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# Does human imitate successful behaviors immediately?

Zhao-Jin Xu[1] & Lian-Zhong Zhang[2,3*]

1. School of Science, Tianjin University of Technology, Tianjin 300384, China

2. School of Physics, Nankai University, Tianjin 300071, China

3. Center for Transnational's Studies of Nankai University, Tianjin 300071, China

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[*] Corresponding author
E-mail: zhanglz@nankai.edu.cn

# [Abstract]

**The emergence and abundance of cooperation in animal and human societies is a challenging puzzle to evolutionary biology. Over the past decades, various mechanisms have been suggested which are capable of supporting cooperation[1-15]. Imitation dynamics, however, are the most representative microscopic rules of human behaviors on studying these mechanisms[8-24]. Their standard procedure is to choose the agent to imitate at random from the population. In the spatial version this means a random agent from the neighborhood. Hence, imitation rules do not include the possibility to explore the available strategies, and then they have the possibility to reach a homogeneous state rapidly when the population size is small[4,10]. To prevent evolution stopping, theorists allow for random mutations in addition to the imitation dynamics[10,21-24]. Consequently, if the microscopic rules involve both imitation and mutation, the frequency of agents switching to the more successful strategy must be higher than that of them transiting to the same target strategy via mutation dynamics. Here we show experimentally that the frequency of switching to successful strategy approximates to that of mutating to the same strategy. This suggests that imitation might play an insignificant role on the behaviors of human decision making. In addition, our experiments show that the probabilities of agents mutating to different target strategies are significantly distinct. The actual mutation theories cannot give us an appropriate explanation to the experimental results. Hence, we argue that the mutation dynamics might have evolved for other reasons.**

# [Text]

Evolutionary game theory is the theory of dynamic adaptation and learning in repeated games, and it describes the systems where the agents receive payoffs from the interaction with others[25,26]. Hence, a model in evolutionary game theory is made complete by postulating the dynamics that describe how the agents update their strategies in the decision stage[4]. By far the most representative evolutionary dynamics on studying human behaviors are imitation, the act of copying or mimicking the actions of others. The essence of imitation is that who imitates whom with what probability. The standard procedure is that an agent (e.g., x) who has the opportunity to update its strategy compares its payoff with that of another agent (e.g., y), randomly chosen from the population[9,10,21]. Depending on the payoff comparison, agent x either sticks to its original strategy or imitates the strategy of agent y. Agent y only plays a benchmark role and its strategy remains intact. In spatial version, agent y is randomly chosen from agent x's immediate neighbors[8,11-15]. Obviously, imitation dynamics cannot introduce the available strategies which are not played by agent x and y. However, behavioral experiments[6,7] imply that humans have higher possibility to explore new strategic options in social interactions. The common solutions provided by theorists are to combine imitation and mutation dynamics linearly[10,21-24]. That is, the agents not only imitate others but also act emotionally.

Traditionally, public goods game (PGG) can be considered as a very useful game theoretical model to qualitatively study the problem of maintaining cooperation in a group of unrelated individuals[5-11,21,27-29]. In our model, the voluntary PGG on square lattice with periodic boundary conditions[8,11] is considered. Each player is confined to a site on the lattice and interacts only with its local neighborhood. In each decision round, the players either can refuse to participate (as a loner L), and will then obtain a small fixed payoff, or can join the PGG. In the latter case, they either can contribute some fixed amount to a common pool (as a cooperator C), or can make null contributions (as a defector D). The payoff a participant achieves in PGG depends on its own strategy as well as the composition of its local neighborhood.

We investigate the consequences with 150 students in 6 sessions of 25 students that played the spatial voluntary public goods game for 40 consecutive rounds. The students observed the introduction to the game including an example on a large screen. They were told that they would have a starting account of 5 CNYs (China Yuan) and would interact anonymously by means of computer screens. In each round, they could choose simultaneously between three available options, which were presented in a neutral language. After each round, they were informed about the choices and payoffs of its neighbors as well as its own payoff in the last round. The experiment was computerized and conducted by using the software z-tree[30]. There were ten practice periods before the actual experiment in order to make the players familiar with the procedures.

