“Do humans play according to the game theory when facing the social dilemma situation?” A survey study.

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https://doi.org/10.5109/2740936

出版情報：Evergreen. 7 (1), pp.7-14, 2020-03. 九州大学グリーンテクノロジー研究教育センター
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"Do humans play according to the game theory when facing the social dilemma situation?" A survey study.

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(Received March 11, 2020; Revised March 31, 2020; accepted March 31, 2020).

Abstract: The aim of this study is to verify whether a human can detect the social dilemma class and its strength for four various games: Prisoner's dilemma, Trivial, Chicken, and Stag-Hunt by using a web-based structural cross-sectional survey. We considered respondent's cooperative and defective behavior by designing multiple sets of 2 × 2 games for two classes in terms of game opponents: whether he is an intimate friend or an unknown person in the questionnaire. In total, 375 respondents participated in this survey. We found that Prisoner's dilemma and Trivial game are recognized easily by the respondents, but they are not aware of the dilemma strength and difference of game opponent's attribute whether the opponent is a close or unknown person.

Keywords: Dilemma strength; Cooperation fraction; Experimental survey; Game theory.

1. Introduction

People have some basic moral characteristics by birth, whereas cooperation and defection are the two most prominent one's among them. Usually, cooperation is profoundly admired since childhood to death. Meanwhile, the set of cooperation(C) and defection (D) is regarded as the common scenario in the game theory, which is called strategy[1]. A game is defined as a set of strategy and payoff structure that models the human decision-making process with the premise that a player intends to maximize his own benefit.

Game theory was published by Morgenstern and Von-Neumann in 1944 [2], which intends to model and quantify the human decision-making process in a quite simplified template the applied mathematics can deal with. The most fundamental template is the so-called symmetric 2-player and 2-strategy game, called 2 × 2 game, where two unacquainted players out of infinite and well-mixed population (that is an environment without any 'social viscosity'[3]), are imposed to choose whether C or D, of which game structure is denoted by the payoff matrix; $\begin{bmatrix} R & S \\ T & P \end{bmatrix}$, where *R (P)* indicates the payoff when mutually cooperating (defecting), *S (T)* means the payoff of the focal player when he cooperating (defecting) but his opponent defecting (cooperating). Although there have been many precursors dedicated to the stock of game theory as well as evolutionary game theory (EGT), recently a new idea to quantify 'dilemma strength' for a 2 × 2 games was introduced [4,5], in which,

$$D_g = T - R \quad (1)$$

$$D_r = P - S \quad (2)$$

$$D_g^{/} = \frac{D_g}{(R-P)} \quad (3)$$

$$D_r^{/} = \frac{D_r}{(R-P)} \quad (4)$$

where D_g indicates the gamble-intending dilemma (GID) — the inclination of two equal players to exploit each other, while D_r indicates the risk-aversion dilemma (RAD) — the inclination of equal players trying never to be exploited. Tanimoto and his colleagues[4,5] further introduced $D_g^{/}$ and $D_r^{/}$ that are defined as respectively normalized D_g and D_r ,because the dilemma strength with a certain mechanism adding social viscosity is quantitatively affected by *R* - *P*.

Although the game theory as well as evolutionary game theory are well accepted, many works have been wheeled around its theoretical aspect or taking simulation approaches to solve down-to-earth questions; for instance, why cooperative behavior has been evolutionally favored

Table 1. Summary of the general design.

Focal point	Detail
Game structure	Symmetric 2 × 2 game
Game class	Whether a responder can understand game classes: Prisoner's dilemma (PD), Trivial (TR), Chicken (CH) and Stag-Hunt (SH). In CASE I, PD and Trivial are paired, while in CASE II, CH and SH are paired.
Game dilemma strength	Whether a responder can distinguish dilemma strength: D_g (D_r) and $D_g^{/}$ ($D_r^{/}$).
Social viscosity resulting from the assumption of a game-opponent	Whether a game-opponent is an *intimate friend/unknown person* to a responder.

