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Abstract

Second-order free riders, who do not owe punishment cost to first-order free riders in public goods games, lead to low cooperation. Previous studies suggest that for stable cooperation, it is critical to have a pool punishment system with second-order punishment, which gathers resources from group members and punishes second-order free riders as well as first-order free riders. In this study, we focus on the priority of punishment. We hypothesize that the pool punishment system that prioritizes second-order punishment is more likely to achieve cooperation than the system that prioritizes first-order punishment, because the former is more likely to obtain sufficient punishment resources. In the experiments, we compare four pool punishment systems: 1To2 (first-order punishment to second-order punishment), 2To1 (second-order punishment to first-order punishment), 1ONLY (first-order punishment only), and 2ONLY (second-order punishment only). We find that the 2To1 and 2ONLY systems can receive more support than the 1To2 and 1ONLY systems and only the 2To1 system can achieve high cooperation. However, the effect of priority of second-order punishment is observed only when the punishment ratio is low (Experiment 1), not high (Experiment 2), in which the punishment resource is relatively abundant.

Keywords: Cooperation, Pool punishment, Second-order free rider, Public goods, Social dilemma

1. Introduction

1.1. Public goods problem and peer punishment

Solutions to public goods problems, such as payment for public TV programs and preservation of the natural environment, are one of the most important issues for human society (1,2). The difficulty of providing such public goods is well formulated by using public goods games (PGGs). In a PGG, individuals in a group decide to contribute to the common pool, and the total amount of the contribution is shared equally by the group members. In this situation, free riders, who do not contribute but receive benefits from others' contributions, are more beneficial than cooperators are, and thus, a group faces a serious difficulty in providing public goods: everyone is worse off than they would have been had they all contributed fully to the public goods. Many studies have suggested that peer punishment could solve this free-rider problem because the benefits of free riders could be lower than the benefits of cooperators if free riders are punished seriously (3-7). However, if peer punishment is costly because of, for example, possible retaliation (8,9) and energy expenditure, then cooperators who do not punish will be better off than cooperators who punish will be. Thus, the provision of punishment of noncooperators is itself a collective act that can suffer another free-rider problem, which is sometimes called the second-order free-rider problem (8,10). As a result, second-order free riders, who do not owe the cost of punishment, can lead their group to a low cooperation level because a sufficiently high cost is not imposed on first-order free riders (noncooperators) to encourage them to refrain from free riding. The first-order punishment can be maintained by the punishment of the second-order free riders (nonpunishers), but this second-order punishment is costly and itself amounts to another collective act (11-13). Speaking in more general terms, to solve the first-order free-rider problem, we should resolve the second-order free-rider problem. However, to solve the second-order free-rider problem, we should resolve the third-order free-rider problem, and thus, the situation falls into infinite retrogression. Peer punishment appears vulnerable to infinite regression. In addition to this theoretical problem, recent anthropological survey revealed that peer punishment to free riders is very rare in small-scale societies, which are similar to an evolved environment (14).

1.2. Pool punishment system as a solution to the public goods problem

By considering the vulnerability of peer punishment, some researchers have focused on the pool punishment system, in which individuals opt to support a punishment system (e.g., a police force) and the system punishes free riders by using resources ("punishment fund") supported by members (15-17). Sigmund et al. (15) compared peer punishment with pool punishment and mathematically showed that the pool punishment system is more stable than the peer punishment system only when the system punishes not just the first-order free riders (noncooperators) but also the second-order free riders (nonsupporters), who do not contribute to the punishment system. Traulsen et al. (17) examined the pool punishment system in a laboratory experiment, which showed that participants tend to select pool punishment over peer punishment. In addition, the authors reported that systems with second-order punishment increased the number of people supporting the system, and thus, high cooperation is more likely to be achieved compared to the condition with only first-order punishment because the system with second-order punishment has sufficient resources to punish noncooperators.

1.3. The priority of first- and second-order punishment

In this study, we focus on the priority of first- and second-order punishment. Since punishment itself is costly and punishment resources are finite, it is important to prioritize punishment, namely, which kind of free riders ("noncooperators" or "nonsupporters") should be punished first, for the system to use the limited punishment resources effectively. However, previous studies about the pool punishment system with second-order punishment have ignored this question, probably for simplicity. For example, in the experiment of Traulsen et al. (17), in which group size is five, each of first- and second-order free riders are punished by 1 token when at least one member of the group decides to provide 0.5 tokens to the pool punishment system. In this situation, if there is only one supporter in the group, the pool punishment system can punish all four other noncooperators or nonsupporters by only 0.5 tokens each, but it seems especially effective to punish all of them with such a limited resource compared to the settings of previous studies (see the metaanalysis of Balliet (18))

Considering the priority of punishment, one may intuitively think that first-order free riders (noncooperators) should be punished first because the aim of pool punishment system is establishment of cooperation. However, we show that that intuition fails. We predict a group can establish a high cooperation level more easily in the system that prioritizes second-order punishment than in the system that prioritizes first-order punishment, because the former can construct a "punishment fund" more easily and lead to cooperative behavior.

By comparing a system with only first-order punishment and that with only second-order punishment, we can clarify the reason for this prediction in detail. On the one hand, in the system with only first-order punishment, a group suffers from the second-order free-rider problem because the second-order free riders (nonsupporters) are not punished. This leads to a shortage of resources to punish the first-order free riders (noncooperators), and thus, high cooperation is not achieved. In other words, the system with only first-order punishment is a social dilemma game and its rational outcome is only noncooperation and nonsupport by all members. On the other hand, in the system with only second-order punishment, the payoff structure does not always suffer from the free-rider problem, because it might be more beneficial for individuals to support the system in certain situations. We introduce a simple system with second-order punishment played by four members. First, each of the four members has 1 token and decides whether to support the system that is, to provide this token for the system. The system punishes nonsupporters by using the resources pooled by the supporters.

Supporters are never punished, and thus, their profit is zero. The profit of nonsupporters depends on the number of supporters and the punishment ratio (PR), which describes the sum of the profit reductions for the targeted members relative to the amount of support for the pool punishment system. Figure 1 shows the profit of supporters and nonsupporters with PR=1 and PR=3.