For later convenience of discussion, we let $\overline{\Omega}_x$ (i.e., unit of x) denote the agent x and its 4 immediate neighbors, $\omega(s)$, where $s \in (C, D, L)$ represents the neighbors' strategy in the last round, denote the probability an agent switching to the other strategy $s$ which was played by its neighbors, $\omega_B(s)$ denote the probability agent x switching to the other strategy $s$ which performed best on average in $\bar{\Omega}_x$, $\omega_W(s)$ denote the probability agent x switching to the other strategy $s$ which performed worst on average in $\bar{\Omega}_x$, $\mu(s)$ denote the probability an agent switching (mutating) to the other strategy $s$ which was not played by its neighbors respectively.

Although imitation dynamics have a wide class of microscopic update rules, they all assure that strategies which perform better on average in the neighborhood have higher chances to be imitated than those which perform worse on average do[8,11-15]. To verify this prediction, we examined the probabilities of an agent transiting to the other strategies in our experiments (see Fig. 1). We found that $\omega(s)$ is significantly lower than $\omega_B(s)$ (P=0.006, n=18; Wilcoxon signed rank test, Z=-2.75, two-tailed), and significantly higher than $\omega_W(s)$ (P<0.001, n=18; Wilcoxon signed rank test, Z=3.47, two-tailed). This implies that the individual behaviors are strongly affected by the last-round payoff. The players are more likely to choose the strategy which performed better in the last round, which seems to accord with the prediction of imitation dynamics. However, most of the imitation dynamics[8-10,14-21] do not allow for an inferior strategy to replace a more successful one, i.e., imitation only occurs if the target strategy is more successful. This is significantly different from the results of our experiments in which agents frequently transited to the strategy whose average payoff is lowest in their own units (see Fig. 1.). Hence, we argue that investigating the evolution of human cooperation with imitation dynamics only might be inappropriate.

In fact, mutation took place frequently in our experiments. It is known that an agent cannot switch to the strategy which is not played by its 4 immediate neighbors via imitation dynamics. For example, agent x will not transit to C or D strategy via imitation if the agents in $\bar{\Omega}_x$ are all loners. We examined the case where all the players in $\bar{\Omega}_x$ were loners. We found that such case took place 205 times in all the six sessions of our experiments, 21.0% of agent x transited to C strategy, and 26.8% of agent x transited to D strategy. To be precise, we have also examined the rates agent transiting to strategy C or D via mutation (see Fig. 2), and found that the average mutation rates in our experiments are significantly higher than 50% (P=0.011, n=18; Wilcoxon signed rank test, Z=2.54, two-tailed). This evidence further indicates that only imitation dynamics cannot provide a reasonable explanation to the behaviors of human decision making in social interaction. That is, the future study of evolution of human cooperation should include a strong focus on the point why the individuals mutate and how.

Theorists solved this problem by adding mutation rates to the imitation dynamics[10,21-24]. Consequently, the probability an agent switching to the other strategy is the sum of probability agent transiting via imitation and mutation dynamics. That is, this dynamics (involving imitation and mutation) will predict that $\omega_B(s) > \mu(s)$ because the probability an agent imitating the strategy which performed best on average in its own unit must be greater than zero, and that $\omega_W(s) \approx \mu(s)$ because the probability an agent imitating the strategy which performed worst on average in its own unit is close to zero. To verify it, we examined the probabilities agents transiting to the other strategy via mutation (see Fig. 3). We found that $\omega_B(s)$ approximates to $\mu(s)$ (P=0.187, n=18; Wilcoxon signed rank test, Z=1.32, two-tailed), and $\omega_W(s)$ is significantly lower than $\mu(s)$ (P=0.002, n=18; Wilcoxon signed rank test, Z=-3.08, two-tailed). The dynamics combining imitation and mutation perhaps can explain the consequence $\omega_B(s) \approx \mu(s)$ with agents imitating the strategy whose average payoff are the best in their units with a very small probability, but they cannot give us an appropriate reason why $\omega_W(s)$ is lower than $\mu(s)$.

Furthermore, our experiments show that the probabilities agents mutating to different target strategy are significantly distinct (see Fig. 3). Precisely, we found that $\mu(L)$ is the highest (45.09 ± 6.74%), $\mu(D)$ takes the second order (31.61 ± 3.59%), and $\mu(C)$ is the lowest (22.60 ± 4.91%). This implies that general mutation dynamics, which suggest that agents will explore the other strategy randomly, seem to be maladaptive. Perhaps non-uniform mutation dynamics could fit the experiment results by setting $\mu(s)$ for each target strategy, but they cannot explain why the agents are more likely to be loners than to be cooperators or defectors.

