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Robot Likeability and Reciprocity in Human Robot Interaction: Using Ultimatum Game to determinate Reciprocal Likeable Robot Strategies

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Abstract

Among of the factors that affect likeability, reciprocal response towards the other party is one of the multiple variables involved in social interaction. However, in HRI, likeability is constrained to robot behavior, since mass-produced robots will have identical physical embodiment. A reciprocal robot response is desirable in order to design robots as likeable agents for humans. In this paper, we discuss how perceived likeability in robots is a crucial multi-factorial phenomenon that has a strong influence on interactions based on reciprocal robot decisions. Our general research question is: What type of reciprocal robot behavior is perceived as likeable for humans when the robot's decisions affect them? We designed a between/within $2 \times 2 \times 2$ experiment in which the participant plays our novel Alternated Repeated Ultimatum Game ($ARUG$) for 20 rounds. The robot used in the experiment is an NAO robot using four different reciprocal strategies. Our results suggest that participants tend to reciprocate more towards the robot who starts the game and using the pure reciprocal strategy compared with other combined strategies (Tit for Tat, Inverse Tit for Tat and Reciprocal Offer and Inverse Reciprocal Offer). These results confirm that the Norm of the Reciprocity applies in HRI when participants play ARUG with social robots. However, the human reciprocal response also depends on the profits gained in the game and who starts the interaction. Similarly, the likeability score is affected by robot strategies such as reciprocal (Robot A) and generous (Robot C). and there are some discrepancies in the likeability score between the reciprocal robot and the generous robot behavior.

Keywords Human–robot interaction · Reciprocity · Game Theory · Alternated Repeated Ultimatum Game · Cooperation

1 Introduction

Likeability is associated with friendly, cooperative and pro-social behaviours [2] such as extroversion, agreeableness, and lack of over-conscientiousness [3,4]. Moreover, likeability is a very complex phenomenon involving behaviours, manners, perceived intelligence, similar socio-cultural context, interests, and even physical attractiveness, acceptability and popularity. In other words, a person is considered likeable when he or she is emotionally well-adjusted and she or he can be engaged in high-quality relationships.

Future acceptance of social robots will be associated with their likeability. The measurement of likeability in robots is mostly associated with their degree of anthropomorphism [5] and the design of the embodiment. However, the likeability of state-of-art robots cannot be based on unique physical features. Robots of the same model will be mass produced; therefore, they will have identical physical embodiment. Sooner rather than later, they may lose their novelty effect and their appearance might become ordinary. Hence, the likeability of the robots will be determined mostly by their behaviours towards humans.

We propose that people will find robots likeable depending on three main conditions, each of which are independent of their external characteristics: (A) How successfully can the robot perform tasks that users expect? (B) How does the robot behaviour match the interest and personality of

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the users? For instance, does the robot present slightly unexpected behaviour to keep the attention of a curious user, and more predictable behaviour for users who prefer routine? (C) How does the human–robot interaction emotionally benefit the user? This third point leads us to ask if humans would drive the robot's behaviours based on their own self-interest or show reciprocal behaviour towards the robots if they received benefits from doing so.

Several studies have been performed on the acceptance and likeability of the robots. Very often, the research studying likeability in HRI has used images, videos of robots [7] or robots with limited interactivity in controlled conditions [8–10]. These studies have not considered the incentives for the human and the reciprocally beneficial human-robot interaction and its impact in perceived likeability. Our study aims to contribute in this regards and focuses on measuring likeability when humans interact with a humanoid robot.

On the other hand, very recently, some studies revealed that humans tend to be reciprocal towards robots and computers when playing Decision Games and when asking for help [11–14]. Furthermore, humans try to reciprocate to robots even when this breaks the social rules as our study in bribery describes [15]. These facts will be considered as possibly contributors to the likeability of the robots. In our previous work users found the anti-social behaviour of a robot briber likeable [11]. Hence, we aim to investigate how different robot behaviours, particularly reciprocal behaviours, could have an effect in the robot-likeability.

