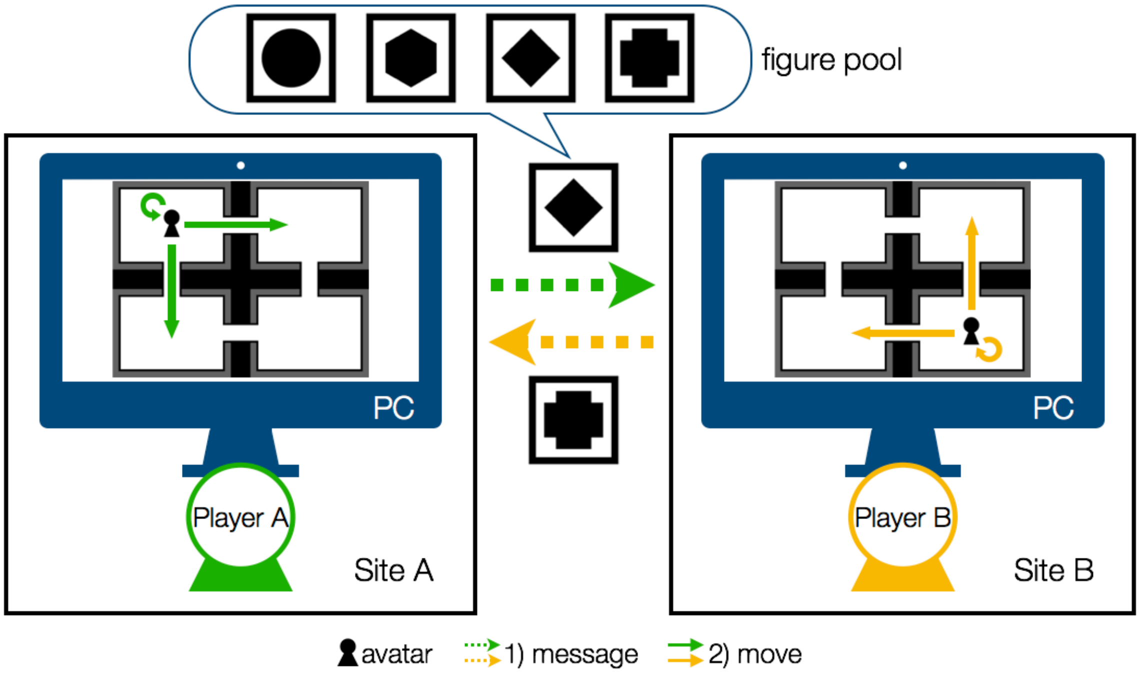

Figure 1. The communicative coordination game.

study the formation of symbolic communication systems in the laboratory proposed by Galantucci (2005) and revised by Konno, Morita, & Hashimoto (2013). This computer game has multiple rounds and a setting with four virtual "rooms" (Figure 1). Paired players, physically separated at two sites, must coordinate their moves to bring their avatars to the same room. Players start each round at random positions that are invisible to each other. There were 12 possible starting positions (Figure S1) for placing two avatars in different rooms. Once-per-round, each player selects one figure from four alternatives to send a message which is immediately displayed on the other's screen, and then takes a move (horizontal, vertical, or stay). The sending order was determined by the players. At the end of each round, they are informed about the result (met/unmet) and the starting and ending positions. A successful symbolic communication system would consist of denotations, namely, one-to-one mappings between figures and rooms; and connotations, namely, the implication of a message (the starting location or the intended meeting location) according to the sending order as a context (see Appendix A2).

Experimental design and procedure

We recruited 40 individuals (all male, right-handed; mean age: 22.1 ± 2.3 years). For reducing the influence of individual differences, the final sample included 35 participants with significant mu-suppression in either game (see Appendix A4). Firstly, as the non-communicative context, all participants individually played a single-player game (SG) against a randomizer (computer program) for 48 rounds, involving a memory demand similar to the CCG but no communication-specific demands (see Appendix A1). Then, as the communicative context, participants played 60 rounds of the CCG in pairs. In both games, to select a figure and a move, participants repeatedly pressed a button to loop through all the options. The figure or the move was determined after 3-s from the last button-pressing. For every 12 rounds, each of the 12 starting positions appeared only once, and the order of appearance was randomized.

