Symbol communication systems integrate implicit information in coordination tasks

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Summary

In order to study the formation of communication systems through interactions, we conducted an experiment in which pairs of participants attempted to complete a coordination task through an exchange of messages composed of a set of abstract figures. At the beginning of the interaction, there was no shared rule for the meanings and usage of the figures as symbols. We observed that the participants completed the coordination task by forming communication systems. We suggested that communication systems can be developed effectively if participants have implicit behavioral tendencies, such as using small number of symbols, meeting at a usual place, and smooth turn taking.

1 Introduction

Humans express and share many meanings using symbols in communication. Meanings change according to situations, contexts, and intentions even if the symbols used are the same[1]. Much information is also expressed implicitly by behavioral patterns, such as gaze, gestures, and turn taking. It is important to clarify the correlation between implicit information and explicit symbol usage in order to understand symbolic communication systems[2]. However, it is difficult to conduct a controlled experiment that reveals this correlation because the existing symbol system, namely, language, is so established and complex that it becomes difficult to observe the formation process of a linguistic communication system.

Galantucci[3] conducted an experiment to observe the formation of symbol communication systems in which participants communicated through a medium that restricted the use of standard communication means such as utterances and letters. He observed that implicit information was conveyed through routine behavior and the temporal order of messages were built into communication systems. This indicates an advantage of the experimental approach with the design of an artificial communication medium. We can observe the effects of implicit, that is, non-linguistic, behavior on the formation of symbol communication systems under a restricted communication medium.

However, this previous research failed to provide adequate and clear evidence for the effectiveness of behavior that conveys implicit information on the formation of symbol communication systems. Therefore, we designed an experiment to analyze implicit behavior quantitatively and to verify its effectiveness with regard to the formation of symbol communication systems. In this experiment, a pair of participants engaged in a coordination task through an exchange of messages composed of a set of abstract figures, where no rule regarding their usage was shared. We expect a significant correlation between task performance and certain behaviors to identify whether implicit information is conveyed.

2 Task

We used a coordination game that was modified from the previous study[3] to obtain quantitative data concerning implicit behavior such as using symbols, forming routine behavior, and the temporal structure of message exchange. The game environment contained two agents, each controlled by two players, and four intercommunicating rooms (Figure 1). The agents could not move to diagonal rooms. The game was composed of several repeated rounds. At the beginning of each round, the agents were randomly located in two different rooms. Each player, who was unaware of the location of the other, aimed to bring her/his agent

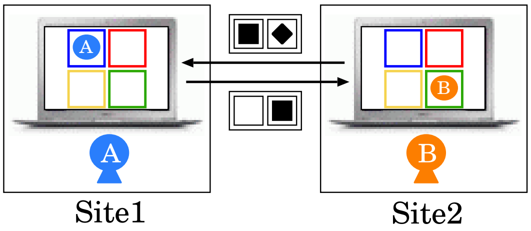

Figure 1: Experimental environment. The player controls her/his own agent using laptop computers located at different sites. She/he coordinates with the agents to bring them into the same room.

to the same room. To accomplish this, each player could send a symbolic message to the other before moving the agent.

In Galantucci's experiment, players exchanged handwritten distorted graphics as messages, and they could exchange the messages as many times as needed in a round. This design makes the frequency of symbol use and the correlation between messages and behavior unclear. In the coordination game, we assumed that implicit information would be conveyed with some behavioral tendencies, such as a bias toward using a specific set of symbols, a bias toward moving to a specific room, and smooth turn taking. To measure the behavioral tendencies quantitatively, we designed the following task procedure.

First, a message was created by composing two figures, such as , using six alternatives, , , , , , and . The meanings and usage of the figures were not shared among participants in advance.

Second, the players exchanged each message once per round. After the exchange, they separately decided the destination of the agents' moves, including keeping the agents in the rooms they originally were in. The initial location and the result of the movement of each agent were displayed on the both players' screens at the same time. This design connected the messages clearly with the behavior.

