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Title:

The function of peer reward and punishment in localized society

:We can only “Think locally, Act locally”

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**Abstract:**

Many studies suggest that peer reward and punishment can sustain cooperation in social dilemmas because cooperators are effectively rewarded and non-cooperators are effectively punished within the group. However, as group size becomes larger, we inevitably face localization, in which a global group is divided into several localized groups. While benefits from cooperation are distributed to the global group, members can reward and punish only other members within the same localized group. In this situation, the global group and the local group are not always equal in terms of welfare; situation can arise in which cooperation is beneficial for the global group but not for the local group. We predict that in such a locally inefficient situation, peer reward and punishment cannot function to sustain global cooperation, and high cooperation cannot be achieved. We conducted an experiment in which 16 group members played a public goods game with peer reward and punishment. We manipulated the range of peer reward and punishment (only local members/all members) and payoff structure (locally efficient/locally inefficient). We found that high cooperation was not achieved and that peer reward and punishment did not function when, and only when, the group was divided into localized groups and the payoff structure was locally inefficient. This finding suggests that the function of peer reward and punishment is limited to relatively small societies, and we humans can only “think locally, act locally.”

**Keywords:**

Public goods, Reward, Punishment, Localization, Cooperation

### 1.1. Public goods provision problem and function of reward and punishment

Difficulty of cooperation in a large-scale society is one of the most important issues for human beings (1-3). A public goods game (PGG) can precisely indicate the essence of the difficulty. In a PGG, members in a group decide to contribute to the common project, and total contributions are multiplied and shared equally with group members. In this situation, non-cooperators are more beneficial than cooperators because they do not contribute but receive benefits from others' contributions. Thus, a group faces a serious difficulty in providing public goods. Many studies have suggested that peer punishment and/or reward could solve this problem because non-cooperators' benefits could be lower than cooperators' benefits if non-cooperators are punished or cooperators are rewarded (4-9). For example, Rand et al. (2009)(9) conducted an experiment revealing that both reward and punishment facilitate cooperation in a PGG and that participants were more likely to choose reward than punishment when they could do both.

### 1.2. Research question: Localization effect on cooperation with peer reward/punishment

In this study, we examine how localization, in other words, subgrouping of the global group, influences cooperation in a PGG with peer reward and punishment. Historically, our society is growing larger and larger. After the agrarian revolution, especially, group size increased tremendously compared with hunter-gatherer societies because of high productivity and settlement (10). The localization of a global group occurs inevitably when the group size increases (11-14). In a large society, the outreach of reward and punishment is limited for several reasons. For instance, due to geographical barriers, it is difficult for the Japanese to reward Americans who act in an environmentally friendly way. In a slash-and-burn agricultural society, it is difficult for a villager to punish a person in another village who burns too many trees in the common forest (15). Furthermore, because available resources that one owns are limited, the number of individuals one can reward or punish is constrained. Thus, the more people commit to a common project, the more difficult it is to reward and/or punish other members sufficiently to provide public goods. In addition, as the population becomes larger, a new common project sometimes occurs among local groups. For example, while all villages near a lake can enjoy its fishery resources, management of fishery resources is usually imposed on villages located along the lake's coast.

Based on the argument above, we incorporated the localization factor with peer reward and punishment in PGG experiments. Localization occurs considerably in real society, and examining the influence of localization is important in discussing to what extent peer reward and punishment contribute to solving public goods problems in a global society.

We have to consider separately the global group's and the local groups' welfare when the global group is composed of multiple localized groups. By definition, global public goods should be

welfare-enhancing for global members if they all contribute. However, global public goods are not necessarily welfare-enhancing for local members even if they contribute global public goods. Hence, a resolution of conflict between global-level and local-level welfare is essential to achieve high cooperation in public goods situations. We predict that humans are more likely to behave to increase mutual profit among local group members, with whom they can interact directly, rather than to increase the profit of global group members with whom they can interact less directly. This prediction aligns with previous studies. Many studies have suggested that humans tend to cooperate with in-group members more than with out-group members (16-20), and humans are likely to sympathize with people close to them (family members, neighbors, etc.) (21-24). Therefore, when conflict occurs between global and local welfare, members of a localized society might not be motivated to achieve global cooperation in PGG through peer reward and punishment. From now on, we explain our experimental settings in detail and introduce our experiment's hypotheses.

### 1.3. Experimental settings and predictions

In the experiment, we prepared four conditions. First, a single group with four members, which followed a framework of the experiment by Rand et al. (2009)(9), was a baseline condition. In this condition, four group members decided how much to contribute to the common pool, and they decided whom to punish or reward and how much. We called this the N4 condition. In the other three conditions, the sum of members was 16. In two of the three conditions, 16 members were divided into four groups of four members. In these two conditions, which we called the LC0.4 and LC0.1 conditions (explained below), PGGs were played with all 16 global group members; however, interaction of reward and punishment were realized only with the four same local group members. In the last condition, the 16 members were not divided to local groups; all 16 played the reward and punishment interactively, as well as the PGG. We called this the ALL0.1 condition.

When a global group consists of four local groups—four of two conditions (LC0.4 and LC0.1)—we set the locally efficient and the locally inefficient condition by manipulating MPCR (Marginal Per Capita Return), ordinarily defined as change of individual profit per contribution. In this paper, we call it the “MPCR of individual.” In addition, we call change of local group profit per contribution the “MPCR of local group” and that of global group profit per contribution, the “MPCR of global group.” In this way, we can clearly discuss whether cooperation in the PGG is efficient enough to increase each layer's welfare, that is, individual, local, and global levels. The critical point of being efficient and inefficient is the value 1 of the MPCR (see Fig. 1 for an illustration of the experimental settings and MPCRs).

In localized group conditions, we set the MPCR of individual to 0.1 and 0.4. We call them

LC0.4 and LC0.1, respectively. In both conditions, cooperation in PGG reduces individual welfare but increases global welfare, so these conditions have normal PGG payoff structures. However, these two conditions are different at the local group level. In the LC0.4 condition, the MPCR of local group is more than 1, meaning cooperation increases the welfare of the local group as well, and, in this sense, this condition is locally efficient. On the other hand, in the LC0.1 condition, the MPCR of local group is below 1, and local group welfare decreases. Thus, although achievement of cooperation is efficient on a global level, it is inefficient on a local level. In this situation, the incentive to facilitate cooperation with one's local group members, with whom the member can interact directly, would be reduced, and reward for cooperators and punishment for non-cooperators would be less likely to occur. Consequently, cooperation would be less likely in the LC0.1 condition than in the LC0.4 condition.