in many animal species from human being to nature[6]. The experimental works vis-à-vis theory and simulation have been extensively studied, many pioneers have tried to validate the game theory by intrigued experimental efforts. Only with respect to recent experimental studies on 2 × 2 game, we can itemize as below: Leonie et al.[7] shed light on mixed strategy setting in their experimental setting, Valerio et al.[8], studied on how social preference influencing the relationship between the ratio of benefit vs cost and cooperation level, Filippos et al. [9] focuses on how the short-range mobility of people affecting cooperation, and Alberto et al.[10] introduced experimental version of spatial game setting. Fort et al.[11] focused on the update rule which enhances cooperation, Jelena et al.[12] stated the impact of the cooperation on the moody and heterogeneous situation, and more; Normann et al.[13], and Hauert et.al.[14]. Other than 2 × 2 game settings, there have been affluent experimental works concerning Public Goods Game [15-33], experimental economics across subject populations [34], when faced with a new game, participants use strategies that reflect both behavioral spillover and cognitive load effects [35], subjects with low accuracy do not tend to retaliate more than those with high accuracy [36], the average intelligence of the world's appears, help to create a more cooperative world [37] , in experimentally, the more cooperative is raised when the dilemma situation becomes less [38], the cooperation of the partner increases in the repeated games for a long horizon and no significant distinguish with a short period of time [39], experience subjects play the vital role for the emergence of cooperation in the repeated prisoner's dilemma games [40], subjects appear to use a "loss-avoidance" selection principle: they expect others to avoid strategies that always result in losses [41], characteristics of interaction partner (i.e., a long-term partner or a stranger) affect human cooperation and punishment in public goods experiment in which increasing the cooperation level, punishment is reduced due to potential free riders [42], long-term interaction is a well-known factor to maintains cooperation; it has been known as theory of direct reciprocity or reciprocal altruism in the social life network [43-44].

Despite the ample accumulation of experimental works on 2 × 2 games, we think there have been insufficient to clearly validate the plausibility of the game theory, especially proving how people recognizing dilemma strength in real contexts.

To this end, in this study, we report the result of our preliminary experimental trial having threefold; whether people fairly recognizing dilemma class; either Prisoner's Dilemma ($D_g > 0$ & $D_r > 0$), Chicken ($D_g > 0$ & $D_r < 0$), Stag Hunt ($D_g < 0$ & $D_r > 0$) or Trivial ($D_g < 0$ & $D_r < 0$), whether people correctly recognizing the dilemma strength, and whether cooperation level observed being dependent on anonymous or not- anonymous situation.

The remaining part of this manuscript consists as below. Section 2 describes experimental design, Section 3 reports result and give discussion, and conclusive remarks would be noted in Section 4.

2. Experimental design

In order to simplify a real context in social interactions, we presumed a simple 2 × 2 games for our questionnaire survey.

2.1 General Design

Consider an infinite and well-mixed situation for the symmetric 2 × 2 game. A query for recognition of four game classes in addition to dilemma strength either be comprehensible for the participants or otherwise in the experiment with/without social viscosity. In brief, going through the summary of the general design (Table 1), we were concerned on; how game class, dilemma strength, and assumption of a game-opponent respectively influence on respondents' cooperation level.

2.2 Questionnaire Design

To know the effects of the social dilemma, we made a questionnaire-based experimental survey in which repeated, and one-shot 2 × 2 games are played. This survey is designed as a structured cross-sectional survey using multiple choice answers through a web-based survey. This is implemented through Google form which offers a simpler solution as below. In the case of field survey, data are collected through face to face interviews. Fig. 1 shows an overview of the questionnaire which is composed of *INTRODUCTION*, and either CASE (I) or CASE (II) after the part where demographic questions were posed. The portion of *INTRODUCTION* pertains to CASE (I) to provide explanation for the Prisoner's dilemma (PD) and Trivial games while the portion of introduction or pertains to CASE (II) to explain Chicken