Behavioral performance analysis

We evaluated participants' final performance in the CCG by met-rate, denotation score, and connotation score; all averaged over the last 12 rounds to cover all possible starting positions. Met-rate is the percentage of the rounds in which the players met in the same room. The denotation and connotation scores for each round were estimated based on a Bayesian probabilistic model developed by Samejima et al. (2016). Denotation score concerned the trend towards a one-to-one mapping between rooms and figures. Connotation score concerned the probability of referring to a starting location when sending firstly, but to an intended meeting location when replying.

EEG recording and analysis

Following the extended 10-20 placement system, we collected 32-channels EEG recordings[1] from two players simultaneously. We examined the EEG signal related to two events. The Fixation event corresponded to the beginning of each round when showing a fixation cross on the screen for 2-s. The Receiving event corresponded to the displaying of a received message, which was visible for 3-s. Participants were asked to refrain from bodily movements during these time windows.

We evaluated participants' mirroring activity in the Receiving event using trial-by-trial mu-suppression (see Appendix A3). To focus on task-specific processing, we measured mu-suppression as the log ratio of 10-12 Hz band power over the left central electrode site C3, relative to the Fixation baseline. After visually checking the averaged power spectrum, we limited the range of latency to 0.5-1 s

1 Brain Products system (http://www.brainproducts.com/, last accessed on 13 November 2019)

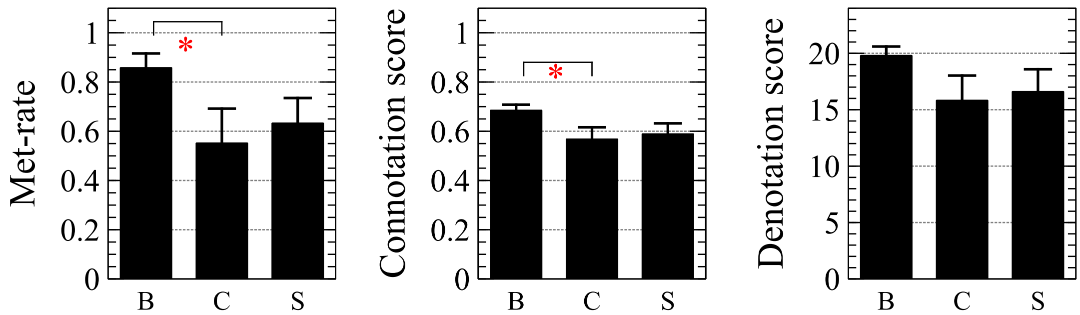

Figure 2. Performance of three groups in the communicative game (*n* (B) = 17, *n* (C) = 8, *n* (S) = 10; *Bonferroni-corrected-*p* < .05; error-bars represent standard errors).

to include only predominant power suppression.

For each participant and each game, we excluded the trials with power values exceeding two standard deviations. For the remaining trials, we conducted single-subject-level statistics (Höller et al., 2013) using non-parametric permutation tests ($N = 2000$) to find out the participants with significant ($p < .05$) mirroring activity in each game.

Results

We grouped participants ($N = 35$) according to the significance of mirroring activity in two games: significant in both games (Group-B, $n = 17$), in CCG only (Group-C, $n = 8$), in SG only (Group-S, $n = 10$). Figure 2 plotted the final behavioral performance in the CCG of Group-B, C, and S.