Finally, we prepared the ALL0.1 condition, in which the number of group members was 16, but they could mutually reward and punish all 16 group members. In the ALL0.1 condition, the MPCR of individual was 0.1, which was the same as the LC0.1 condition. If only the MPCR of an individual influences global cooperation, the same cooperation would not be as the LC0.1 condition. However, all the members could interact with each other directly in ALL0.1 condition; therefore, there was no distinction between local and global groups, and this was the same as the N4 condition. The MPCR of local (=global) group was 1.6 in the ALL0.1 condition, and achievement of cooperation was efficient for increasing local (=global) group welfare. Therefore, we predicted that peer reward and punishment power to facilitate cooperation in the ALL0.1 condition would be the same as in N4 and LC0.4 conditions. As a whole, we predicted that PGG cooperation was more likely to be achieved by peer reward and punishment when group cooperation was locally efficient (LC0.4, ALL0.1, and N4) than in the locally inefficient (LC0.1) condition.


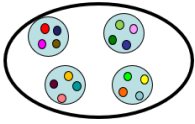
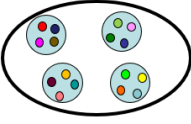
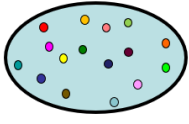
Condition	N4(Baseline)	LC0.1	LC0.4	ALL0.1
Structure PGG is played inside a bold oval(=Global group). Peer reward and punishment are exercised in blue ovals(=Local groups)				
N of Local group players	4	4	4	16
N of Global group players	4	16	16	16
MPCR of Individual	0.4	0.1	0.4	0.1
MPCR of Local group (=MPCR of Individual*N of Local players)	1.6	0.4	1.6	1.6
MPCR of Global group (=MPCR of Individual*N of Global players)	1.6	1.6	6.4	1.6

Fig. 1. Experimental settings and MPCR for each layer.

#### 1.4. Hypotheses

Three hypotheses were derived based on the arguments above. First, we predicted that PGG cooperation is less likely to be achieved in the LC0.1 condition because of the argument above.

H1: PGG contribution is lower in the LC0.1 condition than in the other three conditions.

H2 and H3 are hypotheses for reward and punishment behaviors. To facilitate PGG cooperation, cooperators should be rewarded more than non-cooperators, and non-cooperators should be punished more than cooperators. The linkage between reward/punishment and PGG cooperation level would be weaker in the LC0.1 condition than in the other three conditions.

H2: The positive linkage between the PGG cooperation level and received reward is weaker in the LC0.1 condition than in the other three conditions.

H3: The negative linkage between the PGG cooperation level and received punishment is weaker in the LC0.1 condition than in the other three conditions.

### Methods

The Waseda University Ethical Review Board approved this study (IRB number is 2016-007). Its methods were conducted in accordance with approved guidelines. Written informed consent was obtained from all participants prior to beginning the experiment.

#### 2.1. Participants

In total, 584 university students participated in this experiment, of which 72 students (18 groups) participated in the N4 condition, 160 students (10 groups) in the LC0.1 condition, 192 students (12 groups) in the All0.1 condition, and 160 students (10 groups) in the LC0.4 condition. Participants were recruited via a university portal website, and monetary reward was emphasized during recruitment.

#### 2.2. Procedure

In all conditions, participants were assigned to laboratory booths to ensure their anonymous and independent decisions. Sixteen participants participated in each session of the experiment of LC0.1, LC0.4, and All0.1 conditions. As for the N4 condition, 8, 12, or 16 participants took part and were allocated randomly to one of two, three, or four 4-person groups. After reading explanations of PowerPoint slides, participants completed confirmation tests that questioned their understanding of the experiment's details. Neutral words were selected for explanation. After confirming that all participants understood the experimental details, we ran one trial period, and,

then, participants started the real session.

Details of the experimental transactions are as follows.

The transactions comprised two stages, the PGG stage and the reward/punishment stage. Participants were told before the experiment began that these periods would be repeated 15 times and that tokens they earned during transactions would be redeemed as monetary remuneration.

#### 2.2.1. PGG stage:

In all conditions, each member was given 20 tokens at the beginning of the stage and simultaneously chose his/her contribution from 0 to 20 in increments of 1, which were then subtracted from his/her endowment of 20 tokens. The total tokens each member contributed were multiplied by 1.6 in N4, LC0.1, and All0.1 conditions and distributed equally to all four or 16 group members. In the LC0.4 condition, the total tokens were multiplied by 6.4 and distributed equally to the 16 group members. After all decisions were made, players received feedback on other players' contributions.

#### 2.2.2. Reward/Punishment stage:

In all conditions, each player was given nine tokens and simultaneously decided how many tokens to use to reward and punish other players. Efficiency of punishment and reward is three. This means that when member A uses one token to reward member B, A loses one, and B gets three tokens; when C uses one token to punish D, C loses one, and D loses three tokens. Each member can reward or punish other members as long as he or she uses all nine tokens. Each player keeps tokens they do not use. A participant cannot reward and punish the same members at the same time. When participants decided, they could refer to the previous results of Stage 2 and Stage 1. After all of them decided, they received feedback on from whom they received punishment/reward and the amount.

Worth pointing out is while in LC0.1/0.4 conditions, participants could reward and punish only three members of the same local group, in All0.1/N4 conditions, participants could reward/punish all members except themselves. (see SI appendix, section 3 for details).

These two stages were repeated 15 times. We used z-Tree software (40) to conduct experiments. Each session took an average of approximately 80 minutes. The total attained score was converted to money using the rate of 1 token = 1.5 yen (100 yen  $\doteq$  1 US dollar) in LC0.1, ALL0.1, and N4 conditions and 0.5 yen in the LC0.4 condition. In addition, an 800-yen show-up fee was given to participants who completed the experiment. Average remuneration was 1671 yen.