It is more beneficial for members to support the system than not to support it when two or three other members in PR=3 and three in PR=1 support the system. When no members in PR=3 and no or one other member in PR=1 supports the system, it is more beneficial for them not to support the system. This payoff structure suggests that the system with only second-order punishment is neither a PGG nor a social dilemma game, but a coordination game (19-21), in which the same behavior as the other members is more beneficial, and both support by all members and support by no members are Nash equilibria. Therefore, in the system with second-order punishment, it is possible that people contribute sufficiently to the punishment system. Moreover, previous studies about coordination games in laboratory experiments have suggested that participants tend to choose risk-averse options (20-23). In the system with only second-order punishment, the contribution for the punishment system is risk-averse choice, because supporters have no risk of being punished by the system. For this reason, the equilibrium of all supporters will be more likely to occur than the equilibrium of all nonsupporters.

Based on this argument, we consider the system equipped with both first- and second-order punishment. In the system that prioritizes second-order punishment, we predict that members tend to support the system more and the system can have sufficient resources to punish noncooperators in the PGG, which results in achievement of high cooperation. By contrast, in the system that prioritizes first-order punishment, the members will be less likely to support the system, which cannot punish noncooperators sufficiently and results in low cooperation.

1.4. Experimental design and hypotheses

In our study, we compare four pool punishment systems, which have only first-order punishment (1ONLY), only second-order punishment (2ONLY), first-order to second order punishment (1To2), and second-order to first-order punishment (2To1). We investigate which system enjoys sufficient support and establishes high cooperation in the PGG.

The experiment consists of a PGG stage and a pool punishment stage. As one set, these two stages are repeated 15 times among four group members with partner treatment. In the PGG stage, each member is given 20 tokens and decides how many tokens to contribute to his/her group from 0 to 20. The total contributions are multiplied by 1.6 and distributed equally to all members. In the pool punishment stage, each member is given another 9 tokens and decides how many tokens to provide (support) for the pool punishment system from 0 to 9. After this decision, the system punishes the members according to the rule of each condition. In the 1ONLY condition, the least cooperator in the group is punished first and subsequently, the second least is punished; this process continues until the punishment resources are exhausted. In the 2ONLY condition, the least supporter in the group is punished first and subsequently, the second least is punished; this process continues until the punishment resources are exhausted. The 1To2 and 2To1 conditions are combinations of the 1ONLY and 2ONLY conditions. In the 1To2 condition, if the punishment resources remain after the punishment for noncooperators, the remaining punishment resources are used for the punishment of nonsupporters. In the 2To1 condition, the order of punishment described above is reversed; nonsupporters are punished first and noncooperators second. Full cooperators, who contributed 20 to the group, are never punished in the first-order punishment and full supporters, who provided 9 to the system, are never punished in the second-order punishment. The punishment system of the four conditions is similar to the "relative punishment (penalty)" system employed by other experimental studies (24, 25)

Throughout all conditions, our pool punishment system uses resources provided by the members to reduce the tokens of the free riders, that is, less cooperators and/or less supporters. The system reduces the target's tokens to zero and the system spends its resources, which equals the amount of tokens the system reduced from the target. For example, if the system with 1ONLY has 30 tokens as punishment resources provided by the member before executing punishment. When the least cooperator, who owned 24 tokens, is punished, the 24 tokens are reduced from the least cooperator and the system spends 24 tokens as well. As a result, 6 tokens (=30-24) can be used to the second least cooperator. If the punishment resources are exhausted, the system can no longer punish. This system needs more resources for the larger number of free riders. We consider that this punishment system meets the requirements in real life: as the punishment resources are limited, the system always faces a risk of shortage to punish free riders sufficiently.

We manipulate PR to examine the effects of the amount of punishment resources on people's cooperation. In Experiment 1, PR is 1, which means that the total amount provided by all supporters becomes identically the punishment resources. In Experiment 2, PR is 3, which means that the total amount provided by all supporters is multiplied by 3 and that becomes the punishment resources. The priority of punishment is critical when the punishment resource is scarce. Under scarcity, only the system with 2To1 can obtain sufficient support because the system punishes nonsupporters first, and thus, the system can have sufficient resources to punish noncooperators in the PGG, which results in the achievement of high cooperation. The system with 1To2 suffers from a shortage of punishment resources to punish nonsupporters because the system punishes nonsupporters only after the system uses the limited resources to punish noncooperators. The shortage of resources must be more likely to occur under a low PR. If PR were higher, the system might be able to punish nonsupporters even after punishing all noncooperators because the punishment resources constraint is mitigated by the high PR. Therefore, the priority of first- and second-order punishment is not as important when PR is high. In this study, we examine this prediction by comparing a low PR, 1, and a high PR, 3.

Another important analysis concerns the "surplus of the pool punishment system," which is defined as the final residue that has not been used to punish. Historically, a punishment system was governed by a specific governor or a few governors of the group, such as headmen in villages, lords of manors, or kings of nations. They could obtain the surplus, and thus, might choose more profitable punishment system for themselves (26). Therefore, analysis of the surplus has implications for institutional choice by governors.

We propose the following two hypotheses.

H1: In 2ONLY and 2To1 conditions, in which second-order punishment has a priority, the participants are more likely to support the system than in 1ONLY and 1To2 conditions, in which first-order punishment has a priority.

H2: High cooperation is more likely to achieve in 2To1 condition than in the other three conditions.

H3: Difference of cooperation level between 2To1 condition and 1To2 is observed more clearly under low PR than under high PR.

2. Experiments

2.1. Methods

2.1.1. Participants

We recruited 172 undergraduate students in Experiment 1 and 116 undergraduate students in Experiment 2 from various disciplines using a university portal website. In each session, there were 8–16 participants. Each session was assigned to one of the four conditions (Experiment 1) and three conditions (Experiment 2). Participants were randomly separated into groups of four, and group members were fixed throughout the duration of the experiment according to a partner-matching design. In Experiment 1, 44 participated in 1To2 (11 groups), 52 in 2To1 (13 groups), 40 in 1ONLY (10 groups), and 36 in 2ONLY (9 groups). In Experiment 2, 36 participated in 1To2 (9 groups), 40 in 2To1 (10 groups), and 40 in 1ONLY (10 groups).

2.1.2. Procedure

In all conditions, participants were assigned to laboratory booths to ensure their anonymous and independent decisions. After reading explanations, participants were questioned on the experiment details. All participants completely understood the rules of all transactions and could calculate their payoffs. Participants were then randomly and anonymously allocated to groups of four, and these groups played the PGG and punishment stages (detailed account of these stages are given below). The participants knew that the group composition would be unchanged throughout the experiment, that the periods would be repeated 15 times, and that tokens earned during transactions would be redeemed for money.