(CH) and Stag Hunt (SH) games, and also gives the general background of game setting when participants went through the questionnaire. There are 8 questions, i.e. (a) to (h), for both CASE (I) and CASE (II) in which PD vs Trivial, or CH vs SH games are compared. In the *INTRODUCTION*, a participant was asked his/ her game-opponent to be either an intimate friend or an unknown person. To this end, a participant was asked to select either A (indicating Cooperation) or B (indicating Defection) as his/ her option. The 8 questions were sequentially given to each of the participants, of which order amid (a) to (h) are fully randomized. We introduced such two settings: (i) we ask participants through this experiment to consider game opponent from among unknown people, (ii) allowing participants to choose game opponent from intimate friends. Perfectly, in this anonymous world, a game opponent is given as a man on the street as unknown (zero chances to play again with the same opponent i.e. the one-shot game) ensure zero social viscosity. On the other hand, in the case of an intimate friend, such a game setting has a certain level of social viscosity.

Here, Table 2 illustrates, different dilemma strength parameters that satisfy $\boldsymbol{D_g}$ $(=\ \boldsymbol{D_r}$)and $\boldsymbol{D_g^/}$ $(=$ $\boldsymbol{D_r^/})$ for CASE (I) and different for CASE (II).

2.3 Subjects

Survey participants, i.e. subjects, or respondents, were 375 in total, of which breakdown is given in Table 3.

From May 2019 to July 2019, our field survey chosen randomly, in this regard had been conducted with direct questions at Kyushu University, Japan while a web-based survey had been conducted at Begum Rokeya University, Rangpur, Bangladesh. The questionnaire was provided to the participants through a link and were requested to fill out the demographic data, e.g. gender, age, occupation etc.

3. Results and discussion

3.1 Statistics of demographic characteristics

With Table 3 presents the socio-demographic characteristics of participants; fraction of male and female, occupation and age distribution. Most of them were college-age students.

3.2 Result of Test

PD versus Trivial

The results of how the respondent’s cooperation fraction along dilemma strength influencing both Prisoner’s Dilemma (left) and Trivial (right) games are shown in Fig 2. Here the combination of normalized dilemma strength and original dilemma strength; $(D_{g,}^/\ D_g)$, were varied as $(5, 500)$, $(1, 500)$, (1, 100), (0.2, 100), (- 0.067, -100), (- 0.15, -300), (-0.33, -100), (-0.75, -300) in plots (a) to (h), respectively. The label of panels; (a) to (h), is consistent with that for Case (I); (a) to (h), explained in Fig 2. We presumed $D_g^/ = D_r^/$ $(D_g = D_r)$.

Obeying to what the evolutionary game theory[4)] quantitatively predict, the cooperation fractions for all of PD ((a) – (d)) and Trivial ((e) – (h)) in case of ‘unknown person’ must be consistent with 0 and 1, respectively. But the result showed somehow cooperative (less than 0.5) in case of PD, and not perfectly cooperative in case of Trivial. This is because a real situation, usual people exposed in daily life, cannot be ideally similar to what the theory premises as perfectly well-mixed and infinite population.

The result of ‘intimate friend’ was expected to observe more cooperation than that of ‘unknown person’, because the assumption of whether intimate or unknown may affect people’s recognition of anonymity. In fact, as many previous studies based on the theory and simulations validated, when the game environment implements a certain mechanism to add ‘social viscosity’ lessening anonymity amid agents, reciprocity such as; direct, indirect, network reciprocity, etc, can be observed even in a severe PD situation, which leads to a higher cooperation. In our result, although there can be observed slightly more cooperation of ‘intimate friend’ case in a Trivial setting, the difference between ‘intimate friend’ and ‘unknown person’ for both PD and Trivial seems unclear, perhaps can be said no different when noting quite large standard deviations. Also, the difference resulting from varying dilemma strength seems unclear, although more cooperation can be observed with the decrease of $D_g^/$ in the case of ‘unknown person’, which is consistent with the theoretical prediction[4,5)]. The only thing we successfully confirmed is the difference of cooperation fractions between PD and Trivial. It implies that people were able to be cognizant of dilemma class differences, i. e., whether he/ she is exposed to PD; a strong dilemma situation, or Trivial; non dilemma situation.