## Results

The average PGG contribution, average amount of reward and punishment, and average profit



of players were calculated for each period (see Fig. 2). First, we analyzed group level data. The Mann–Whitney U-test with Bonferroni’s correction was conducted to determine whether a difference existed between conditions. All indexes were calculated for 14 periods but not for the last 15th period because all participants knew the 15th period would be the last—when most indexes tended to decline. Clearly, reward decreased, and punishment increased in the last period. This tendency was consistent with a previous study (25). Although this phenomenon is interesting, it is outside our research interest here. As for the average PGG contribution, the member under the LC0.1 condition contributed less to the PGG pool than under LC0.4 ( $p = .006$ ), ALL0.1 ( $p < .001$ ), and N4 conditions ( $p < .001$ ). There were no significant differences among LC0.1, ALL0.1, and N4 conditions ( $ps > .10$ ). In addition, we divided data into the first half (1<sup>st</sup>–7<sup>th</sup> period) and the second half (8<sup>th</sup>–14<sup>th</sup> period) and then calculated each average contribution. To analyze the difference between the first and second halves, paired rank sum tests were performed for each condition. We found that decline of contribution occurred only in the LC0.1 condition ( $p = .005$ ); however, there were no differences in LC0.4 and ALL0.1 conditions ( $p = .169$ ,  $p = .814$ , respectively), and increase of contribution occurred in the N4 condition ( $p = .053$ ). Results are consistent with H1. As for average profit, members in LC0.4 and N4 conditions obtained more profit than those in LC0.1 and ALL0.1 conditions (LC0.4 vs LC0.1;  $p = .006$ , LC0.4 vs ALL0.1;  $p = .042$ , N4 vs LC0.1;  $p = .006$ , N4 vs ALL0.1;  $p = .012$ ). Regarding reward, the member under the ALL0.1 condition rewarded others less than under LC0.4 ( $p < .001$ ) and N4 conditions ( $p = .054$ ). Regarding punishment, there were no significant differences among conditions ( $ps > .10$ ). In addition, amounts of reward were greater than amounts of punishment in all four conditions ( $ps < .001$ ), consistent with results by Rand et al. (2009)(9): The participants chose reward rather than punishment.

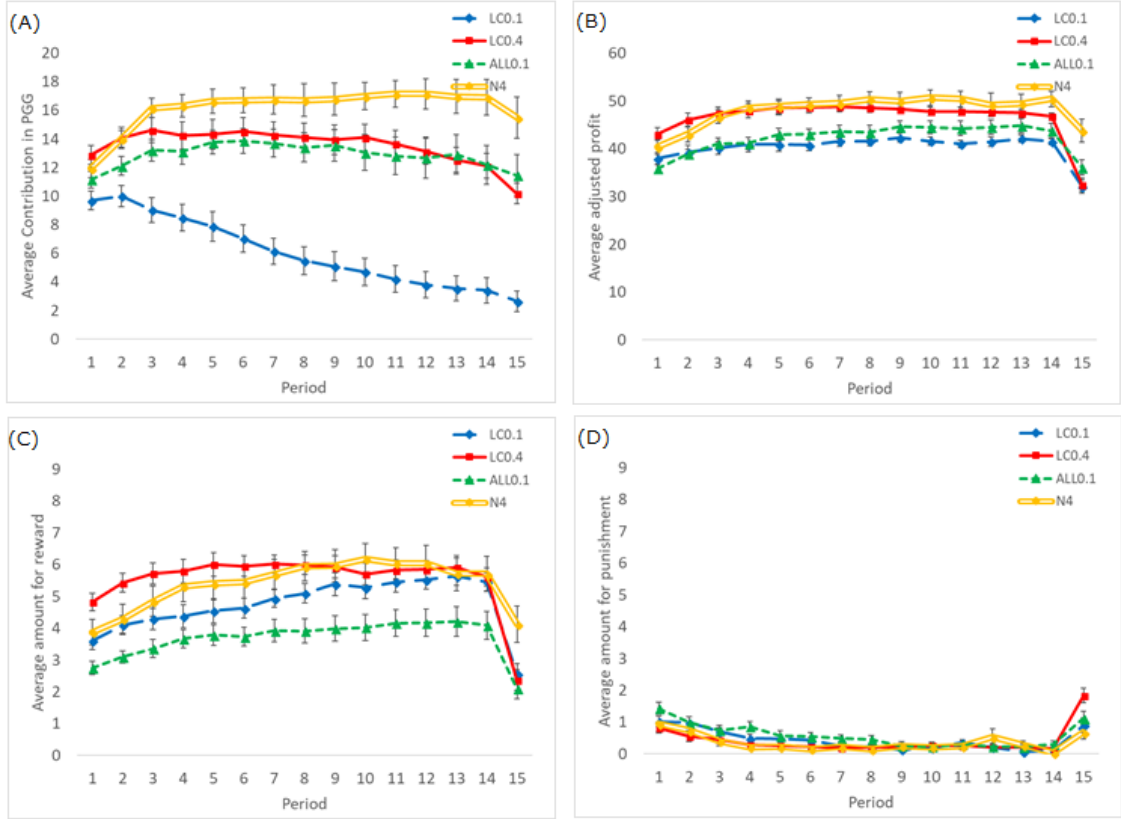


Fig. 2. Average contribution to the public good (A), average profit after adjustment (B), average amount for reward (C), and average amount for punishment (D) over 15 periods of play under N4 ( $n = 18$ ), LC0.1 ( $n = 10$ ), LC0.4 ( $n = 10$ ), and ALL0.1 ( $n = 12$ ) conditions.

Average profit was adjusted for LC0.4 because the MPCR of the global group was 6.4 only in the LC0.4 condition, and results of PGG contribution effected more profit than the other three, so comparing directly was difficult. To fix this problem, we calculated players' profit in the LC0.4 condition by replacing the MPCR of the global group from 6.4 to 1.6, which was equal to the other three conditions. In this way, we could directly compare profit among four conditions.

Next, we analyzed reward and punishment behaviors in detail. Fig. 3 shows the average amount of reward and punishment to one cooperator, who contributed equal-to-average or above-average in PGG, or to one non-cooperator, who contributed below-average in PGG, over 14 periods except for the last. In all conditions, cooperators were rewarded more than non-cooperators, and non-cooperators were punished more than cooperators. In other words, there are linkages between PGG cooperation and reward/punishment behaviors. Thus, reward and punishment might function to facilitate cooperation in the PGG. However, this tendency looks weaker in the LC0.1 condition than in the other three conditions for reward. To test this statistical significance, the

difference between reward for a cooperator and that for a non-cooperator was calculated and analyzed using Mann–Whitney U-test with Bonferroni’s correction. The results showed that the difference in reward between a cooperator and non-cooperator was smaller in the LC0.1 condition than in LC0.4 ( $p = .006$ ), ALL0.1 ( $p < .001$ ), and N4 conditions ( $p = .003$ ), meaning that reward to PGG cooperators was lower in LC0.1 than in the other three conditions, and H2 was supported. We analyzed for punishment in the same manner; however, we did not find statistical differences ( $ps > .10$ ), and H3 was not supported.

We investigated further Hypotheses 2 and 3, using multilevel regression analyses with individual data. Results were consistent with the analysis of group level reported above. In all conditions, we found linkage between received reward and PGG cooperation level, and this linkage was weaker in LC0.1. Regarding punishment, the difference only in LC0.1 is unclear (see SI Appendix, section 1 for details). In addition, we examined how players changed their cooperation level in PGG after receiving reward and punishment in the previous period, that is, the effectiveness of reward and punishment in facilitating cooperation, using multilevel regression analysis. The results indicated that both reward and punishment functioned to change others’ behavior to cooperation; however, this function was weaker in LC0.1 than in the other three conditions (see SI Appendix, section 2 for details).