PGG stage. Each of the four members 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 was subtracted from his/her endowment of 20 tokens. The total tokens each member contributed were multiplied by 1.6 and distributed equally to the group members.

Pool punishment system stage. Each member was given another 9 tokens at the beginning of the stage. Each member simultaneously decided how many tokens he/she would provide (support) to his/her pool punishment system from 0 to 9. In Experiment 1, total tokens provided to the system became the punishment resources of the system and in Experiment 2, total provided tokens were multiplied by three, becoming the punishment resources of the system.

The punishment rule varied among conditions. In the 1ONLY condition, the first-order free riders—less cooperators—were punished in the following order. First, the least cooperator's tokens were reduced to zero. The second least, third least, and fourth least cooperators were punished in that order. If there were more than two members who contributed the same amount, the order was determined at random. A full cooperator, who contributed 20 tokens, was never punished. When the system reduced one member's tokens to zero, the punishment resources of the system also decreased by the same amount. When the system cannot reduce the tokens of the member to 0 because of the shortage of punishment resources, the system reduced as many tokens as possible. After the punishment resources become 0, the system cannot punish any more.

In the 2ONLY condition, second-order free riders—less supporters—were punished in the following order. First, the least supporter was punished. Next, the second least, third least, and fourth least supporters were punished in that order. Except for the order of being punished, the punishment rule was the same as in the 1ONLY condition.

In the 1To2 condition, the first-order punishment was executed first followed by the second-order punishment. In the 2To1 condition, the second-order punishment was executed first, followed by the first-order punishment. The punishment rule was the same in these conditions.

The PGG results were provided to all members after the decision of support. We applied Traulsen et al.'s (2) assumption that the nature of the pool punishment system is to decide whether to support the punishment organization to establish the organization before the results of the PGG. All members were informed who had been punished and by how much immediately after the decision of support for the system (see supplementary method).

These two stages were repeated 15 times. We used z-Tree software (27) to conduct the experiments. Each session took approximately 70 minutes to complete on average. The total attained score was converted to money using the rate 1 token = 0.7 yen (100 yen = +- 1 US dollar), and a 500-yen show-up fee was given to participants who concluded the experiment. The average remuneration was 2,117 yen. Written informed consent was obtained from all subjects prior to beginning the experiment.

2.2. Results: Experiment 1

In Experiment 1, PR was 1. The data were analyzed at the group level to take into account interdependence of outcomes for members of a given group. All the multiple comparison results of the nonparametric analyses were corrected by Bonferroni's method.

The total PGG contribution, total support for the system, group profit, and system's surplus (= total support – total use for punishment) were calculated for each period (Figure 2). We compared the average of each index of the second half of the periods, that is, from the 8th to 14th periods, when participants had sufficient time to settle on their conditions. We excluded the final (15^{th}) period from the data, because all participants knew it would be the last, and therefore, they were considered to behave differently. Mann–Whitney U-tests were conducted to determine whether a difference existed between the conditions.

Participants in the 2To1 and 2ONLY conditions supported the system more than did those in the 1ONLY and 1To2 conditions (2To1vs1ONLY, U=0, p< .001; 2To1vs1To2, U=3, p< .001. 2ONLYvs1ONLY, U=2, p=.001; 2ONLYvs1To2, U=3, p=.001). There were no significant differences in the other comparison of conditions (2To1vs2ONLY, U=56.5, p=1.00.; 1To2vs1ONLY, U=41.5, p=1.00). These results are consistent with H1, that is, participants support the system more in the system that prioritized second-order punishment. Moreover, high cooperation was more likely in the 2To1 condition than in the 1To2 (U=18.5, p=.007), 1ONLY (U=21, p=.027), and 2ONLY (U=5, p<.001) conditions. There were no differences in the other comparisons of conditions (1To2vs1ONLY, U=39.5, p=1.00; 1To2vs2ONLY, U=27, p=.571; 1ONLYvs2ONLY, U=14, p=.061). These results are consistent with H2, that is, high cooperation is more likely in the 2To1 condition than in the other three conditions.

Group profit was lower in the 2ONLY condition than in the 1To2 (U=7, *p*=.003) and

1ONLY (U=4, *p*=.002) conditions, while there were no differences in the other comparison of conditions (1To2vs1ONLY, U=32, p=.687; 1To2vs2To1, U=66, p=1.00; 1ONLYvs2To1, U=46, p=1.00; 2onlyvs2To1, U=23, p=.091). Although the 2To1 condition could achieve high cooperation, the condition could not obtain higher profit than the other conditions, because punishment cost to maintain high cooperation was higher in the 2To1 condition than in the other conditions and support for the system continued even after full contributions were achieved. This low efficacy in the 2To1 condition is consistent with previous studies of the pool punishment system (15,17). The system's surplus was higher in the 2ONLY and 2To1 conditions than in the 1ONLY and 1To2 conditions (2To1vs1ONLY, U=20, *p*=.010; 2To1vs1To2, U=25, *p*=.011 2ONLYvs1ONLY, U=5, *p*=.001; 2ONLYvs1To2, U=6, *p*<.001). There were no significant differences in the other comparison of conditions (2To1vs2ONLY, U=52, p=1.00; 1To2vs1ONLY, U=50, p=1.00). This suggests that the system prioritizing second-order punishment could receive more surplus, which might result in more profit for the system's governor(s).

2.3. Results: Experiment 2

In Experiment 2, the PR moved from 1 to 3. This experiment investigated whether the effect of the priority of the first- and second-order punishment would be the same even with higher punishment efficiency. We predicted that the priority was not critical for cooperation when punishment resources were relatively sufficient (H3). We eliminated the 2ONLY condition in Experiment 2. The 2ONLY condition in Experiment 1 shows that the system was supported fully and could yield large profit, but the group could not achieve high cooperation. It is natural to assume that this result would be replicated in Experiment 2.

The total PGG contribution, total support for the system, group profit, and system's surplus were calculated for each period (see Figure 3). The analyses for the second half were conducted. Support for the system was higher in the 1To2 and 2To1 conditions than in the 1ONLY condition (1To2vs1ONLY, U=0, p>.001, 2To1ONLY, U=0, p>.001). There was no significant difference between the 2To1 and 1To2 conditions (U=36, p=.957). We observed the same tendency in the PGG contribution: it was higher in the 1To2 and 2To1 conditions than in the 1ONLY condition (1To2vs1ONLY, U=0, p>.001, 2To1ONLY, U=5, p>.001), but there was no significant difference between the 2To1 and 1To2 conditions (U=36, p=1.00). Unlike Experiment 1, the priority of the first- and second-order punishment did not matter to induce support and high PGG cooperation in Experiment 2. These results clearly reveal that to achieve high PGG cooperation, second-order punishment matters, but the importance of the priority of the first- and second-order punishment depends on PR.