Why is the tendency of an agent's options for different target strategies distinct? Surprisingly, we found that the probabilities agents mutating to various target strategies are similar to the average frequencies of the three strategies (45.77 ± 6.37% loners; 31.20 ± 3.03% defectors; 23.03 ± 3.82% cooperators). The intuition behind this is that the players in our experiments might play mixed strategies, which are probability distribution over pure strategies, and come up with one of their feasible actions with a certain pre-assigned probability in each decision round even if the actions are not successful in the earlier round. The effect of last-round payoff can be described as that agents would increase the tendency to choose the strategy which performed better in the last round, and vice versa, that is, agent's mixed strategies change continually according to the information it obtained. Hence we argue that the difference among values of $\mu(C)$, $\mu(D)$, and $\mu(L)$ is result from the memory of human, i.e., the game's earlier history might have a strong impact on the behavior of human decision making. For example, agents always know that they would obtain a fixed payoff 1.0 game point if they refuse to participate in the game. Consequently, the agent has higher chance to choose L strategy when the average payoffs of C and D strategy are lower than 1.0, even if no agents played L strategy in its unit. We had examined this case where the agent's unit is composed of cooperators and defectors. We found that 46.8% agents transited to L strategy when the C and D's average payoffs are lower than 1.0, and 31.3% agents transited to L strategy when both average payoffs of C and D are higher than 1.0. These results approximate to those obtained in Figure 1.

Our evidence has profound implication for the study of human behaviors in social interactions. In the past, most research has focused on the imitation, mutation, and the combination of imitation and mutation. We found experimentally that all these dynamics might not provide an appropriate explanation to the behavior of human decision making. By analyzing the probability agent switching to the other strategy in different cases, our study indicates that the memory of human plays an important role in human decision making. Thus, our evidence suggests that the evolution study of human cooperation in social interactions should include a focus on explaining how the memory of human works.

## Methods

A total of 150 subjects (76 men, 74 women) of Nankai University played a public goods game with optional participation on a $5\times 5$ square lattice with period boundary that lasted for 40 rounds. Each experiment was begun by agents' seeing the introduction to the game including one example round on a large screen, answering one or two test questions to verify understanding of the payoffs, and playing 10 practice periods. We mimicked a larger lattice by telling the students that there was a pool of additional players in the form of strategies recorded from earlier sessions, and each of them and the additional players would be confined to a site on a larger square lattice randomly at the start of actual periods. The students sat between partitions, and interacted anonymously through the software z-Tree[30]. They did not know the total number of rounds.

In each round, all the players had to choose simultaneously between three available options (loners, cooperators, and defectors), which were presented in a neutral language (e.g., A, B, C strategy). The payoff score a subject obtained depends on its own decision as well as the decisions of the players it interacted. For the sake of convenience, we defined subject x and its 4 neighbors as unit of x, and characterize the payoff scores the subjects obtained in a unit only. In one single unit, the players L who refused to join the public group receive a fixed score 0.2 game points (GP). Of the rest players who were all willing to participate, C contributed 0.2 GPs to the common pool, and D made null contribution. Then the content of the pool was multiplied by 3, and divided evenly among the participants (i.e., C and D). For example, there were 2 cooperators, 2 defectors, and 1 loner in a unit. The scores for L, C, and D are then 0.2 GPs, 0.1GPs, and 0.3 GPs respectively. The actual score for a subject is accumulated over 5 units, i.e., by summing up the subject's performance in its own unit as well as in the units of its 4 neighbors. After each round, they were shown the choices and payoff scores of its 4 neighbors as well as its own score in the current period. At the end of the sessions, they were presented with the final scores.

In each session, the students were paid a 5 CNYs show-up fee. Their final score summed over all actual rounds was multiplied by 0.5 CNYs to determine additional earned incomes, i.e., one game point corresponded to 0.5 CNYs. The average payment per subject was 23.45 CNYs and the average session length was 1.0h.

## Acknowledgements

Support from the National Natural Science Foundation of China under Grant No. 10672081 and the Zuzhibu Foundation of Nankai University. Thanks Zhen Wang and Hong-Peng Song for useful discussions.