We consider that reciprocity will determine how meaningful the interactions between humans and the agents will be. Although we cannot claim that robots and humans will develop relationships as deep as friendship or love; we consider that in the future robots with a more engaging, interesting and likeable behaviour will have a greater chance of being accepted and popular among users despite their lack of physical attractiveness [16,17].

In this paper, our goal is to describe quantitatively the relationships between robot-likeability defined in the Godspeed questionnaire [18] and the reciprocal interactions between NAO robots and humans playing 20 rounds of Alternated Repeated Ultimatum Game ($ARUG$). Furthermore, we investigate two factors: robot's reciprocal decisions (RRD) and robot's reciprocal offer (RRO) over the course of the interaction. We measure their impact in measurements such as: participant's reciprocal decisions (PRD), participant's reciprocal offer (PRO), and participant's profit (PP). We also measure the correlation between four different reciprocal strategies ($RRD \times RRO$)used by the robot playing $ARUG$ and the likeability scores and preference ranking.

2 Literature Review

Likeability is an important topic in HHI and HRI because humans tend to establish their relationships based on how much they like (or dislike) certain kinds of people. The use of the term "likeable" is broad. Our short definition is: *easy to like and having pleasant or appealing qualities* [6]. Extensive research has been done on likeability in human–human interaction. Some of this can be analogous to robot-likeability research in that people try to find the way to be likeable when they are apart of a new group or in a new environment. For instance, likeability in adolescents [3,4] and social groups living in unfamiliar environments have been investigated [19]. In other cases, when a person starts a friendship or a romantic relationship they tend to do it based on likeability criteria. Over time, physical attractiveness and other factors tend to become less important in the building of a relationship, and focus more on the emotional and material benefits mutually obtained.

However, likeability can be a contradictory phenomenon. Apparently people can find likeable some behaviours that are not necessarily reciprocal, cooperative and mutually beneficial. The nicest behaviour of a person is not necessarily the most likeable for others; sometimes it is perceived as boring. Conversely, in certain cases, a subject can be aggressive, arrogant and manipulative, but despite that, people might still find them likeable [2]. Public figures such as rock-stars, athletes and politicians sometimes show rude or even disgusting behaviour but are still fascinating to the public.

Apparently, our reciprocal relationships with robots are almost as complex as our relationships with other humans. The question we raise in the domain of HRI is: Can human likeability be translated to a human–robot interaction? In other words: Should robots show likeable/unlikeable reciprocal behaviour in order to be liked? Our previous studies have shown that robots showing unexpected behaviours or even unacceptable behaviours received higher scores in likeability as we discuss in [15] and [11].

2.1 Likeability and Reciprocity

Fehr and Gachter discuss reciprocity in terms of positive and negative reciprocity [20–22]. They claim that *in response to friendly actions, people are frequently much nicer and much more cooperative than predicted by the self-interest model; conversely, in response to hostile actions they are frequently much more nasty and even brutal*. Likeability and Reciprocity are strongly connected; if we consider somebody friendly and pleasant it is because generally we receive a reciprocal treatment from this person or agent.

Although Kahn et. al. proposed reciprocity as a benchmark in the evaluation of future human–robot interaction

[1], reciprocal behaviour in human–robot interaction has not been sufficiently explored. Robot designers have tried to implement highly cooperative behaviours in robots but this is not necessarily the best solution for encouraging social interaction between humans and robots. In this paper, we suggest that reciprocal behaviours (no necessarily cooperative behaviour) in robots can offer another approach in terms of an effective, useful and engaging social interaction.

In order to measure reciprocal behaviours related with likeability in HRI, we use the insights of Game Theory. Using this approach, it is possible to take quantitative measurements of profit obtained, number of cooperations and number of reciprocations in order to correlate them with certain human characteristics into simplified social scenarios called decision games. Several studies have been done using decision games (Ultimatum Game, Prisoner's Dilemma and Rock, Paper Scissors Game) as experimental setup in HRI [11,27–29].