Next we performed an analysis to understand why the 1To2 condition in Experiments

1 (PR=1) and 2 (PR=3) was completely different regarding members' choices. Figure 4 shows the punishment resources before the second-order punishment, that is, the remaining resources after the first-order punishment, and actual use for the second-order punishment in the 1To2 conditions. The punishment resources were richer in Experiment 2 than in Experiment 1 in the first half ($U=0$, $p<.001$) and second half ($U=0$, $p<.001$) and the punishment use was higher in Experiment 2 in the first half ($U=11$, $p=.011$). These results suggest that because of richer punishment resources, nonsupporters were punished more frequently in Experiment 2 than in Experiment 1. This is because the punishment resources in Experiment 2 were three times as high as in Experiment 1 even with the same support amount. Thus, the systems in Experiment 2 could keep more residue of punishment resources than those in Experiment 1 could after the systems punished noncooperators (see Supplementary analysis for further explanation).

Lastly, the group profits were not different among conditions (1To2vs1ONLY, $U=33$, $p=.980$, 1TO2vs2TO1, $U=35$, $p=.957$; 1ONLTvs2TO1, $U=35$, $p=.345$). The system surplus was higher in the 1To2 and 2To1 conditions than in the 1ONLY condition (1To2vs1ONLY, $U=0$, $p>.001$, 2To1ONLY, $U=0$, $p>.001$), but there was no significant difference between the 2To1 and 1To2 conditions ($U=35$, $p=1.00$), as both 1To2 and 2To1 conditions could induce stable support by members.

3. Discussion

3.1. Importance of punishment priority in pool punishment system

In these experiments, we focused on the priority of first- and second-order punishment in pool punishment systems. The results of Experiment 1 revealed that placing priority on the second-order punishment is critical for establishing cooperation in the PGG. As discussed in the introduction, the pool punishment system with only second-order punishment is not a social dilemma game, but a coordination game, and thus, full support by all members forms one of the equilibria. The results of the 2ONLY condition in Experiment 1 suggest that the risk-dominant equilibrium, that is, full support for the system by all members, was more likely to be chosen than the other equilibria. In the 2To1 condition, the pool system could punish noncooperators by using the residue of punishment resources, because the number of nonsupporters was relatively small. By contrast, in the 1To2 condition, the second-order free-rider problem occurred: the system could not punish noncooperators, because of a shortage of support by the members. The original purpose of the pool punishment system was to establish high cooperation in the PGG, and to achieve this purpose, the punishment not of noncooperators in the PGG but of nonsupporters of the punishment system should be prioritized. This conclusion seems to be counter-intuitive.

In Experiment 2, in which the punishment resources are abundant (PR=3), the effect of the priority disappeared. High cooperation was achieved regardless of the priority of the first- and second-order punishment. This was because under abundant punishment resources, the nonsupporters could be punished even after the first-order punishment, and thus, the priority was no longer critical. The results of Experiments 1 and 2 suggest that the priority is nonnegligible when the punishment resources are scarce. We can claim that the priority of second-order punishment in the pool system is applicable to a wider range of real life, in which resources are usually scarce. For example, when the members of a group do not have sufficient resources to support the system, the system tends to lack the resources to punish noncooperators even if the punishment ratio is not small. Alternatively, when the default of cooperation level is quite low in a group, the pool system needs a large amount of resources to punish noncooperators and tends to lack such resources. Even in those cases, the pool system that gives priority to second-order punishment will be more likely to obtain high and general support and to achieve high cooperation in the PGG by effective punishment. When we intend to implement the pool punishment system to achieve high cooperation in real life, it is worth examining the priority of first- and second-order punishment.

3.2. Future development: institution selection by governor and governed

To explore the further possibilities of this research, we clarify the points that concern the surplus of the system itself. As some individual, presumably a governor, such as a king or queen, has governed actual pool punishment systems historically, she/he might be interested in the surplus of the system, which could be his/her economic base. Our results suggest that the system that prioritizes second-order punishment obtains higher surplus than the system that prioritizes first-order punishment. Hence, the rational selfish king or queen would choose 2To1 over 1To2, and therefore, a more socially efficient system could be chosen by him/her. It is interesting to mention the possibility that pursuing private interest could promote the public interest. Of course, a selfish governor also has an incentive to choose 2ONLY. In Experiment 1, the system with 2ONLY receives as much profit as does the system with 2To1. In the system with 2ONLY, group members do not cooperate but support the system to be unpunished so that only the governor benefits. In other words, the pool punishment system has the potential risk of leading to tyranny. Recently, Ozono et al. (26) conducted an experiment in which the pool punishment system was governed by a participant and he/she could freely punish group members. The authors found that some governors of the system punished both first- and second-order free riders spontaneously and the group resulted in high cooperation, but other governors punished only nonsupporters and received a certain benefit. This finding is consistent with the arguments presented earlier in this section.

Now, we consider an institution selection problem from the viewpoint of both the governors and governed. Hilbe et al. (28) examined whether participants chose a pool punishment system with or without second-order punishment, using a "voting with feet" paradigm, in which each participant could freely choose and change the system to which they belonged. The authors revealed that the participants tended to choose the punishment system without second-order punishment, especially at the beginning of the experiment. If both the governed and governor of the system could choose punishment system rule, the system with second-order punishment (in our experiment, the 2TO1 condition) might be chosen more than that without second-order punishment (in our experiment, the 1ONLY condition), because the former is more beneficial for governors. The governors, however, have an incentive to choose 2ONLY, so if the governed cannot migrate easily, tyrannical states are more likely to emerge. As far as we know, no prior study has investigated the dynamic process of system choice by both governors and the governed, and this is a promising approach to study the development of punishment systems in real life.

Ethics. The Waseda University Ethical Review Board specifically approved this study. Written informed consent was obtained from all participants prior to beginning the experiment.