Chicken versus Stag Hunt

Table 4 provides average and standard deviation of observed cooperation fractions in Case (II); (a) – (d) for Chicken, and (e) – (h) for Stag Hunt. According to what the theory predicting as long as a well-mixed and infinite population for players, cooperation fraction should be 0.5 for all of the settings (a) – (h) because of $D_g^/ = -D_r^/$ $(D_g = -D_r)$, irrespective to whether it coming to Chicken or SH, and irrespective to the dilemma strength. However, all of the observed average cooperation fractions except for (f) and (g) presuming ‘intimate friend’ setting show more than 0.5. Although this might result from the instinct of human tendency that he / she decently behaves to others, it would be said that the observed result is unclear if noting a larger standard deviation against average.

CASE (I) (Prisoners Dilemma(PD) & Trivial game)

PD game

(a)

You \ Opponent	A	B
A	100, 100	-500, 600
B	600, -500	0, 0

(b)

You \ Opponent	A	B
A	500, 500	-500, 1000
B	1000, -500	0, 0

(c)

You \ Opponent	A	B
A	100, 100	-100, 200
B	200, -100	0, 0

(d)

You \ Opponent	A	B
A	500, 500	-100, 600
B	600, -100	0, 0

Trivial game

(e)

You \ Opponent	A	B
A	1500, 1500	100, 1400
B	1400, 100	0, 0

(f)

You \ Opponent	A	B
A	2000, 2000	300, 1700
B	1700, 300	0, 0

(g)

You \ Opponent	A	B
A	300, 300	100, 200
B	200, 100	0, 0

(h)

You \ Opponent	A	B
A	400, 400	300, 100
B	100, 300	0, 0

CASE (II) (Chicken (CH) & Stag hunt game(SH))

CH game

(a)

You \ Opponent	A	B
A	100, 100	500, 600
B	600, 500	0, 0

(b)

You \ Opponent	A	B
A	500, 500	500, 1000
B	1000, 500	0, 0

(c)

You \ Opponent	A	B
A	100, 100	100, 200
B	200, 100	0, 0

(d)

You \ Opponent	A	B
A	500, 500	100, 600
B	600, 100	0, 0

SH game

(e)

You \ Opponent	A	B
A	500, 500	-100, 400
B	400, -100	0, 0

(f)

You \ Opponent	A	B
A	100, 100	-100, 0
B	0, -100	0, 0

(g)

You \ Opponent	A	B
A	500, 500	-500, 0
B	0, -500	0, 0

(h)

You \ Opponent	A	B
A	100, 100	-500, -400
B	-400, -500	0, 0

Fig. 1: Each of the case (both (I) and (II) has eight questions. PD and CH have (a), (b), (c), (d) question, and Trivial and SH have (e), (f), (g), (h) question.

Table 2. Summary of the dilemma strength for the CASE (I) (PD vs trivial game) and CASE (II) (CH vs SH game).For CASE(I), D_g $(= D_r)$ and $D_g^{\prime}$ $(= D_r^{\prime})$in addition to CASE (II) has different dilemma strength.

Case (I)	**PD setting**	**(a)**	**(b)**	**(c)**	**(d)**
	D_g $(= D_r)$	500	500	100	100
	$D_g^{\prime}$ $(= D_r^{\prime})$	1	5	0.2	1
	Trivial setting	**(e)**	**(f)**	**(g)**	**(h)**
	D_g $(= D_r)$	-300	-300	-100	-100
	$D_g^{\prime}$ $(= D_r^{\prime})$	-0.75	-0.15	0.067	-0.33
Case (II)	**CH setting**	**(a)**	**(b)**	**(c)**	**(d)**
	D_g (D_r)	500 (-500)	500 (-500)	100 (-100)	100 (-100)
	$D_g^{\prime}$ $(D_r^{\prime})$	1 (-1)	5 (-5)	0.2 (-0.2)	1 (1)
	SH setting	**(e)**	**(f)**	**(g)**	**(h)**
	D_g (D_r)	-100 (100)	-100 (100)	-500 (500)	-500 (500)
	$D_g^{\prime}$ $(D_r^{\prime})$	-1 (1)	-0.02 (0.02)	-5 (5)	-1(1)

Table 3. Survey of participants in different games (M = Male, F = Female, S = Student, J = Job) (Total = 375).