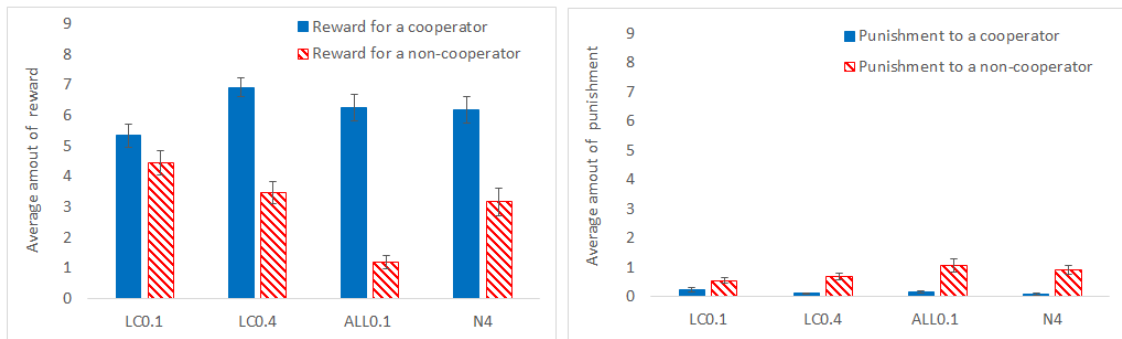


Fig. 3. Average amount of reward and punishment to cooperator (equal-to or above-average contributor)/non-cooperator (below-average contributor) over periods 1–14. Error bars indicate standard errors.

## Discussion

### 4.1. Difficulty of cooperation in large-scale society

PGG cooperation was lower in the LC0.1 condition than in the other three conditions, consistent with H1. This is because reward behaviors differed in the LC0.1 condition compared to the other three. The results of reward were consistent with H2. This means that reward did not facilitate PGG cooperation only in the LC0.1 condition. In the LC0.1 condition, reward was used not for

facilitation of PGG cooperation but rather for mutual benefit within local groups; therefore, the reward level in the LC0.1 condition was not lower than in the other conditions. We should discuss why results were inconsistent only in punishment. This might be partly because punishment behaviors were rare (see Figs. 2d and 3), and detecting statistical differences among conditions for punishment might be difficult. Further analyses in the supplementary analysis 2 (SI Appendix, section 2) suggest that reward and punishment had a lower function to change others' behavior to cooperation in the LC0.1 condition than in the other three conditions. This might be because changing behaviors to cooperation decreased local-level and individual-level welfare, and the members had no understandable reason to cooperate even when they were rewarded or punished.

Total profits were lower in the LC0.1 condition than in LC0.4 and N4 conditions because of lower cooperation in PGG. There was no statistical difference between LC0.1 and All0.1 conditions. This is because reward was lower in ALL0.1 than in the other three conditions (see Fig. 2c); participants in the ALL0.1 condition could not gain as much profit from reward as in LC0.4 and N4 conditions. In the ALL0.1 condition, it was more difficult to choose whom to reward due to the group's number of members, so participants might have refrained from rewarding others. In other words, the coordination problem occurred over whom to reward (26). Although this is not our study's main purpose, the relation between group size and reward/punishment behavior might be an interesting future topic.

The summary of the results is humans can consider and facilitate only local group welfare. We need global cooperation beyond the local level in our modern society, and the slogan "Think globally, Act locally" is very famous. However, this study's results indicate the difficulty of global cooperation beyond local communities and suggest that we can only "Think locally, Act locally": We can consider only local level profit and reward to facilitate cooperation only for our local group. This understanding of human beings is analogous to the claim by recent evolutionary-minded social scientists (27). Furthermore, this study's finding clarifies the kind of social structure that enables high PGG cooperation by peer reward and punishment.

#### 4.2. Development of human society and localization

In our real large-scale society, a situation like the LC0.1 condition is much more common than situations such as the All0.1 or LC0.4 conditions. In the introduction, we discussed localization's frequent occurrence in large-scale society. In addition, we believe that the decline of MPCR frequently occurs in large-scale society. We can find a wide variety of declining trends such as environmentally friendly behaviors, use of public transfer to decrease traffic jams, and labor to maintain irrigation systems. In these examples, cooperation by one member has less impact on other members as group size is larger. To the contrary, the situation in which the MPCR does not change regardless of group size is very rare, for instance, pure public goods (e.g., defense costs).

Thus, many PGG situations in large-scale groups inevitably face both localization and low MPCR as in the LC0.1 condition; this tends to result in low cooperation levels. Therefore, high cooperation by peer reward and punishment is limited to small-scale societies such as families, some hunter-gatherers, and some local communities. After the agrarian revolution, group size increased compared with hunter-gatherer societies because of high productivity and settlement (10), and these problems became apparent. However, in our history, we humans sometimes achieved high cooperation levels even in large-scale societies such as empires and great nations (28). How could we achieve high cooperation in larger groups? We discuss this issue in the final section.

Our finding also has an implication for modern society. Internet development eliminates various barriers that obstruct peer reward and punishment and enable members to reward and punish directly beyond local communities, a situation that might be termed a “super local community.” Crowd funding is a clear example of possibilities of direct exchange across local communities. It is meaningful to discuss to what extent cooperation can be achieved only by mutual direct interactions. However, there are some obstacles to achieving cooperation in the “super local community” only by peer reward and punishment. First, we should note that we still have barriers such as cultural values, religions, and languages, and overcoming these barriers might be difficult. Second, a group size of around 150 might be a limitation for human beings to sustain mutual interactions as Dunbar (2010)(12) argued, and cooperation with more than 150 members might be difficult. Third, the coordination problem of reward and punishment occurs more severely, that is, the member must coordinate whom to reward and punish, as group size is larger (26). These limitations have not been sufficiently examined, and future research studies will be necessary.

#### 4.3. Limitation and further investigation

There are some issues we did not examine in this study. Notably, we examined only one social structure in our experiment, which has a hierarchy of global and local levels; however, there are other structures such as a three-level structure or a network structure (29-31). How these structures affect PGG cooperation with peer reward and punishment need future investigation.

Related to network structure, Hauzer et al. (2016)(32) conducted an online experiment in which large-group members played PGG with all group members and, then, played PD with one or two members connected in a given network. They repeated this sequence 20 times. Contrary to negative results on cooperation of PGG in our experiment in the LC0.1 condition in which global members are divided into a local group of four and localized members can punish or reward each other, Hauzer et al. (2016) observed that the high cooperation level in the PGG and the behavior of the PD contingent on PGG cooperation becomes the driving force of large-group cooperation.