Finally, the messages were displayed on the partners' screen immediately after they were sent. Therefore, the second sender could see the first sender's message and manage turn taking. Temporal differences in the message exchange indicated a degree of smooth turn taking.

3 Method

Participants: Twenty-one dyads, consisting of graduate students and university researchers, voluntarily participated in this study. They were aged between 22 and 37 years ($mean\ age = 25.5$, $SD = 3.0$).

Apparatus: The dyads engaged in a coordination game from different sites using interconnected laptop computers[1] (Figure 1).

Procedure: The experimental procedure consisted of one trial session and three test sessions. In the trial session, the participants attempted to develop a communication system within a time limit of one hour. If they moved to the same room, the players got two points or else they lost one point, but the scores did not drop below zero. When the score reached fifty points, the trial session was interrupted.

The test sessions were conducted subsequently. TEST1 restricted any message exchanges. In TEST2, messages were displayed on the partners' screens after both the players had sent their messages. Thus, turn taking was prevented in this test session. TEST3 was conducted under the same condition as the trial session. From the difference in performances between TEST1 and TEST3, we confirmed the effectiveness of symbol use. We also confirmed the effectiveness of turn taking from the difference between TEST2 and TEST3. Each test had twelve rounds that contained all combinations of two agents' locations. The order of appearances were set at random.

4 Results

4.1 Performances in the trial session

In the trial session, fourteen of twenty-one pairs (66.7%) scored 50 points within one hour. A number of rounds averaged 54.8 ($SD = 25.1$). An average of the time was 40 min. 41 sec. ($SD = 16$ min. 25 sec.). Figure 2 shows the concordance rate of destinations of each pair in the last 12 rounds in the trial session ($mean = 0.72$, $SD = 0.22$). We assume that this rate reflects the performance of the communication system each pair built. We measured the performances of the communication

[1] Each laptop computer exchanged information through a server, using a web browser (Firefox). The server–client system was a web application with SQL database and PHP.

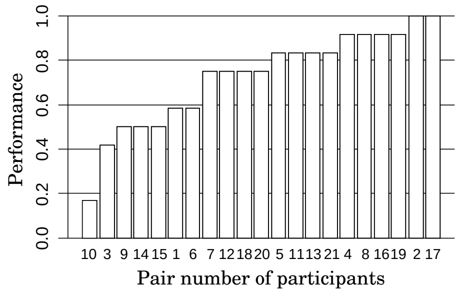

Figure 2: Performances measured by the concordance rate of the moves in the last 12 rounds in the trial session.

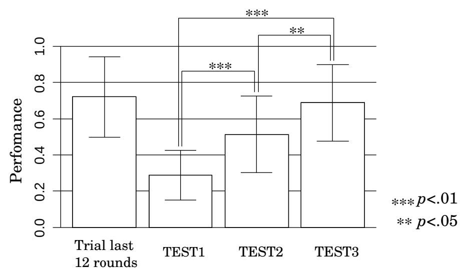

Figure 3: Averages of concordance rates of the moves in the trial and test sessions. Error bars show the standard deviation.

systems by the concordance rate of the moves coordinated thereafter. Almost all participants successfully completed the coordination task because the performances surpassed the expectation value of this game, which was 0.22 (two times match in nine rounds).

4.2 Performances in the test session

Figure 3 indicates the average performance scores of the three tests. We conducted a one-way within-subject analysis of variance (ANOVA) using test type as an independent variable to assess the features of the formed communication systems[2] and found the significant main effect of the task ($[F(2, 19) = 31.66, p < .01]$). Furthermore, multiple comparisons (Tukey's HSD test) revealed significant differences between TEST1 and other test scores ($p < .01$), suggesting that the players could form communication systems with effective symbol usage. We also found a difference between TEST2 and TEST3 ($p < .05$), confirming that players developed communication systems including an effective management of turn taking.

4.3 Correlations between implicit behavior and performances

We investigated correlations between the performances of the three tests and the behavioral indexes of the trial session to detect implicit information related to the formation of symbol communication systems. We analyzed three behavioral indexes: bias towards using a specific set of symbols, B_{Sym}, bias towards moving to a specific room, B_{Pos}, and temporal differences in message exchange, TD_{Mes}.