2.2 Alternated Repeated Ultimatum Game

The Ultimatum Game has offered a valuable instrument to measure different psychological and economic measures. For instance, Burnell et. al., have researched the optimal strategies without fairness when the Repeated Ultimatum Game is played [23] and Oosterbeek found common behavioural patterns regardless of cultural differences in a meta analysis into the Repeated Ultimatum Game [24]. Besides, individual differences related with reputation [25], attractiveness [26], and the strategies displayed during the Ultimatum Game (UG) have been studied in depth in the economics field. These concepts are strongly linked with the concept of likeability that we use in this study (face-to-face setup). In our case, likeability is more related to the robot behaviour and its reputation during the game rather than its physical appearance, anthropomorphism or embodiment.

Similarly, Repeated Ultimatum Game is a well-known game used very often in Behavioural Economics experimental research [22]. In the original version, a proposer decides how to distribute a certain amount of money and the recipient can decide whether or not to accept the distribution. If accepted both players keep the money and conversely if the recipient rejects the offer both players lose the money. For this study we propose a novel configuration of the Ultimatum Game called Alternated Repeated Ultimatum Game ($ARUG$). In this version the mechanics of the game are the same as in the original version. However, in our version the players alternate roles every round. For instance, player 1 is proposer in round 1 and recipient in round 2 and so on. This is done in order to measure the inter-dependencies in terms of cooperation and reciprocation created for the reciprocal responses and offers of our robots. In this study we had nine predetermined money distributions programmed into the robot for each role it played.

3 Research Questions

The aim of the experiment is to analyse the responses in terms of the robot's likeability (RL), participant's reciprocal decision (PRD), participant's reciprocal offer (PRO), and participant's profit (PP). We further describe these measurements in Sect. 4.6. The $ARUG$ involved two factors: robot's reciprocal decisions (RRD) and robot's reciprocal offer (RRO). Additionally, there is a between-condition called group (G) that describes if the participant or the robot starts the game ($ARUG$). In order to evaluate our aim we propose four research questions:

1. Is Robot Likeability (RL) significantly affected by the robot's reciprocal decisions (RRD), robot's reciprocal offer(RRO) and the starter of the interaction (G) individually or interactively?
2. Is the participant's reciprocal decision (PRD) significantly affected by the RRD, RRO and G individually or interactively?
3. Is participant's reciprocal offer (PRO) significantly affected by *RRD*, *RRO* and G individually or interactively?
4. Is participant profit (PP) significantly affected by the RRD, RRO and G individually or interactively?
5. What is the correlation between robot likeability RL and participant's reciprocal decision PRD, participant's reciprocal offer PRO, and participant's profit PP?
6. Do participants rank the robots differently depending on the robot's factors and is this difference significant?

4 Method

We use 20 rounds of $ARUG$ as a decision game able to conduct a mix between/within 2 × 2 × 2 factors experiment. In which the between factor is G, in other words, the starter of the session is human or robot. The within factors (2 × 2) are robot's reciprocal decisions (RRD) and robot's reciprocal offer (RRO). RRD has two conditions: Tit for Tat's decision (TfT) and Inverse Tit for Tat's ($I - TfT$). Similarly, RRO has two conditions: Reciprocal Offer (RO) and Inverse Reciprocal Offer ($I - RO$).

TfT means that the robot follows the decision of the participant. For instance, if the participant accepted the robot's offer in round X, the robot will accept the participant's offer in round X+1. Conversely, $I - TfT$ consist of rejecting the offer in the current round if the participant accepted the offer in the previous round.