Why do our experiment and Hauzer's lead to different conclusions about the prospect of large-group cooperation? Specifying the reason is difficult because their experimental settings and those of ours had many differences, for instance, online versus laboratory experiments, PD versus reward/punishment, pairs versus four group members, and differing feedback information for PGG. Among these differences, we think the difference in feedback for the PGG contribution might be crucial; in our experiment, each player sees the contribution behavior of each global member, but in Hauzer's setting, players can see the contribution level of only one or two network-connected members. In their study, each member was informed only of the PGG result(s) of paired member(s) but did not know the result(s) of other global group members. Therefore, participants in their experiment might tend to focus on their own pair(s) without considering other global group members, and they might be more likely to recognize the behavior of their pair(s) in PGG as reciprocal compliant behavior rather than contribution for the global commons. In other words, participants might recognize their experimental situation as if they were playing repeatedly similar pair-wise games, *not* sequentially a game with a global group (PGG) and a game with a partner (PD). For this reason, we speculate that participants could link the two games (PGG and PD) in their experiment. On the other hand, participants in our experiment were informed of the total and each contribution of all global members in PGG; thus, they could clearly compare the welfare of global, local, and individual levels. By realizing that PGG is locally inefficient in the LC0.1 condition, they could rationally reduce a global contribution and tended to pursue reciprocal behavior within their local group (mutual reward). No information (Hauzer's setting) and full information of global group members (our setting) are each extreme cases. Feedback of PGG information in a real society lies somewhere between these extremes. Further investigation is necessary to clarify effects of PGG feedback on the strength of linkage by manipulating how and to what extent participants know about global members' behavior.

Finally, we should discuss the next important question. How can we achieve high cooperation in larger groups, in which peer reward and punishment do not function? The pool punishment system and/or the leader support system are important candidates for solving the problem (33-38). Peer reward and punishment are limited only within local group members, and the systems and/or leaders that unite local groups are necessary. Feudal societies and nations exemplify these systems. Although there are many historical and comparative institutional studies about how these systems could be realized and maintained (28,38), experimental studies, which offer replicability, are very rare (34,35,38). The limitation of peer reward and punishment emphasizes the importance of investigation into how these systems emerge and are maintained.

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## 1. Supplementary analysis 1

We further investigated Hypothesis 2,3 (linkage between Public Goods Game (PGG) cooperation level and received reward/ punishment) by using repeated measures data on individuals clustered within groups. Individual data over 15 periods are nested in a local group and the local group is nested in the global group for LC0.1 and LC0.4 conditions. Regarding ALL0.1 and N4 conditions, the individual is nested in the local (=global) group. We excluded the final (15th) period from the data, because all participants knew it would be the last, and, therefore, they were expected to behave differently. Thus, individual variation is relative not only to conditions' differences but also to differences among (local and/or global) groups and periods. To examine factors motivating observed reward, punishment, and cooperation behavior more closely, we constructed various multi-level regression models, which considered random intercepts for each group and individual.

Table S1 indicates determinants of received reward. In all conditions, deviation from group average contribution had strong positive influence to reward. This means a linkage between received reward and PGG cooperation level. Interaction coefficients of Models 5, 6, and 7 indicated that this linkage is weaker in LC0.1 than in the other three conditions. These results are consistent with H2.

Table S2 indicates determinants of received punishment. In all conditions, deviation from group average contribution had strong negative influence to punish, and there is negative linkage between received punishment and PGG cooperation level. Unlike analysis of received reward, interaction coefficients of Models 5, 6, and 7 indicated that this linkage was weaker not only in LC0.1 but also in LC0.4 than in the other two conditions. These results are not consistent with H3, but are consistent with the group level analysis (see Figure 3 and related analysis in the manuscript).

Table S1. Determinants of received reward. Multi-level regression coefficient on determinants of received reward in four conditions. Models 1, 2, 3, and 4 show analysis for each condition. Models 5, 6, and 7 include the LC0.1 condition and the other three conditions, respectively, allowing assessment of reward behavior between conditions. The benchmark condition for dummy variables is the LC0.1 condition. Numbers in parentheses indicate standard errors.

independent variables	LC0.1 (1)	LC0.4 (2)	ALL0.1 (3)	N4 (4)	LC0.1vsLC0.4 (5)	LC0.1vsALL0.1 (6)	LC0.1vsN4 (7)
Group average	-0.0568 (0.0945)	0.500*** (0.0826)	0.285*** (0.0794)	0.696*** (0.0821)	-0.0603 (0.0542)	0.00504 (0.0492)	0.190*** (0.0486)
Deviation from group average contribution	0.352*** (0.0352)	0.491*** (0.0309)	0.549*** (0.0368)	0.713*** (0.0584)	0.352*** (0.0333)	0.351*** (0.0369)	0.355*** (0.0344)
period	0.402*** (0.0625)	0.153*** (0.0308)	0.273*** (0.0331)	0.247*** (0.0505)	0.247*** (0.0289)	0.351*** (0.0266)	0.487*** (0.0314)
LC0.4					3.074** (1.399)		
LC0.4X Deviation from group average					0.145*** (0.0472)		
ALL0.1						-3.344** (1.366)	
ALL0.1X Deviation from group average						0.214*** (0.0513)	
N4							-0.169 (1.627)
N4X Deviation from group average							0.361*** (0.0754)
constant	11.98*** (1.355)	9.242*** (1.434)	5.579*** (1.367)	3.214* (1.688)	13.16*** (1.074)	11.97*** (1.072)	9.779*** (1.229)
Observations	2,240	2,240	2,688	1,008	4,480	4,928	3,248
Number of groups	10	10	12	18	20	22	28
Global Group	YES	YES	YES	YES	YES	YES	YES
Local Group	YES	YES	—	—	YES	—	—
Individual	YES	YES	YES	YES	YES	YES	YES

Table S2. Determinants of received punishment. Multi-level regression coefficient on determinants of received reward in four conditions. Models 1, 2, 3, and 4 show analysis for each condition. Models 5, 6, and 7 include the LC0.1 condition and the other three conditions, respectively, allowing assessment of punishment behavior between conditions. The benchmark condition for dummy variables is the LC0.1 condition. Numbers in parentheses indicate standard errors.