Correspondence and Requests for materials should be addressed to: E-mail: zhanglz@nankai.edu.cn, Telephone: 0086-22-23503454, Fax: 0086-22-23503454.

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## Figure Legends

**Figure 1| The rates agents transiting to different target strategies.** Black bars refer to the average probabilities an agent transiting to the strategies which perform best on average in its own unit, i.e., $\omega_B(s)$. Light gray bars refer to the average probabilities an agent transiting to the strategies which perform worst on average in its own unit, i.e., $\omega_W(s)$. White bars refer to the average probabilities an agent transiting to the target strategies which are played by its neighbors, i.e., $\omega(s)$. Columns show mean ± s.e.m. per session of 25 subjects.

**Figure 2| Transition rates via mutation dynamics under different conditions.** It is known that agent x can not transit to the strategy which does not occurred in its unit via imitation. Hence, the transition rates presented above are due to mutation. **a,** the rates agent x mutating to C and D when agents in its unit are all loners. **b,** the rate focal agent mutating to C when its unit is composed of loners and cooperators. **c,** the rate focal agent mutating to D when its unit is composed of loners and defectors. **d,** the rate focal agent mutating to L when its unit is composed of defectors and cooperators.

**Figure 3| Rates an agent transiting to various target strategies via mutation.** It is shown that the probability an agent transiting to the strategy which is not played in this agent's unit. Columns show mean ± s.e.m. per session of 25 subjects.

## Figures

Figure 1.

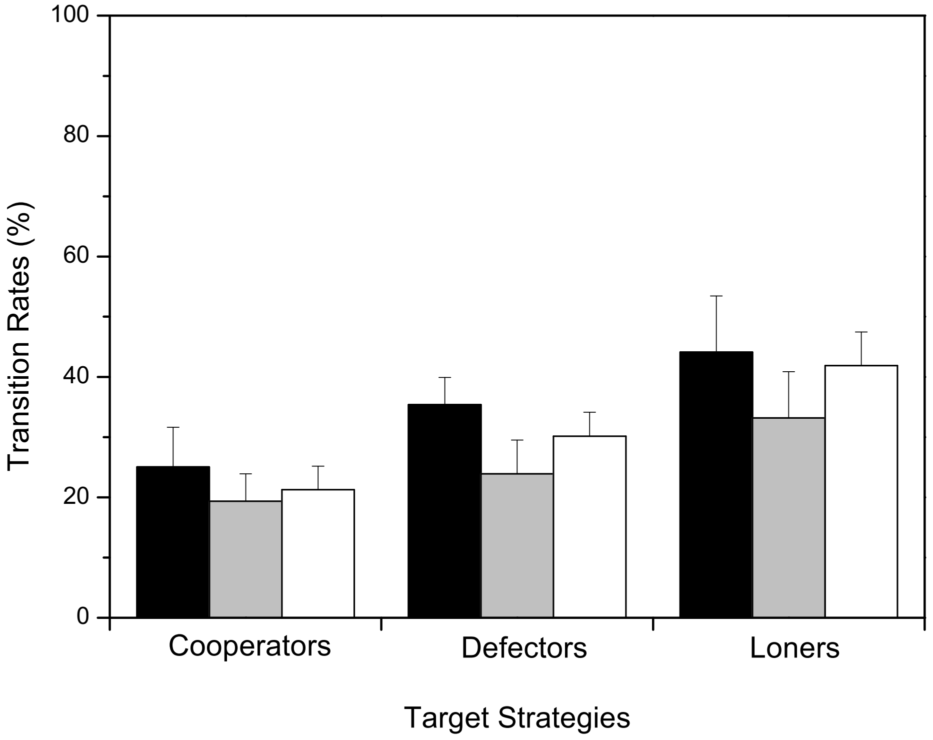


Figure 2.