Game		Gender (%)	Occupation (%)	Age year (%)
Case (I) (PD+ Trivial)	Unknown person (150)	M = 73.3 F = 26.7	S = 98.4 J = 1.6	15-20 (14.8) 21-25 (80.3) 26-30 (4.1) 36-40 (0.8)
	Intimate friend (169)	M = 24.3 F = 75.7	S = 85.3, J = 14.7	15-20(21) 21-25(51.7) 26-30(11.9) 31-35(3.5) 36-40(1.4) ≥ 40(5.6)
Case (II) (CH + SH)	Unknown person (28)	M = 82.1 F = 17.9	S = 46.4, J = 53.6	15-20(3.6) 21-25(14.3) 26-30(28.6) 31-35(25) 36-40(25) ≥ 40(3.6)
	Intimate friend (28)	M = 85.7 F = 14.3	S = 89.3 J = 10.7	21-25(21.4) 26-30(42.9) 31-35(25) 36-40(10.7)

Table 4. Summary of the subjective responses according to the questionnaire for CH and SH game by intimate friends and unknown people go through different dilemma strengths (D_g , D_r , $D_g^/$, $D_r^/$). There are 8 questions in which the first four i.e. (a), (b), (c), (d) belongs to CH and remaining four i.e. (e), (f), (g), (h) are from SH game (fc ± SD = Average cooperation fraction ± standard deviation) .

	CH				SH			
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
D_g , D_r	500, -500	500, -500	100, -100	100, -100	-100, 100	-100, 100	-500, 500	-500, 500
$D_g^/$, $D_r^/$	5, - 5	1, -1	1, -1	0.2, -0.2	-0.2, 0.2	-1, 1	-1, 1	-5, 5
Intimate friend (fc ± SD)	0.53 ± 0.50	0.64 ± 0.48	0.6 ± 0.49	0.6 ± 0.49	0.5 ± 0.5	0.46 ± 0.5	0.42 ± 0.5	0.78 ± 0.41
Unknown person (fc ± SD)	0.53 ± 0.50	0.85 ± 0.35	0.6 ± 0.49	0.6 ± 0.48	0.53 ± 0.5	0.57 ± 0.5	0.57 ± 0.5	0.75 ± 0.44