One-way between subjects ANOVAs found significant ($p < .05$) effects of mirroring on met-rate (F (2,32) = 3.404, $p = .046$) and connotation score (F (2,32) = 3.627, $p = .038$) but not on denotation score (F (2,32) = 2.258, $p = .121$) for the three groups. Using independent-samples *t*-tests with Bonferroni-correction for *p*-values, we conducted follow-up planned comparisons: a contrast between Group-B and S to estimate the direct effect of mirroring on met-rate and connotation score, and a contrast between Group-B and C to estimate the bias effect. Contrasting Group-B with Group-S found no statistically significant effect on met-rate ($M_B = .858$, $SD_B = .237$; $M_S = .633$, $SD_S = .322$; t (25) = 2.081, corrected-$p = .096$) and connotation score ($M_B = .685$, $SD_B = .096$; $M_S = .589$, $SD_S = .135$; t (25) = 2.154, corrected-$p = .082$), showing a lack of direct effect of mirroring. Meanwhile, contrasting Group-B with Group-C found that Group-B performed significantly better than Group-C on met-rate ($M_C = .552$, $SD_C = .396$; t (23) = 2.421, corrected $p = .048$) and connotation score ($M_C = .568$, $SD_C = .135$; t (23) = 2.508, corrected-$p = .039$), showing a significant bias effect of mirroring.

Discussion

We expected to find both direct and bias effects of mirroring on connotation-forming in symbolic communication. We found a significant bias effect of mirroring, while the direct effect was not statistically significant. There were no statistically significant differences in the connotation scores, denotation scores, or met-rates between the Group-B and S. Although the Group-B also showed significant mirroring in the communicative context (i.e., CCG-mirroring), the performance was not significantly different from the Group-S, who showed non-communicative-only mirroring, demonstrating a lack of the direct effect of mirroring. CCG-mirroring probably reflects the mirroring of signaling action upon receiving messages in a communicative context. Typically, the mu-suppression was related to performing or imagining body movements (Höller et al., 2013). To send a message in the CCG, participants had to press a button to loop through figures, in which case button-pressing became a signaling action. Upon receiving a message, although the sender's signaling action was invisible, the receiver may mirror that action, which could manifest significant mu-suppression. Iacoboni et al. (2005) proposed that mirroring is directly involved in intention-reading of the observed action. However, we found no evidence for the direct contribution of mirroring in the communicative context on intention-reading in symbolic communication without visible signaling action.

We found that Group-B outperformed Group-C on both connotation score and met-rate, but not on denotation score. Compared to the Group-C, who showed communicative-only mirroring, the Group-B that also showed significant mirroring in the non-communicative context (i.e., SG-mirroring) performed significantly better on connotation-forming, demonstrating a bias effect of mirroring. SG-mirroring probably reflects the tendency towards the imagination of signaling action upon receiving messages in a non-communicative context. Upon receiving a message, participants knew that it was randomly generated by a computer program and thus could not be linked to signaling action. However, participants may still perceive these messages as communicative signals, as if they were selected and sent by someone. The participants who had a strong tendency to "mirror" the imagined signaling action even in a non-communicative context would show significant mu-suppression, which could be manifested by imagining body action (Höller et al., 2013). Therefore, our results suggest that the tendency to imagine signaling action could eventually facilitate intention-sharing in symbolic communication, fundamentally benefiting connotation-forming in symbolic communication.

Alternatively, our results could be interpreted as the effects of attention or memory instead of mirroring, since the frequency-band of mu-suppression overlapped with occipital alpha power suppression, which had been related to selective attention (Foxe & Snyder, 2011) and memory (Hanslmayr, Spitzer, & Bauml, 2009). However, we examined occipital power suppression and found no significant bias effect on met-rate, denotation score, or connotation score (Figure S2). Hence, attention or memory could not explain the observed effects.

In conclusion, this study suggests that the formation of connotation in symbolic communication benefits from mirroring in a non-communicative context, which probably reflects the tendency to imagine signaling action for producing symbolic messages. Peeters et al. (2009) suggested that a unique feature of the mirror system in humans is the specific activation corresponding to tool action. The evolution of this feature in the human mirror system might provide a neural substrate for the emergence of symbolic communication, where the symbols are used as a tool for communication. This idea is consistent with our results, although future works are required to provide further evidence and to understand the underlying mechanism.

Acknowledgments

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Supplementary Material

Electronic supplementary material is available online.

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