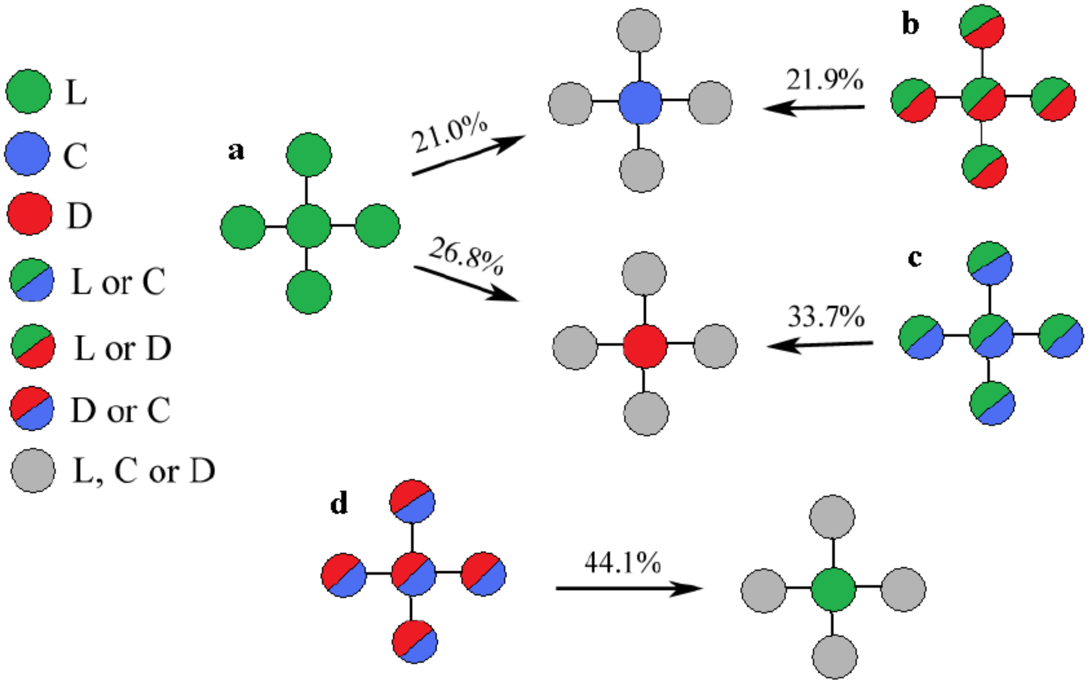
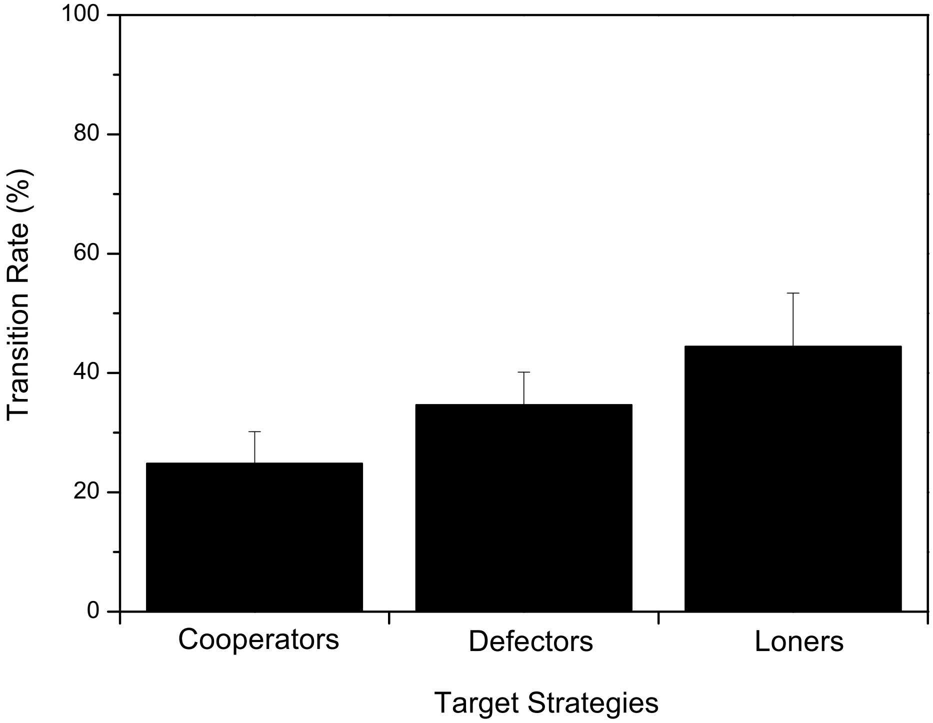


Figure 3.


100
80
60
40
20
0
Transition Rate (%)
Cooperators
Defectors
Loners
Target Strategies