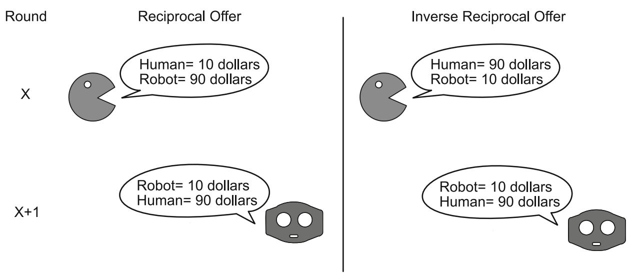

Fig. 1 The figure illustrates the differences between RO and $I - RO$ in two consecutive rounds. In $I - RO$ if the participant is selfish, the robot reciprocates generously and vice-versa

Table 1 The four factor used in the experiment

Robot/human starting	Robot's Rec. Decision (RRD)	
Robot's Rec. offer (RRO)	TfT	I–TfT
RO	Robot A	Robot B
I–RO	Robot C	Robot D

RO Reciprocal offer, *I–RO* inverse reciprocal offer, *Tf* tit for tat, I–TfT inverse tit for tat

In RRO factor, RO condition means that the robot matches the participant's offer in terms of distribution. The robot and participant have 9 predetermined options to distribute the dollars between them. The options are: Human 10 dollars:Robot 90 dollars, Human 20 dollars:Robot 80 dollars, …, Human 90 dollars:Robot 10 dollars. An additional condition exist when the robot starts the game. In this case the robot initiates his game with an offer of Human 50 dollars: Robot 50 dollars. For example, in RO if the participant offers a distribution such as: Human 10 dollars: Robot 90 dollars, the robot offers the same reciprocal distribution in the next round; i.e. Human 90 dollars: Robot 10 dollars. In $I - RO$ the robot offers a non-reciprocal distribution. To illustrate, if the participant offers a distribution such as: Human 10 dollars: Robot 90 dollars, then the robot will offer an inverse distribution such as Human 10 dollars: Robot 90 dollars in the next round. See Fig. 1.

These factors are aimed to be perceived by the participants as the individual strategies of four different robots (A, B, C, D) in the experimental conditions. We named the robots in this way in order to make them easier to remember for the participants. The strategies deployed by the four robots were the result of four unique combinations of the robot's reciprocal decision (RRD) and robot's reciprocal offer (RRO) conditions; $TfT \times RO$ is Robot A, $I - TfT \times RO$ is Robot B. $TfT \times I - RO$ is Robot C and $I - TfT \times I - RO$ is Robot D. See Table 1. A video demonstrating how the $ARUG$ was played during this study can be found at this URL video https://www.youtube.com/watch?v=a5B3A9LVwpE.

Fig. 2 Setup of the experiment. The participant can choose from nine different options and the robot can point out the options

4.1 Experimental Setup

We rotated the order of the robots using the Latin square method, with interaction between the participant and the robot consisting of both visual and audio communication. All four robots showed the same minimal level of verbal interaction and animosity to minimise the emotional impact on the perceived likeability of each robot. Offers where made both verbally and visually by the robot, first stating its offer and secondly point to the card containing its offer. The robot received the participants responses to its offers verbally using speech recognition. The participants presented their offers visually by showing the robot a card containing their offer. Apart from verbally relaying their offers/responses and general guidance, robots also verbally rephrased participant's actions. For instance, after a participant offered Human 70 dollars: Robot 30 dollars, the robot would say "You offer me 30. Ok, I accept it".

4.2 Materials

We used one NAO robot programmed in Choreographe and Python, presented under the disguise of four different robots to participants. Experiment layout had an "Accepted" area and a "Rejected" area for the offers to be put into accordingly. A fixed layout of cards with offer rates was placed before the robot, to which it pointed with its finger to indicate its offer. Twenty units of cards for each offer rate were placed in a similar fashion in front of the participants, and were used for making offers to the robots and also for tracking the accepted/rejected amounts. A laptop was placed on a nearby desk for the online questionnaire. See Fig. 2.