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References

1. Hardin G. 1968 The Tragedy of the Commons. *Science* **162**, 1243. (doi:10.1080/19390450903037302)
2. Olson M. 1965 *The Logic of Collective Action: Public Goods and the Theory of Groups* , Harvard University Press, Cambridge.
3. Fehr E, Gächter S. 2000 Cooperation and punishment in public goods experiments. *Am. Econ. Rev.* **90**, 980–994. (doi:10.1257/aer.90.4.980)
4. Fehr E, Gächter S. 2002 Altruistic punishment in humans. *Nature* **415**, 137–140. (doi:10.1038/415137a)
5. Ostrom E, Walker J, Gardner R. 1992 Covenants with and without a sword: Self governance is possible. *Am. Pol. Sci. Rev.* **86**, 404-417. (doi:10.2307/1964229)
6. Rand DG, Dreber A, Ellingsen T, Fudenberg D, Nowak MA. 2009 Positive interactions promote public cooperation. *Science* **325**, 1272–1275. (doi:10.1126/science.1177418)
7. Boyd R, Richerson P. 1992 Punishment allows the evolution of cooperation (or anything

else) in sizable groups. *Ethol. Sociobio.* **13**, 171-195. (doi: 10.1016/0162-3095(92)90032-Y)

8. Cinyabuguma M, Page T, Putterman L. 2006 Can second-order punishment deter perverse punishment? *Exp. Econ.* **9**, 265-279. (doi: 10.1007/s10683-006-9127-z)
9. Nikiforakis N. 2008 Punishment and counter-punishment in public good games: Can we really govern ourselves? *J. Public. Econ.* **92**, 91-112. (doi:10.1016/j.jpubeco.2007.04.008)
10. Panchanathan K, Boyd R. 2004 Indirect reciprocity can stabilize cooperation without the second-order free rider problem. *Nature* **432**, 499-502. (doi:10.1038/nature02978)
11. Henrich J, Boyd R. 2001 Why people punish defectors: Weak conformist transmission can stabilize costly enforcement of norms in cooperative dilemmas. *J. Theor. Biol.* 208, 79-89. (doi:10.1006/jtbi.2000.2202)
12. Yamagishi T. 1986 The provision of a sanctioning system as a public good. *J. Pers. Soc. Psychol.* **51**, 110–116. (doi:10.1037/0022-3514.51.1.110)
13. Oliver P. 1980 Rewards and punishments as selective incentives for collective action: theoretical investigations. *Am. J. Sociol.* 1356-1375. (doi:10.1086/227168)
14. Guala F. 2012 Reciprocity: Weak or strong? What punishment experiments do (and do not) demonstrate. *Behav. Brain. Sci.* **35**, 1-59. (doi:10.1017/S0140525X11000069)
15. Sigmund K, De Silva H, Traulsen A, Hauert C. 2010 Social learning promotes institutions for governing the commons. *Nature* **466**, 861–863. (doi:10.1038/nature09203)
16. Perc M. 2012 Sustainable institutionalized punishment requires elimination of second-order free-riders. *Scient. Rep.* **2**, 344. (doi:10.1038/srep00344)
17. Traulsen A, Röhl T., Milinski M. 2012 An economic experiment reveals that humans prefer pool punishment to maintain the commons. *Proc. R. Soc. B.* 279, 3716–3721. (doi: 10.1098/rspb.2012.0937)
18. Balliet D, Mulder LB, Van Lange PA. 2011 Reward, punishment, and cooperation: a meta-analysis. *Psycho. Bull.* **137**, 594-615. (doi:10.1037/a0023489)
19. Cooper RW, DeJongDV, Forsythe R, Ross T W. 1990 Selection criteria in coordination games: Some experimental results. *Am. Econ. Rev.* **80**, 218-233.
20. Van Huyck JB, Battalio RC, Beil RO. 1990 Tacit coordination games, strategic uncertainty, and coordination failure. *Am. Econ. Rev.* **80**, 234–248.
21. Van Huyck JB, Battalio RC, Beil RO. 1991 Strategic uncertainty, equilibrium selection, and coordination failure in average opinion games. *Q. J. Econ.* **106**, 885–910.
22. Devetag G, Ortmann A. 2007 When and why? A critical survey on coordination failure in the laboratory. *Exp. Econ.* **10**, 331-344. (doi:10.1007/s10683-007-9178-9)
23. Kamijo Y, Ozono H, Shimizu K. 2016 Overcoming coordination failure using a mechanism

based on gradualism and endogeneity. *Exp. Econ.* **19**, 202-217. (doi: 10.1007/s10683-015-9433-4)

24. Kamijo Y, Nihonsugi T, Takeuchi A, Funaki Y. 2014 Sustaining cooperation in social dilemmas: Comparison of centralized punishment institutions. *Games. Econ. Behav.* **84**, 180-195. (doi:10.1016/j.geb.2014.01.002)
25. Yamagishi T. 1986 The provision of a sanctioning system as a public good. *J. Pers. Soc. Psycho.* **51**, 110-116. (doi:10.1037/0022-3514.51.1.110)
26. Ozono H, Jin N, Watabe M, Shimizu K. 2016 Solving the second-order free rider problem in a public goods game: An experiment using a leader support system. *Scient. Rep.* **6**, 38349. (doi:10.1038/srep38349)
27. Hilbe C, Traulsen A, Röhl T, Milinski M. 2014 Democratic decisions establish stable authorities that overcome the paradox of second-order punishment. *Proc. Natl. Acad. Sci. U S A.* **111**, 752-756. (doi:10.1073/pnas.1315273111)
28. Fischbacher U. 2007 z-Tree: Zurich toolbox for ready-made economic experiments. *Exp. Econ.* **10**, 17-178. (doi:10.1007/s10683-006-9159-4)

Figure 1. Profit of supporters and nonsupporters with PR=1 and PR=3 in the pool system with only second-order punishment

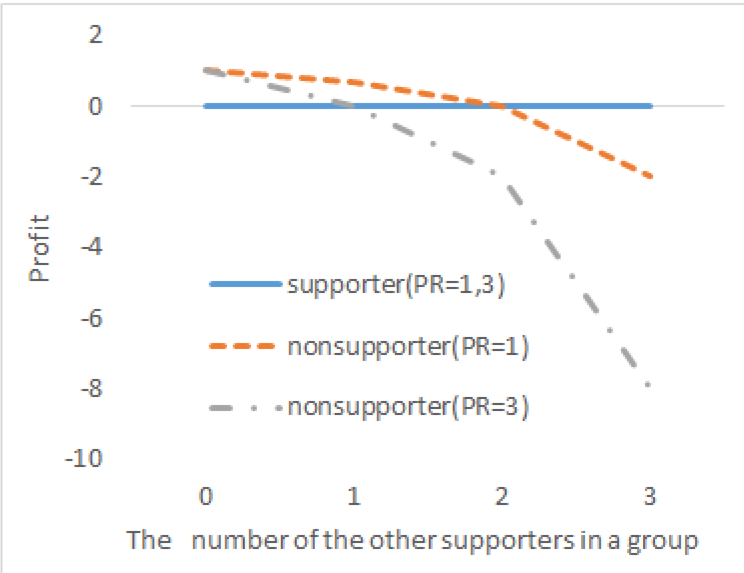


Figure 2. (A) Total PGG contribution, (B) total support for the system, (C) group profit(C), and

(D) system's surplus (= total support – total use for punishment) over 15 periods of play under four conditions in Experiment 1 (error bars denote standard errors).