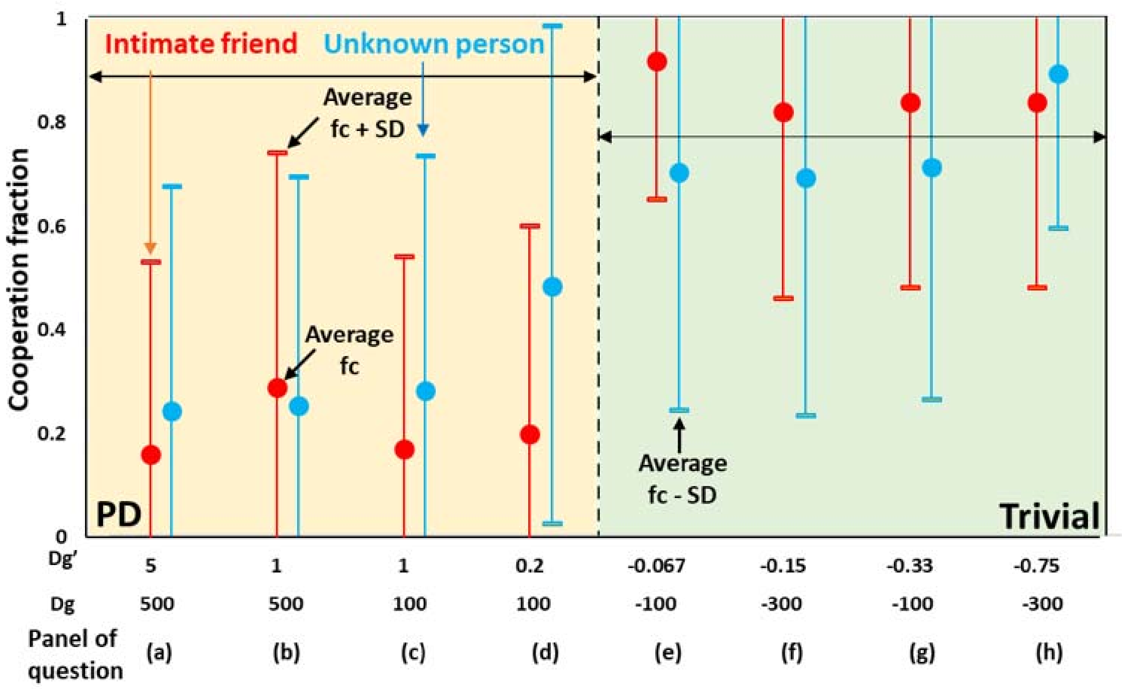

Fig. 2. Graphical representation of average cooperation fraction for intimate friend and unknown person in case of PD vs trivial game over dilemma strength (D_g , $D_g^{/}$). There are 8 questions in which first four i.e. (a), (b), (c), (d) belongs to PD and remaining four i.e. (e), (f), (g), (h) are from trivial game.

3.3 Statistical Analysis

Following to the discussion in the previous section, let us explore the statistical tests. Table 5 represents the summary of the statistical analysis of the χ^2 (Chi-square) test for four different games: PD, Trivial, CH and SH with an intimate friend as well as an unknown person along with dilemma strength. This test quantifies whether the cooperation fraction at each dilemma strength can be seen as significantly different or not. The statistical hypotheses for all the eight cases are denied. It implies that subjects did not recognize the dilemma strength implemented by different $D_g^{/}$ and $D_r^{/}$ (D_g and D_r).

Table 6 presents the statistical analysis of the PD versus Trivial and CH versus SH game by using the T-test. This T-test quantifies whether the average cooperation fraction of all of PD settings are significantly different from that of Trivial or not; and whether the average cooperation fraction of all of CH settings are significantly different from that of SH or not. The result confirms that subjects clearly distinguish the game class difference if both PD and Trivial are imposed but did not for the case comparing CH and SH.

Table 5. χ^2 (Chi-square) test is used to determine the dilemma strength but none of them are significant.

Game	playing with	P-value	If P-value < 0.05 then
PD	Intimate friend	0.99696	not significant
	Unknown person	0.98901	not significant
Trivial	Intimate friend	0.99998	not significant
	Unknown person	0.99816	not significant
CH	Intimate friend	0.99971	not significant
	Unknown person	0.99278	not significant
SH	intimate friend	0.98549	not significant
	Unknown person	0.99723	not significant

Table 6. T-test: two-sample assuming unequal variances to recognize the different game classes.

Game	P-value	If P-value < 0.05 then
PD versus Trivial	1.93×10^{-08}	significant
CH versus SH	0.33	not significant

4. Conclusion

With respect to the 2 by 2 game, most important and fundamental archetype of evolutionary game theory, motivated by the current trend of study that both theoretical and simulation aspects have been well explored, we dare back to the simplest question; whether a human fairly recognizes social dilemma class and its strength. To answer this question, we designed a quite simple questionnaire survey based on 2 by 2 games with the four game classes. The results suggest that people did not recognize the dilemma strength and showed none of the significant difference in cooperation fraction when premised whether 'intimate friend' or 'unknown person' is a game opponent. But it confirmed that they clearly recognize the difference of game class between Trivial game (i.e., none dilemma game) and Prisoner's dilemma, most sever social dilemma.

One justification why our result partially diverges from what the theory predicts is that our procedure to instruct game setting to the subjects was not so persuasive and comprehensive when compared to the social dilemma story, like pizza game [30] and realistic public goods game[31] settings, was implemented.