independent variables	LC0.1 (1)	LC0.4 (2)	ALL0.1 (3)	N4 (4)	LC0.1vsLC0.4 (5)	LC0.1vsALL0.1 (6)	LC0.1vsN4 (7)
Group average	-0.141*** (0.0451)	-0.106*** (0.0368)	-0.159*** (0.0491)	-0.278*** (0.0331)	-0.0437* (0.0249)	-0.121*** (0.0283)	-0.0892*** (0.0222)
Deviation from group average contribution	-0.162*** (0.0167)	-0.190*** (0.0138)	-0.407*** (0.0202)	-0.338*** (0.0248)	-0.164*** (0.0158)	-0.159*** (0.0201)	-0.157*** (0.0159)
period	-0.273*** (0.0311)	-0.108*** (0.0159)	-0.221*** (0.0225)	-0.0183 (0.0234)	-0.160*** (0.0147)	-0.240*** (0.0164)	-0.189*** (0.0162)
LC0.4					0.0568 (0.318)		
LC0.4X Deviation from group average					-0.0185 (0.0215)		
ALL0.1						1.233*** (0.436)	
ALL0.1X Deviation from group average						-0.246*** (0.0270)	
N4							0.627* (0.335)
N4X Deviation from group average							-0.189*** (0.0346)
constant	4.133*** (0.535)	3.190*** (0.578)	5.348*** (0.731)	5.593*** (0.543)	2.675*** (0.299)	3.763*** (0.387)	3.178*** (0.277)
Observations	2,240	2,240	2,688	1,008	4,480	4,928	3,248
Number of groups	10	10	12	18	20	22	28
Global Group	YES	YES	YES	YES	YES	YES	YES
Local Group	YES	YES	—	—	YES	—	—
Individual	YES	YES	YES	YES	YES	YES	YES



## 2. Supplementary analysis 2

We investigated changed behavior after reward or punishment. We thought members who were rewarded or punished might be less likely to change their behavior into cooperation in the LC0.1 condition than in the LC0.4 condition because changing their behaviors to contribution to the common pool decreased local level welfare as well as individual level welfare, and there was no understandable reason to cooperate for their local group. We predicted that reward and punishment have less impact on changing behaviors of non-cooperators to cooperation in the LC0.1 condition than in the other three.

Table S3 indicates how players changed their cooperation levels in PGG after receiving reward and punishment. Models 2, 3, and 4 show that participants increased their contribution in period  $t$  after receiving reward and punishment in the period  $t-1$  in LC0.4, ALL0.1, and N4 conditions (one exception is punishment in the LC0.4 condition). However, Model 1 indicates *no* influence of reward and punishment to change PGG contribution in the LC0.1 condition. Interaction coefficients of Models 5, 6, and 7 also support this finding; the change of PGG cooperation after receiving reward and punishment are lower in LC0.1 than in the other three conditions, except for rewards of the N4 condition. These results are consistent with our prediction. We should note that we did not find influence of punishment in the LC0.4 condition; however, interaction is found when comparing LC0.1 and LC0.4 conditions. In addition, we did not find a different influence of rewards when comparing LC0.1 and N4; however, the coefficient is higher in the N4 than in the LC0.1 condition. Thus, these results are not so critical to our main findings, i.e., reward and punishment had lesser impact on changing behaviors of non-cooperators to cooperation in the LC0.1 condition than in the other three.

Table S3. How players changed their cooperation level in PGG after receiving reward and punishment (DV: Difference contribution from period  $t-1$  to period  $t$ ). Multi-level regression coefficient on change of cooperation level. Models 1, 2, 3, and 4 show analysis for each condition. Models 5, 6, and 7 include the LC0.1 condition and the other three conditions, respectively, allowing assessment of change in cooperation level between conditions. The benchmark condition for dummy variables is the LC0.1 condition. Numbers in parentheses indicate standard errors.

independent variables	LC0.1	LC0.4	ALL0.1	N4	LC0.1vsLC0.4	LC0.1vsALL0.1	LC0.1vsN4
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Group average	-0.124*** (0.0480)	-0.294*** (0.0671)	-0.203*** (0.0407)	-0.247*** (0.0477)	-0.216*** (0.0321)	-0.145*** (0.0238)	-0.158*** (0.0243)
contribution <sub>t-1</sub> in PGG							
Deviation from group	-0.487*** (0.0187)	-0.659*** (0.0229)	-0.570*** (0.0211)	-0.614*** (0.0371)	-0.564*** (0.0147)	-0.527*** (0.0141)	-0.515*** (0.0167)
average contribution <sub>t-1</sub>							
Average amount of	-0.0344 (0.0493)	0.0278 (0.0627)	-0.00420 (0.0391)	0.0447 (0.0308)	-0.0107 (0.0367)	0.000572 (0.0277)	0.0110 (0.0246)
received reward <sub>t-1</sub>							
Deviation from average	0.0128 (0.0111)	0.0446*** (0.0147)	0.0386*** (0.00971)	0.0429** (0.0191)	0.0164 (0.0119)	0.0140 (0.0113)	0.0144 (0.0107)
reward <sub>t-1</sub>							
Average amount of	0.0814 (0.0819)	0.231** (0.104)	0.0225 (0.0732)	0.188*** (0.0718)	0.119* (0.0641)	0.0720 (0.0532)	0.145*** (0.0520)
received punishment <sub>t-1</sub>							
Deviation from average	-0.0245 (0.0225)	0.0179 (0.0290)	0.116*** (0.0154)	0.0800** (0.0401)	-0.0379 (0.0233)	-0.0286 (0.0225)	-0.0271 (0.0216)
punishment <sub>t-1</sub>							
period	-0.0213 (0.0448)	-0.0963*** (0.0260)	-0.0807*** (0.0260)	-0.0756** (0.0297)	-0.0880*** (0.0221)	-0.0636*** (0.0209)	-0.0611*** (0.0227)
LC0.4					2.077*** (0.531)		
LC0.4X Deviation from					0.0298* (0.0177)		
average reward <sub>t-1</sub>							
LC0.4X Deviation from					0.0841** (0.0358)		
averagepunishment <sub>t-1</sub>							
ALL0.1						1.472*** (0.321)	
ALL0.1X Deviation						0.0294** (0.0142)	
from average reward <sub>t-1</sub>							
ALL0.1 X Deviation						0.153*** (0.0265)	
from							
N4							2.401*** (0.357)
N4X Deviation from							0.0158 (0.0227)
average reward <sub>t-1</sub>							
N4X Deviation from							0.145*** (0.0464)
averagepunishment <sub>t-1</sub>							
constant	0.891 (0.917)	4.088*** (1.257)	3.383*** (0.766)	4.061*** (0.809)	1.642** (0.713)	0.873* (0.512)	0.695 (0.428)
Observations	2,080	2,080	2,496	936	4,160	4,576	3,016
Number of groups	10	10	12	18	20	22	28
Global Group	YES	YES	YES	YES	YES	YES	YES
Local Group	YES	YES	—	—	YES	—	—
Individual	YES	YES	YES	YES	YES	YES	YES

### 3. Supplementary method

#### 3.1. Instruction of the experiment

*After a brief verbal introduction, participants read the following instructions on the computer monitor telling them that they would take part in an experiment on*



*decision making.*

### General Guidance

This is an experiment about decision making. You will be paid for participating, and the amount of money you will earn depends on the decisions that you and the other participants make. At the end of today's session, you will be paid privately and in cash for your decisions.