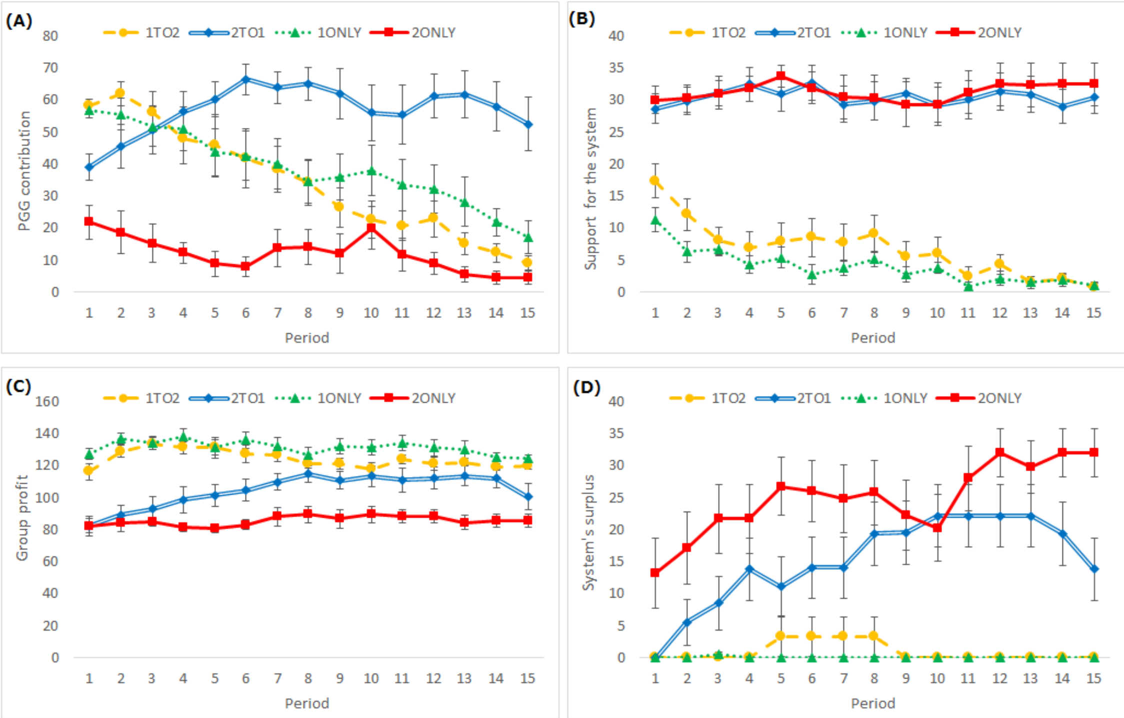


Figure 3. (A) Total PGG contribution, (B) total support for the system, (C) group profit, and (D) system's surplus (= total support – total use for punishment) over 15 periods of play under three conditions in Experiment 2 (error bars denote standard errors).

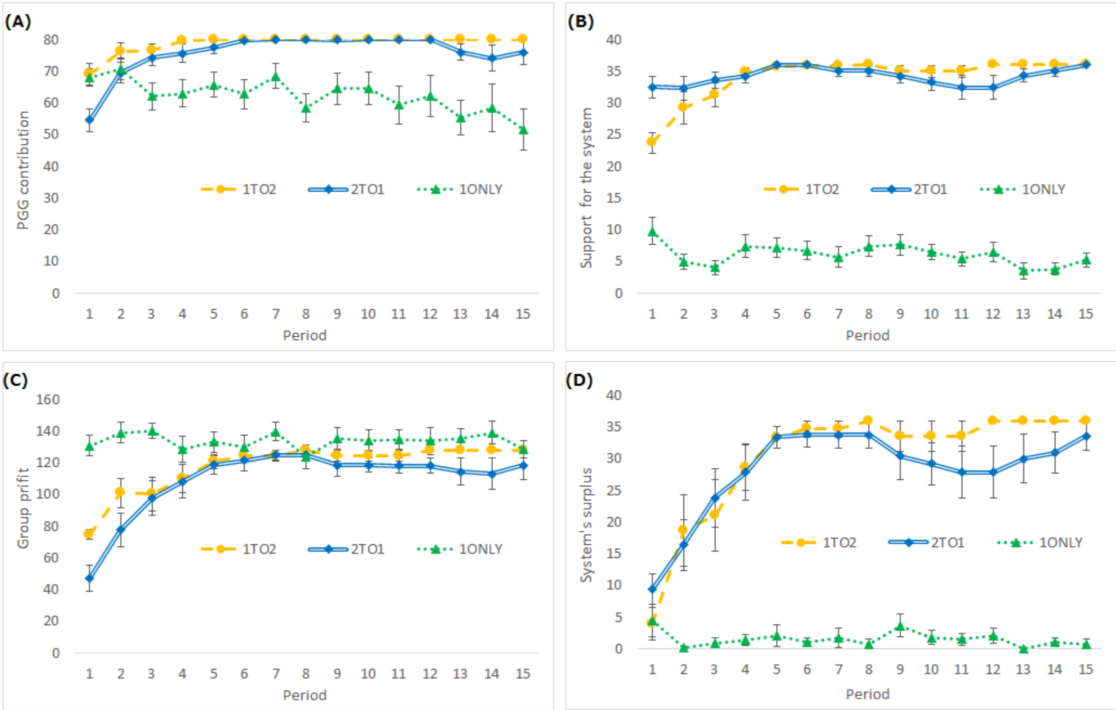
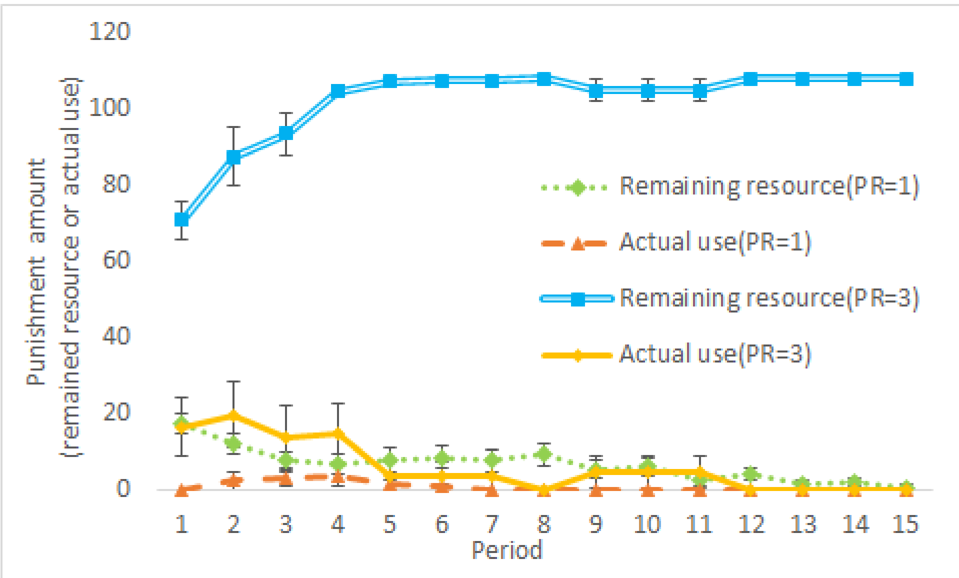