References

1) R. Axelrod and W. D. Hamilton, "The Evolution of Cooperation," *Evolution (N.Y).*, **211** (4489) 1390–1396 (1981).
2) J.V. Neumann, and O. Morgenstern "Theory of games and economic behavior, " Princeton University Press, 1953.
3) M.A.Nowak, and S. Coakle, "Evolution, Games, and God: The Principle of Cooperation,". Harvard University Press, 2013.
4) J. Tanimoto ,"Fundamentals of Evolutionary Game Theory and its Applications," Springer, 2015.
5) J.Tanimoto ,"Evolutionary Games with Sociophysics ," Springer, 2018.
6) T.Fujisaki, "Evaluation of Green Paradox:Case Study of Japan,"*Evergreen.*,**5**(4) 26-31(2018).
7) L. Heuer and A. Orland, "Cooperation in the Prisoner's Dilemma: an experimental comparison between pure and mixed strategies," *R. Soc. Open Sci.*, **6** (7) 182142, (2019).
8) V. Capraro, J. J. Jordan, and D. G. Rand, "Heuristics guide the implementation of social preferences in one-shot Prisoner's Dilemma experiments," *Sci. Rep.*, **4** 1-5 (2014).
9) F. Exadaktylos, A. M. Espín, and P. Brañas-Garza, "Experimental subjects are not different," *Sci. Rep.*, **3** (1213) 1–6 (2013).
10) A. Antonioni, M. Tomassini, and A. Sánchez, "Short-range mobility and the evolution of cooperation: An experimental study," *Sci. Rep.*, **5** (10282) 1–9 (2015).
11) H . Fort and S. Viola,"Self-organizationina simple model of adaptive agents playing 2 × 2 games with arbitrary payoff matrices." *Phys. Rev. E - Stat. Nonlinear, Soft Matter Phys.*, **69** (036110) 1-16 (2004).
12) J. Grujic, C. Fosco, L. Araujo, J. A. Cuesta, and A. Sanchez, "Social experiments in the mesoscale: Humans playing a spatial prisoner's dilemma," *PLoS One*, **5** (11) (2010).
13) H. T. Normann and B. Wallace, "The impact of the termination rule on cooperation in a prisoner's dilemma experiment," *Int. J. Game Theory*, **41** (3)707–718 (2012).
14) C. H. Hauert, "Effects of space in 2 × 2 games," **12**(7) 1531–1548 (2002).
15) J. Keil *et al.*, "Getting less than their fair share: Maltreated youth are hyper-cooperative yet vulnerable to exploitation in a public goods game," *Dev. Sci.*,**22** (3) 1–13 (2019).
16) P. R. Blake, D. G. Rand, D. Tingley, and F. Warneken, "The shadow of the future promotes cooperation in a repeated prisoner's dilemma for children," *Sci. Rep.*, **5** (14559) 1–9 (2015).
17) H.Qi, S. Ma, N.Jia, and G.Wang," Experiments on individual strategy updating in iterated snowdrift game under random rematching," *J. Theor. Biol.*,**368** 1-12 (2015).
18) Q. Chen, T. Chen, and R. Yang, "Using rewards reasonably: The effects of stratified-rewards in public goods game," *Chaos, Solitons and Fractals*,**120** 67–74 (2019).
19) M. Pereda, V. Capraro, and A. Sánchez, "Group size effects and critical mass in public goods games," *Sci. Rep.*, **9** (5503) 1–10 (2019).
20) G. J. Kimmel, P. Gerlee, J. S. Brown, and P. M. Altrock, "Neighborhood size-effects in nonlinear public goods games,"**2** (53) 1–25,(2019).
21) Q. Wang and X. Chen, "Stochastically stable equilibria in the nonlinear public goods game," *Phys. D Nonlinear Phenom.*, **388** 33–39 (2019).
22) L. G. González, W. Güth, and M. V. Levati, "When does the game end? Public goods experiments with non-definite and non-commonly known time horizons," *Econ. Lett.*, **88** (2) 221–226 (2005).
23) S. Suri and D. J. Watts, "Cooperation and contagion in web-based, networked public goods experiments," *PLoS One*, **6** (3) 1-18 (2011).
24) M. Milinski and D. Semmann, "Stabilizing the Earth '