The former two indexes were calculated by the geometric mean of two Kullback–Leibler divergences between two probability distributions P and E.

$$B = \sqrt{D_{\mathrm{KL}}(P_1||E) \cdot D_{\mathrm{KL}}(P_2||E)} \ ,$$
$$D_{\mathrm{KL}}(P_i||E) = \sum_{n=1}^{N} P_i(n) \log \frac{P_i(n)}{E} \ , \qquad (1)$$

where P_i was the probability distribution of symbol use or the destination rooms of the player i; E was the uniform distribution, and N was the number of bins of the probability distributions[3]. If the distribution P deviated from the uniform distribution, the index would increase.

The latter index, TD_{Mes}, was calculated as follows.

$$TD_{\mathrm{Mes}} = \frac{1}{N_r} \sum_{r=1}^{N_r} |t_{m_1}(r) - t_{m_2}(r)| \ , \qquad (2)$$

where N_r denoted the number of rounds and t_m denoted the time that had elapsed since a message was sent to the partner from the beginning of the round. This index measured temporal differences between the first and the second transmission of messages.

We calculated Pearson's product-moment correlations between the three indexes and the performances in the three tests (Table 1). Consequently,

[2] Pair 5 was excluded for failure in the test session because a player of the pair unilaterally changed the rules from the trial session.

[3] For the distribution of symbol use, $E = 1/6, N = 6$. For the distribution of destination rooms, $E = 1/4, N = 4$.

Table 1: Correlation results of the performances with three behavioral indexes

index	TEST1	TEST2	TEST3
B_{Sym}	0.005	0.479^{**}	0.292
B_{Pos}	0.620^{**}	0.441^{*}	0.307
TD_{Mes}	-0.367	-0.602^{**}	-0.222

Note. $^{*}p < .1;^{**}p < .05$ indicates significant correlations.

first, we found significant correlations between the performance in TEST1 and B_{Pos}. The index indicated that the players had a bias of routine movement behavior such as moving upward or to the left side. If the players had this bias, they would move to the same room without an exchange of messages. Second, we found significant correlations between the performance in TEST2 and the three behavioral indexes. Third, these behavioral indexes did not correlate with the performance in TEST3. We discuss these results in the next section.

5 Discussion

The three indexes, which showed the bias towards using a specific set of symbols, the bias towards moving to a specific room, and the temporal differences in message exchange, indicated a significant correlation with the performance in TEST2, in which turn taking was prevented.

This result provides the basis for three general conclusions. First, the bias toward using a specific set of symbols indicates that both the players' messages are composed of small number of symbols. This bias implies that the messages would not convey excess information, thus causing a misunderstanding. Second, the index of the bias toward moving to a specific room indicates that both the players move to a usual place. The behavioral tendency will probably convey implicit information to help inference in a situation where turn taking is restricted in TEST2. Finally, the index concerning a temporal structure of messaging negatively correlated with the performance in TEST2. This indicates the relation between immediate responses and the formation of a symbol communication system.

Surprisingly, we could not find any correlation between the performance in TEST3 and the three behavioral indexes. To achieve the best performance in TEST3, participants need to divide roles in communication. For example, in the case of pair 2, one player sent a message representing her/his current position and the other decided on a destination where both of them could meet. We need to consider the type of behavior that contributes to form a communication system integrating the role-sharing strategy. The results presented in Table 1 suggest that the development of the role-sharing strategy in communication is independent from the three implicit behaviors we examined.

6 Conclusions

This study explored how people initiated coordination by forming communication systems under a condition where no rule on symbol usage was shared. The results suggest that communication systems can develop effectively if participants have implicit behavioral tendencies, such as using small number of symbols, meeting at the usual place, and smooth turn taking. However, these behavioral tendencies did not contribute to the division of roles using turn taking. In the future, we will explore factors influencing role division in communication systems.

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