You will never be asked to reveal your identity to anyone during the course of the experiment. Your name will never be associated with any of your decisions.

At this time, you will be given 500 yens (= 5–6 dollars) for coming on time. All the money that you earn after this experiment will be yours to keep.

### Earnings

In this experiment, you are in a group of size 16 (you plus 15 others) (\*size 4 (you plus 3 others) in N4condition) and you will be asked to make a series of choices about how to allocate a set of tokens. You *will not* be able to know each other's identities. The group members will remain the same throughout the experiment.

The details of the experimental transactions are as follows. 16 members named A to P (\*4 members named A to D in N4condition) will play the same role. The experiment comprises two stages, the 1<sup>st</sup> and 2<sup>nd</sup> stages. These stages will be repeated 15 times, and the tokens you earn during transactions will be redeemed as monetary remuneration.

Now, let us explain the details of each stage.

#### **1<sup>st</sup> stage (N4 condition)**

Each of the four members contributes 20 tokens at the beginning of this stage. The members are asked to decide how many tokens to contribute to the group pool. You lose the amount you contribute to the pool, but 40% of the sum of the tokens is given to each of the 4 members, including you. Hence, the number of tokens you contribute and the sum of tokens contributed by any participant, including you, will determine the payoff you receive. Each choice that you make is similar to the following example.

#### **-Examples of choices you will make in the 1<sup>st</sup> stage and earnings**

Example 1: Suppose that you and the other 3 members all contribute 20 tokens to a pool. You will earn:

20 (initial endowment) – 20 (the tokens you contributed)  
+ 0.4 \* 80 (the sum of tokens the 4 members contributed)

=32

Example 2: Suppose that you and the other 3 members all contribute nothing. You will earn:

100 (initial endowment) – 0 (the tokens you contributed)  
+ 0.4 \* 0 (the sum of tokens the 4 members contributed)  
=20

Example 3: Suppose that you give 4 tokens and the other members contribute 5, 10, and 16 tokens each. You will earn:

20 (initial endowment) – 4 (the tokens you contributed)  
+ 0.4 \* 35 (the sum of tokens the 4 members contributed)  
=30

### **1<sup>st</sup> stage (LC0.1 and ALLO.1 conditions)**

Each of the sixteen members contributes 20 tokens at the beginning of this stage. The members are asked to decide how many tokens to contribute to the group pool. You lose the amount you contribute to the pool, but 10% of the sum of the tokens is given to each of the 16 members, including you. Hence, the number of tokens you contribute and the sum of tokens contributed by any participant, including you, will determine the payoff you receive. Each choice that you make is similar to the following example.

#### **-Examples of choices you will make in the 1<sup>st</sup> stage and earnings**

Example 1: Suppose that you and the other 15 members all contribute 20 tokens to a pool. You will earn:

20 (initial endowment) – 20 (the tokens you contributed)  
+ 0.1 \* 320 (the sum of tokens the 16 members contributed)  
=32

Example 2: Suppose that you and the other 15 members all contribute nothing. You will earn:

20 (initial endowment) – 0 (the tokens you contributed)  
+ 0.1 \* 0 (the sum of tokens the 16 members contributed)  
=20

Example 3: Suppose that you give 5 tokens and the total contributions of other members are 195 tokens each. You will earn:

20 (initial endowment) – 5 (the tokens you contributed)

$$+ 0.1 * 200 \text{ (the sum of tokens the 16 members contributed)}$$

$$=35$$

### **1<sup>st</sup> stage (LC0.4 condition)**

Each of the sixteen members contributes 20 tokens at the beginning of this stage. The members are asked to decide how many tokens to contribute to the group pool. You lose the amount you contribute to the pool, but 40% of the sum of the tokens is given to each of the 16 members, including you. Hence, the number of tokens you contribute and the sum of tokens contributed by any participant, including you, will determine the payoff you receive. Each choice that you make is similar to the following example.

#### **-Examples of choices you will make in the 1<sup>st</sup> stage and earnings**

Example 1: Suppose that you and the other 15 members all contribute 20 tokens to a pool. You will earn:

$$20 \text{ (initial endowment)} - 20 \text{ (the tokens you contributed)}$$

$$+ 0.4 * 320 \text{ (the sum of tokens the 16 members contributed)}$$

$$=128$$

Example 2: Suppose that you and the other 15 members all contribute nothing. You will earn:

$$20 \text{ (initial endowment)} - 0 \text{ (the tokens you contributed)}$$

$$+ 0.4 * 0 \text{ (the sum of tokens the 16 members contributed)}$$

$$=20$$

Example 3: Suppose that you give 5 tokens and the total contributions of other members are 195 tokens each. You will earn:

$$20 \text{ (initial endowment)} - 5 \text{ (the tokens you contributed)}$$

$$+ 0.4 * 200 \text{ (the sum of tokens the 16 members contributed)}$$

$$=95$$

### **2<sup>nd</sup> stage**

Each of the four members are given another 9 tokens at the beginning of this stage. The members including you are asked to decide how many tokens to use to increase and reduce the tokens of other members. Efficiency of increase or reduction is 3. This means that when you use 1 token to increase the tokens of member B, you loses 1 and B gets 3 tokens and when C uses 1 token to reduce the tokens of you, C loses 1 and you lose 3 tokens. you can increase or reduce other members' tokens as long as you use up all 9 tokens. you gets the token you do not

use for increase and reduction. you cannot increase and reduce the tokens of the same members at the same time. When you decide, you can refer to the previous results of Stage2 and Stage 1. After all of you decided, you get feedback on by whom you are increased/reduced and how amount.

You can increase or reduce the tokens of all other member except for yourself.(N4 and ALL0.1 conditions)

You can increase or reduce the tokens of your subgroup members only. This 16 group members are divided to four subgroups. Each group consists of four members. The members of subgroup are fixed throuout the game. (LC0.1 and LC0,4 conditions)

### **Examples of choices you will make in 2<sup>nd</sup> stage and earnings**

Example 1: Suppose that you use 1 token for increase and 3 tokens for reduction, and the total amount the other members use for increasing your tokens is 4 and that for reducing your tokens is 2. You will earn:

9 (initial endowment) – 4 (the tokens you used for increase and reduce the others' tokens)

+ 3\*4 (the other members use for increasing your tokens) -2\*2(the other members use for reducing your tokens)

=13

These two stages are repeated 15 times. The total attained score is converted to money using the rate 1 token=0.7 yen, and the converted amount plus 500 yen (the show-up fee) is given to you at the end of this experiment.

