

Human-Robot Cooperation in Prisoner Dilemma Games

People Behave More Reciprocally than Prosocially Toward Robots

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ABSTRACT

This study investigated human-robot cooperation in the context of prisoner's dilemma games and examined the extent to which people's willingness to cooperate with a robot would vary according to the incentives provided by a game context. We manipulated the payoff matrices of human-robot prisoner's dilemma games and predicted that people would cooperate more often in the situation where cooperating with the robot was a relatively more rewarding option. Our results showed that, in the early rounds of the game, participants made significantly more cooperative decisions, when the game structure providing more incentives for cooperation. However, their subsequent game decisions were dominantly driven by Cozmo's previous game choices and the incentive structure was no longer a predictive factor to their decisions. The findings suggest that people have a strong reciprocal tendency to social robots in economic games and this tendency might even surpass the influence of the reward value of their decisions.

KEYWORDS: Human-robot interaction, cooperation, prisoner's dilemma games, social decision-making

1 Introduction

Social robots are already proving to be valuable tools in assisting people in many aspects of society, including elderly healthcare, education, and therapy for individuals with an autism spectrum condition [1]. However, despite the social features of some robots, they remain non-living machines, which might lead us to question how much socialness we could ever attribute to robots and the extent to which we might actually form amiable relationships with them [2]. Across humans' many characteristic social behaviors, one important theme to emerge is cooperative tendency [3]. Our cooperative tendency is so prominent that we are usually willing to give up some parts of self-interest and contribute to the collective interest mostly for social reasons [3, 4, 5]. However, if the collaborator is a robot, will we still do so to maintain a cooperative and social relationships with it?

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To examine people's willingness to cooperate with robots, the human cooperation literature suggests that the prisoner's dilemma (PD) game is an informative paradigm [6, 7]. To briefly explain a classic PD game, two players make simultaneous decisions – either to cooperate or to defect – in the game, and their individual payoff is determined by both of their decisions. First, if both choose to cooperate, they will each earn a moderate amount but not the highest rewards (e.g., £7 each). Second, if only one of the two chooses to cooperate, the one defecting will receive the most rewarding payoff (e.g., £10), while the one cooperating will get the worst outcome (e.g., £0). Finally, if both are tempted and choose to defect, both will receive the smallest payoff (e.g., £1 each). In other words, defection might be a profitable choice in terms of individual gain, but cooperation brings about better chances of forming cooperative social relationships and possibly leads to higher mutual gain in the long run.

Even though the same logic structure underpins all PD games, experimenters can determine the value of rewards and punishments [8]. Furthermore, recent evidence verifies that different incentive structures of PD games – defined by the designs of payoff matrices – significantly influence people's cooperative tendency [8]. In order to standardize incentive structures of PD games, Rapoport [9] proposed K-index as a measure of anticipated cooperation, which is calculated by the below equation:

$$\frac{(R - P)}{(T - S)}$$

Here R represents the rewards of mutual cooperation (which is £7 in the aforementioned example), P means the punishment of mutual betrayal (£1), T is the temptation given when one betrays the other, and S shows sucker's – the one being betrayed by the other – payoff (£0). To simply put, the K-index represents the incentives for cooperation provided by a PD game's payoff matrix [9]. A higher K-index means more incentives for cooperation are provided by the game context and has shown to lead to higher cooperation rates among human players [9, 10].

In the current study, we explored people's willingness to cooperate with a social robot when PD games' incentive structures (i.e., K-index) are manipulated. In line with previous evidence [8], we predict that participants who play a high K-index PD game with a robot will make more cooperative decisions than those who play a low K-index game will.

2 Method

We developed a human-robot PD game via Python and used an entertainment robot Cozmo (manufactured by Anki Inc.) as participants' game opponent. The game was explained to participants as follows:

In this study, we are running a robot competition and aim to know which Cozmo is the best economic game player. In each game round, a certain amount of coins will be available to you and Cozmo, and both players will make simultaneous decisions either to keep all the coins or to share them with the other. Your individual payoff will depend on both of your decisions.

The more coins you get the higher possibility you'll win a shopping voucher in the end, and the Cozmo that wins will be used in our following study, but if Cozmo loses the game, its memory and data will be entirely erased.

Participants were randomly assigned to either the high K-index game ($K = \frac{7-1}{10-0} = 0.6$) or the low K-index game ($K = \frac{6-4}{10-0} = 0.2$)¹ (Table 1 & 2). The experiment setup is shown in Figure 1. Participants made their decisions by tapping one of the touch-sensitive cubes in each round, and a screen was placed in front of them showing the payoff matrix, real-time outcomes, and scores during the 20-round game. The Cozmo robot's decisions were pre-programmed to have 10 times keeping and 10 times sharing and were presented in a random order, to control its behavioral competitiveness across subjects.

Table 1: The payoff matrix in the high K-index PD game

	Cozmo keeps coins	Cozmo shares coins
Human keeps coins	Human: 1 coin Cozmo: 1 coin	Human: 10 coins Cozmo: 0 coins
Human shares coins	Human: 0 coins Cozmo: 10 coins	Human: 7 coins Cozmo: 7 coins

Table 2: The payoff matrix in the low K-index PD game

	Cozmo keeps coins	Cozmo shares coins
Human keeps coins	Human: 4 coins Cozmo: 4 coins	Human: 10 coins Cozmo: 0 coins
Human shares coins	Human: 0 coins Cozmo: 10 coins	Human: 6 coins Cozmo: 6 coins

3 Results and Conclusion

Seventy participants (average age = 23.6 years old; 71.4% females) were recruited from the university's subject pool system. First, the cooperation rate² of participants in the high K-index condition was 0.40 while that of participants in the low K-index condition was 0.34.

¹ The designs of payoff matrices were following a previous study [8] where they found that participants' cooperative tendencies differed significantly in these two conditions.

² Cooperation rate is calculated by dividing the sum of human sharing times by the total game rounds played.



Figure 1: The experimental setup of the PD game

Second, to examine the effect of game incentives on participants' binomial game responses, we ran mixed effects logistic regression models, while controlling the random effects of subjects and game rounds. We found that, over the 20 game rounds, the game incentive structure was not a significant predictor ($p = .12$) on human decisions, which means participants did not make more cooperative decisions in the situation providing more cooperative incentives. Finally, since reciprocity is an important and typical social behavior [3, 6, 7, 11], we divided the dataset into two parts and conducted respective analyses, to explore the extent to which participants behaved reciprocally towards Cozmo.

For the first part of dataset, we treated participants first game decisions as one-shot PD games, to examine the influence of game incentives before any interaction history happened. A logistic regression model revealed that participants' first game decisions were significantly impacted by the game structure ($\beta = -1.10$, $p = .043$) -- participants made more cooperative choices in the high K-index game than did those in the low K-index game.

For the second part of the dataset, we paired participant's second to twentieth game decisions with Cozmo's previous decisions³ and ran a mixed effects logistic regression model to examine the effects of incentive structure and Cozmo's previous decisions. The results showed a significant fixed effect from Cozmo's previous decisions ($\beta = 1.08$, $p = .005$), but the incentive structure was non-predictive to human players' decisions ($\beta = 0.0007$, $p = .998$).

In conclusion, the study showed that the willingness to cooperate with a robot in the PD game was not significantly impacted by different payoff matrices, contradicting previous evidence in PD games played between people [8]. However, we also found people to reliably behave in a reciprocal manner (play a tit-for-tat strategy) to Cozmo, which surpassed the initial effect of game incentives and dominated participants' cooperative decisions throughout the game.

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³ E.g., human's second decision was paired with Cozmo's first decision

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