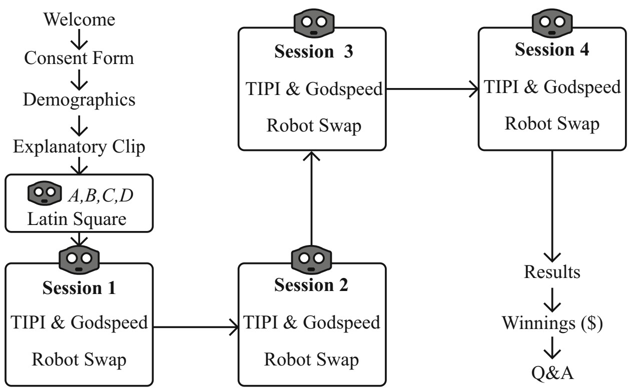

Fig. 3 Experimental proceduree

4.3 Process in Human Starting Condition

In both conditions, we performed individual sessions of four $ARUG$ games. Participants were welcomed and led into the experiment room to receive a brief description of the experiment. After reviewing and signing a consent form, they were asked to fill out an online questionnaire that gathered demographic data including their previous experience with robots. Then, participants were then provided with an ID number and shown a short video that demonstrated the experimental process. When they were ready, the robot was activated through its feet bumpers, after which it asked the for the ID number of the participant, who replied verbally. After introducing the mechanics of the experiment to participants, we started the experiment and discretely observed the first 2 rounds from outside of the room to make sure the participant was not experiencing technical issues, and then we left the room. After each session we came back to change the robot and calculate the results of the sessions to compare them with data recorded in the robot and left again so that participants would not feel pressured by having an observer. Participants filled an online survey with the TIPI and Godspeed questionnaire after each experiment and a comment section regarding their opinions of the robot. After each session, the experimenter came to count the cards, re-stack them and pretend to replace the robot with the next one. Once all four sessions were done, participants filled out the ranking about how much they liked each robot. Then any questions were briefly answered. At the end of the experiment participants were compensated by 0.03% of their accumulated symbolic earnings which ranged between $6.00 and $13.00. This experiment was approved by the Human Ethics Committee of the University of Canterbury [HEC APPLICATION 2015/36/LR-PS]. See Fig. 3 to see the simplified flow of the rounds.

A NAO robot was introduced as the participant's opponent in $ARUG$. The robot wore a tag that displayed "A", "B", "C" or "D" to emulate the perception that the participant was facing four different robots (whereas we used a single robot and reprogrammed it between sessions). The robot asked for the ID number to start the session in each condition. Once the session started the robot requested the participant to take the first turn, and asked the participant to show the card that displayed the offer they wanted to give. By default all four robots were programmed to accept the first offer to prevent participants from identifying its action pattern on the first round. Starting from the 2nd round the robot started its programmed reciprocation patterns. We designed it in this way to be consistent with the assumption of the cooperative behaviour of social robots. After each session the robot was taken out of the room, and while the participant filled out the survey, was reprogrammed for the next reciprocation pattern and its tag replaced accordingly, then represented to the participant as their new opponent.

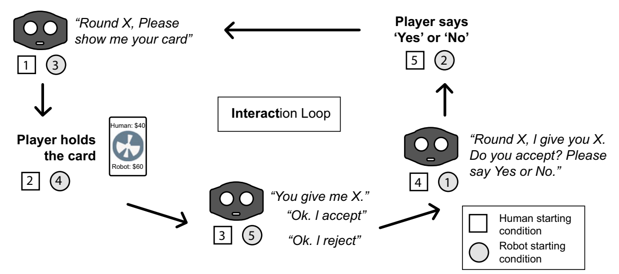

Fig. 4 Initialising the game depending if the human or the robot starts

At the beginning of each round the robot announced the number of the current round, and then if it was the robot's turn to offer it pointed to the proper card. It then asked whether the participant accepted or not and using the speech recognition system distinguished whether the participant responded with a Yes or No. If it was the participant's turn to offer, the robot told the participant to hold the card bearing the offer, and then it gave its response based on its reciprocation pattern using its vision system. At the end of the session of 20 rounds, the robot announced that the session was over. The participant then was asked to fill out a survey on their opinion on the robot and their perceived earnings. After completing the final survey they were given the amount of their earning on that session. See Fig. 4 to see the experimental process per participant.