Figure 4. Remainder of punishment resources before second-order punishment and actual use of second-order punishment under 1To2 condition in Experiments 1 (PR=1) and 2 (PR=3) (error bars denote standard errors).



Supplementary analysis

The reasons why the amount of punishment resources for the second-order punishment is abundant in Experiment 2.

There are several reasons why the amount of punishment resources for the second-order punishment is abundant in Experiment 2. First, as written in the main text, the punishment resources in Experiment 2 are three times as much as in Experiment 1 even if the support amount is the same, and thus, the systems in Experiment 2 can keep more residue of punishment resources than can the systems in Experiment 1 after the systems have punished noncooperators, The second reason is encapsulated by the following concept : “As the punishment resources are rich, I will be punished if I don’t cooperate.” Since the PR=3 condition correlates the current choice with the future (possible) punishment, it can enhance cooperation in the current period. As a result, the cost for first-order punishment may be less in Experiment 2 than in Experiment 1 and more resources can be used for second-order punishment in Experiment 2. The data supported this argument. The PGG contribution was higher in Experiment 2 than in Experiment 1 both in the first half ($p<.001$) and second half ($p<.001$). In addition, the PGG contribution in the first period in Experiment 2 was higher than in Experiment 1 ($p=.016$), which suggests that the participants in Experiment 2 expected the first-order punishment more probably before the game started. Third, the punishment resources for the second-order punishment remained rich because of the high level of cooperation in PGG, and thus, the participants supported the system more to avoid the second-order punishment and the punishment resources increased. Actually, the support amount was higher in Experiment 2 than in Experiment 1 both in the first half ($p<.001$) and second half ($p<.001$) as an absolute value. While the support amount in the first period was not different between Experiments 1 and 2 ($p=.12$), the participants in Experiment 2 gave more support in the second period than in the first period (Wilcoxon matched-pairs signed-rank test: $p=.047$). By contrast, the participants in Experiment 1 seemed to give less support in the second period than in the first period (Wilcoxon matched-pairs signed-rank test: $p=.063$). These results suggest that the participants in Experiment 2 might realize the second-order punishment would be executed after experiencing the first period but the participants in Experiment 1 might not think so. For the abovementioned three reasons, as for the 1To2 conditions, the second-order punishment was more effective and the members were more cooperative in Experiment 2 than in Experiment 1.

Supplementary method

1. **Instruction of the experiment**

After a brief verbal introduction, participants read the following instructions on the computer monitor telling them that they will 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 in cash for your decisions privately.

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 4 (you plus 3 others) and you will be asked to make a series of choices about how to allocate a set of tokens. You and the other participants has been randomly assigned to the group, and you *will not* be able to know each other's identities. But the group members remained the same throughout the experiment.

The details of the experimental transactions are as follows. Four members named A, B, C and D will play the same role. The experiment comprised two stages, 1st stage and 2nd stage. 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.

1st stage:

Each of the four members are contribute 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 the 0.4 of the sum of the tokens is given to all 4 members including you. each. 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 1st 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 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 4 members contributed)

=20

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

20 (initial endowment) - 4 (the tokens you contributed)

+ 0.4 * 35(the sum of tokens 4 members contributed)

=30

2nd stage (1TO2 condition with PR=1):

Each of the four members are given another 9 tokens at the beginning of this stage. The members are asked to decide how many tokens to provide to the "reduction system" from 0 to 9. Total tokens provided to the system became the "reduction resources" of the system.The system reduces the members in the following order. There are two steps.

Step 1

In Step 1, first, the least contributor for the group pool in the 1st stage just before this 2nd stage is reduced their tokens: the tokens the least contributor has are reduced to zero. Next, the second least, third least, and fourth least contributors are reduced in that order. If there are more than two members who contributed the same amount, the order is determined at random. A full contributor, who contributed 20 tokens, is never punished. When the system reduced one member's tokens to zero, the repuction resources of the system also decreased by the same amount. For example, imagine the situation in which the initial reduction resources of the system is 40 and the least contributor had 28 tokens before being reduced. When the least contributor is punished, his/her tokens are reduced from 28 to 0 by the system and the reduction resources decrease from 40 to 12 (=40−28) tokens. When the system cannot reduce the tokens of the member to 0 because of the shortage of reduction resources, the system reduces as many tokens as possible. For example, imagine a situation in which the initial punishment resources of the system is 10 and the least contributor had 22 tokens before being reduced. When the least contributor is reduced, his/her tokens are reduced from 22 to 12(=22−10) by the system and the reduction resources decrease from 10 to 0 (=10−10) tokens. After the reduction resources become 0, the system cannot reduce the members' tokens any more.

Step 2

In Step 2, less providers for the reduction system in this 2nd stage are reduced their token if reduction resources are not drained in Step 1. The system reduces the members' token in the following order. First, the least provider is punished. Next, the second least, third least, and fourth least providers are punished in that order. Except for the order of being reduced, the reduction rule is completely the same as in Step 1, that is, less providers are reduced their tokens to 0 and full providers, who provided 9 tokens to the system, are never reduced.