s climate is not a losing game :supporting evidence from public goods experiments," *Proceedings of the National Academy of Sciencess*, **103**(11) 3994-3998 (2006)
25) Y. Horita, M. Takezawa, K. Inukai, T. Kita, and N. Masuda, "Reinforcement learning accounts for moody conditional cooperation behavior: experimental results," *Sci. Rep.*, **7** (39275) 1–10 (2017).
26) J. Quan, J. Zheng, X. Wang, and X. Yang, "Benefits of asynchronous exclusion for the evolution of cooperation in stochastic evolutionary optional public goods games," *Sci. Rep.*, **9** (1)1–11 (2019).
27) D.-M. Shi, Y. Zhuang, and B.-H. Wang, "Group diversity promotes cooperation in the spatial public goods game," *EPL (Europhysics Lett.*, **90** (5) 58003 (2010).
28) J. F. Nash, R. Nagel, A. Ockenfels, and R. Selten, "The agencies method for coalition formation in experimental games," *Proc. Natl. Acad. Sci. U. S. A.*, **109** (50) 20358–20363 (2012)
29) J. Grujić, B. Eke, A. Cabrales, J. A. Cuesta, and A. Sánchez, "Three is a crowd in iterated prisoner's dilemmas: Experimental evidence on reciprocal behavior," *Sci. Rep.*, **2** (638) 1–7 (2012).
30) J. Keil, A.Michel, F.sticca, K.Leipold, A.Klein, S.Sierau, K.V. Klitzing, and L.O.White , "The Pizzagame: A virtual public goods game to assess cooperative behavior in children and adolescents," *Behav. Res. Methods*, **49** (4) 1432–1443 (2017).
31) W. T. Harbaugh and K. Krause, "Children's altruism in public good and dictator experiments," *Econ. Inq.*, **38** (1) 95–109 (2000).
32) M. Vogelsang, K. Jensen, S. Kirschner, C. Tennie, and M. Tomasello, "Preschoolers are sensitive to free riding in a public goods game," *Front. Psychol.*, **5** (729) 1-9 (2014).
33) J. Zelmer, "Linear public goods experiments: A meta-analysis," *Exp. Econ.*,**6** (3) 299–310 (2003).
34) G. R. Fréchette, "Experimental economics across subject populations," *Handb. Exp. Econ.* **2** 1–70(2016).
35) T. X. Liu, J. Bednar, Y. Chen, and S. Page, "Directional behavioral spillover and cognitive load effects in multiple repeated games," *Exp. Econ.*, **22** (3) 705–734 (2019).
36) Y. Kayaba, H. Matsushima, and T. Toyama, "Accuracy and retaliation in repeated games with imperfect private monitoring: Experiments," *Games Econ. Behav.*,**120** 193–208(2020).
37) G. Jones, "Are smarter groups more cooperative? Evidence from prisoner's dilemma experiments, 1959-2003," *J. Econ. Behav. Organ.*, **68** (3–4) 489–497(2008).
38) F. Mengel, "Risk and temptation: a meta-study on prisoner's dilemma games," *Econ. Journal*, **128** (616) 3182–3209 (2018).
39) P. D. Bó, " Cooperation under the Shadow of the Future: experimental evidence from infinitely repeated games," *American Economic Review*. **95**(5) 2205-29 (2005)
40) P. Bó and G. Fréchette,"The evolution of cooperation in infinitely repeated games: experimental evidence," *American Economic Review*, **101**(1) 411-29(2011).
41) G. P. Cachon and C. F. Camerer, "Loss-Avoidance and Forward Induction in Experimental Coordination Games," *Q. J. Econ.*, **111**(1) 165–194(1996).
42) E. Fehr and S. Gächter, "Cooperation and punishment in public goods experiments," *Am. Econ. Rev.*, **4** 980–994 (2000).
43) R. L. Trivers," The evolution of reciprocal altruism," *Q. Rev. Biol.*, **46** (1) 35–57 (1971)
44) R. Axelrod,"The evolution of cooperation," New York:Basic Books, 1984.