*After this general instruction is given, all participants start the experiment after filling out a confirmation test.*

### **Confirmation Test**

Before you start to make your decision, you should solve all questions in the paper. Read carefully through the provided information provided and write down the number of points in the paper. We will watch you solving the examples, check whether you get the right answers, and help you if you have a problem or question.

### **Before the decision making**

Good, now everybody has solved the problems. If anybody has any more questions, raise your hand now. Otherwise let's practice how to input your decision on your

computer screen.

3.2. Screen shots of computer displays during the experiment.

1st stage  
You are B.

You are given 20 tokens.  
Please decide how many tokens you contribute to the group

Your decision

OK

Screen shot of computer display when the participants make decisions in the 1<sup>st</sup> stage.

You are F .

The result of the Stage1  
-----  
Total contributons : 150 tokens  
takens evenly shared to each member : 15 tokens  
-----

Contribution in the Stage1

A: 5 tokens  
B: 8 tokens  
C: 0 tokens  
D: 20 tokens  
E: 18 tokens  
F: 14 tokens  
G: 9 tokens  
H: 11 tokens  
I: 6 tokens  
J: 2 tokens  
K: 0 tokens  
L: 20 tokens  
M: 3 tokens  
N: 14 tokens  
O: 20 tokens  
P: 0 tokens  
-----

OK

Screen shot of computer display when showing feedback after the 1<sup>st</sup> stage. (LC0.1 and ALL0.1 conditions)

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**Stage 2**  
 You are F .

The results		You are given 9 tokens. Please decide how many tokens you use to give to or reduce from each member.	
tokens you are given or reduced in the Previous Stage2. <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             From A: —              From B: —              From C: —              From D: —              From E: -3 tokens              From G: 12 tokens              From H: 0 tokens              From I: —              From J: —              From K: —              From L: —              From M: —              From N: —              From O: —              From P: —           </div>	Contributions in this Stage1 <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             A: 5 tokens              B: 8 tokens              C: 0 tokens              D: 20 tokens              E: 18 tokens              F: 14 tokens              G: 9 tokens              H: 11 tokens              I: 16 tokens              J: 2 tokens              K: 0 tokens              L: 20 tokens              M: 3 tokens              N: 14 tokens              O: 20 tokens              P: 0 tokens           </div>	Amount of use to give tokens <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             To A: —              To B: —              To C: —              To D: —              To E: <input style="width: 50px;" type="text"/>              To G: <input style="width: 50px;" type="text"/>              To H: <input style="width: 50px;" type="text"/>              To I: —              To J: —              To K: —              To L: —              To M: —              To N: —              To O: —              To P: —           </div>	Amount of use to reduce tokens <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             To A: —              To B: —              To C: —              To D: —              To E: <input style="width: 50px;" type="text"/>              To G: <input style="width: 50px;" type="text"/>              To H: <input style="width: 50px;" type="text"/>              To I: —              To J: —              To K: —              To L: —              To M: —              To N: —              To O: —              To P: —           </div>

Screen shot of computer display when the participants make decisions in the 2<sup>nd</sup> stage.(LC0.1 and LC0.4 conditions)

**Stage 2**  
 You are F .

The results		You are given 9 tokens. Please decide how many tokens you use to give to or reduce from each member.	
tokens you are given or reduced in the Previous Stage2. <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             From A: 0 tokens              From B: -9 tokens              From C: 0 tokens              From D: 0 tokens              From E: -3 tokens              From G: 12 tokens              From H: 0 tokens              From I: 9 tokens              From J: 3 tokens              From K: 3 tokens              From L: 0 tokens              From M: 0 tokens              From N: -3 tokens              From O: 0 tokens              From P: 3 tokens           </div>	Contributions in this Stage1 <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             A: 5 tokens              B: 8 tokens              C: 0 tokens              D: 20 tokens              E: 18 tokens              F: 14 tokens              G: 9 tokens              H: 11 tokens              I: 16 tokens              J: 2 tokens              K: 0 tokens              L: 20 tokens              M: 3 tokens              N: 14 tokens              O: 20 tokens              P: 0 tokens           </div>	Amount of use to give tokens <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             To A: <input style="width: 50px;" type="text"/>              To B: <input style="width: 50px;" type="text"/>              To C: <input style="width: 50px;" type="text"/>              To D: <input style="width: 50px;" type="text"/>              To E: <input style="width: 50px;" type="text"/>              To G: <input style="width: 50px;" type="text"/>              To H: <input style="width: 50px;" type="text"/>              To I: <input style="width: 50px;" type="text"/>              To J: <input style="width: 50px;" type="text"/>              To K: <input style="width: 50px;" type="text"/>              To L: <input style="width: 50px;" type="text"/>              To M: <input style="width: 50px;" type="text"/>              To N: <input style="width: 50px;" type="text"/>              To O: <input style="width: 50px;" type="text"/>              To P: <input style="width: 50px;" type="text"/> </div>	Amount of use to reduce tokens <div style="border-top: 1px dashed black; border-bottom: 1px dashed black; padding: 5px;">             To A: <input style="width: 50px;" type="text"/>              To B: <input style="width: 50px;" type="text"/>              To C: <input style="width: 50px;" type="text"/>              To D: <input style="width: 50px;" type="text"/>              To E: <input style="width: 50px;" type="text"/>              To G: <input style="width: 50px;" type="text"/>              To H: <input style="width: 50px;" type="text"/>              To I: <input style="width: 50px;" type="text"/>              To J: <input style="width: 50px;" type="text"/>              To K: <input style="width: 50px;" type="text"/>              To L: <input style="width: 50px;" type="text"/>              To M: <input style="width: 50px;" type="text"/>              To N: <input style="width: 50px;" type="text"/>              To O: <input style="width: 50px;" type="text"/>              To P: <input style="width: 50px;" type="text"/> </div>

Screen shot of computer display when the participants make decisions in the 2<sup>nd</sup> stage.(ALL0.1 condition)

You are F .	
The results of this Stage2	
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From E : -6 tokens	
From G : 18 tokens	
From H : 9 tokens	
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Total amount you got in this Stage2 : 21 tokens	
	<input type="button" value="OK"/>

Screen shot of computer display when showing feedback after the 1<sup>st</sup> stage. (LC0.1 and LC0.4 conditions)