-Examples of choices you will make in 2nd stage and earnings

Suppose that contribution of A, B,C and D in the 1st stage is 10, 2, 8 and 0 respectively and the provision to the reduction system in the 2nd stage is 9, 7, 9 and 8 respectively. In this case, the total amount each member received before the reduction in step 1 is 18, 28, 20 and 29 respectively and the total provision to the reduction system (= reduction resources) is 33 (=9+7+9+8).

In Step1, First, D is the least contributor, so D's tokens are reduced from 29 to zero (=29 -29).
The system use 29 tokens to reduce D's tokens and the reduction resources becomes 4 (=33-29).
Second, B is the second least contributor. The system does not have reduction resources enough to reduce all of B' 28 tokens, so the system reduces as many tokens as possible. As a result, B's tokens reduce from 28 to 24 (=28-4).
The reduction resources becomes zero(=4-4), so the system cannot reduce the other members any more.

In this case, the system cannot reduce in Step 2, because there are no reduction resources.
But if reduction resources are not drained in Step 1, Next, less providers for the reduction system in this 2nd stage are reduced their token .

Feedback
The results of stage 1, that is, how many tokens each member contributed to the group pool, are provided to all members after the decision of provision for the system in stage 2. All members are informed who has been reduced and by how much immediately after the decision of provision for the reduction system.

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

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

Confirmation Test

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

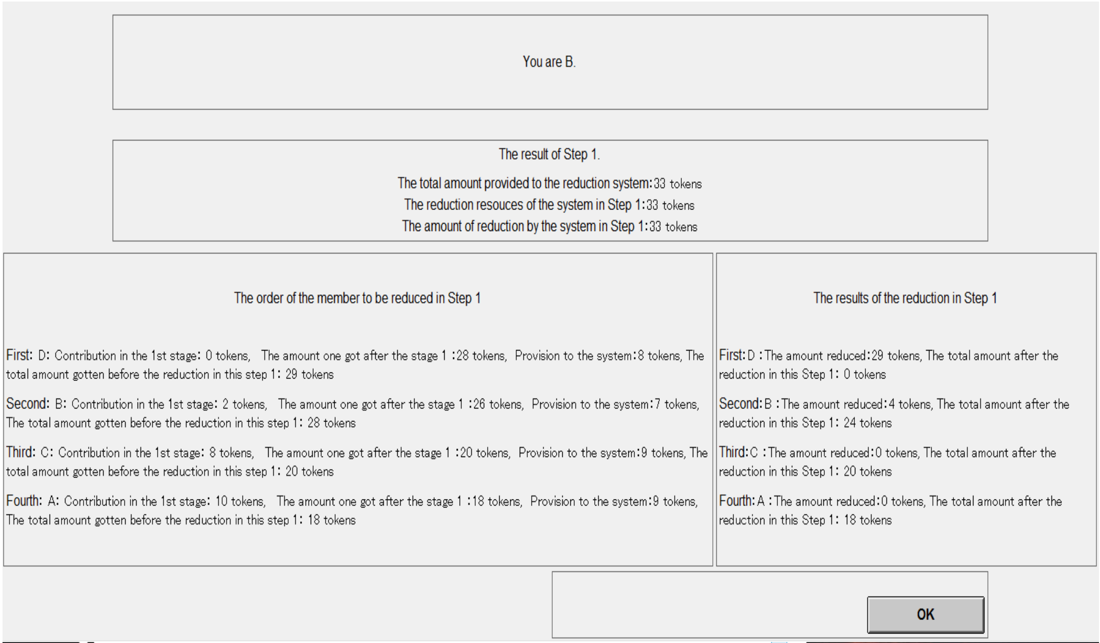
Before the decision-making

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

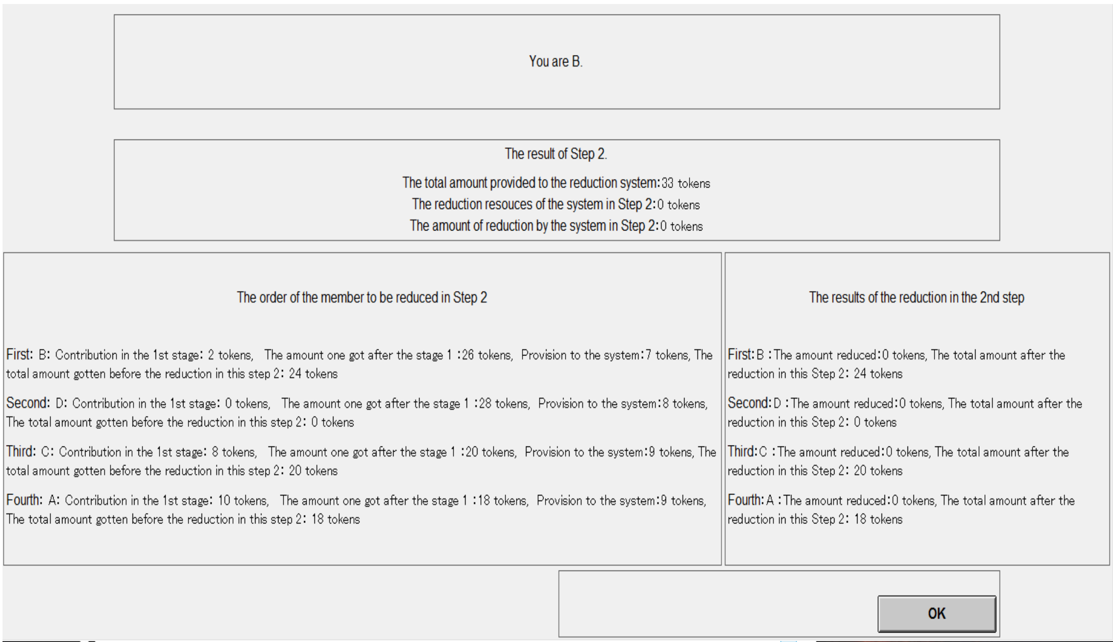
2. Screen shots of computer displays during the experiment.

Screen shot of computer display when the participants make decisions in the 1st stage.

Screen shot of computer display when participants make decisions in the 2nd stage.



Screen shot of computer display when showing feedback of Step 1 of the 2nd stage.



Screen shot of computer display when showing feedback of Step 2 of the 2nd stage.