4.4 Process in Robot Starting Condition

In robot starting condition, once the experiment started the robot informed the participant that it would take the first turn. It then proceeds to make a fair offer (Human 50 dollars: Robot 50 dollars) as default. This was used in all four sessions to prevent the participants from identifying its action pattern in the first round. From the second round the robot began its programmed reciprocation patterns.

4.5 Participants

We contacted participants via university boards, dedicated websites, and Facebook groups in the city. After disposing of the data from sessions which were not carried out successfully due to human error or a robotic malfunction, we had 38 participants in our experiment: 20 in the robot starting condition and 18 in the human starting conditions. Half of the participants were male. 42% of the participants had prior experience in interacting with robots in demonstrations and studies. 5% were high school graduates, 42% were currently in college, 21% had college/university degrees, 13% were currently in graduate or professional school, and 18% had graduate or professional degrees. 68% of the participants currently had jobs. 37% were from Oceania (Australia, New Zealand and other countries), 29% were from Asia (China, India, Japan and others), 18% were from Europe and 16% were from North and South America. The average age was 25 years old (SD = 6.99).

4.6 Measurements

The measurements in the experiment are: robot's likeability (RL), which is an item of the Godspeed questionnaire series [18], participant's reciprocal decision (PRD), means that the participant follows the behaviour of the robot in the immediate next round, participant's reciprocal offer (PRO), means that the participant matches the offer of the robot in the immediate next round, and participant's profit (PP) obtained by the participant in each condition. Finally, participants did a general ranking of their favorite robots.

5 Results

We performed a three-way mixed ANOVA ($2 \times 2 \times 2$) in which the between factor is group G and the within factors are robots's reciprocal decision (RRD) and robot's reciprocal offer (RRO). The measurements were robot's likeability (RL), participant's reciprocal decision (PRD), participant's reciprocal offer (PRO), and participant's profit (PP). See measurements, interaction effects, main effects, means and standard deviations of each measurement in Tables 2, 3, 4 and 5.

The first research question; *(Is Robot Likeability (RL) significantly affected by the robot's reciprocal decisions (RRD), robot's reciprocal offer (RRO) and the starter of the interaction (G) individually or interactively?)* investigated the effect of G, RRD, RRO on robot's likeability (RL). There is a statistically significant three-way interaction effect between RRD, RRO, and G, ($F(1, 36) = 6.072$, $p = 0.019$). The outliers were kept in the analysis. There was a significant two-way interaction ($F(1, 19) = 4.452$, $p = 0.048$) between in RRD and RRO appeared in the human condition but not in the robot condition ($F(1, 17) = 1.930$, $p = 0.183$). There is a significant simple main effect ($F(1, 19) = 4.902$, $p = 0.039$) of RRD in the human starter group condition and a significant main effect of RRD in the robot group, ($F(1, 17) = 10.742$, $p = 0.004$). See Table 2 for interaction effects, means and standard deviations. The robot C ($TfT \times I - RO$)received a high score in likeability (4.12 out of 5) when the participant started the interaction. In this interaction, the robot reciprocates low offers with high offers. Robot C might be perceived as a generous robot. The second highest likebility score is granted to Robot A ($TfT \times RO$) when the robot started the interaction. Robot A has the second highest RL score when reciprocal to the offers of the participant, $RL = 4.01$. Similarly, the results suggest that there is a significant interaction effect because the reciprocal strategy of the robot ($RRD \times RRO$) affecting the likeability score and independence of the starter of the game (robot or human). Also, the starter of the game has a significant impact in the robots' likeability score. See 2.

The second research question *(Is the participant's reciprocal decision (PRD) significantly affected by the RRD, RRO and G individually or interactively?)* investigates the effect of robot's reciprocal decision (RRD), robot's reciprocal offer (RRO) and group (G), on participant's reciprocal decision (PRD). A statistically significant three-way interaction between RRD, RRO and G that affects PRD was found, ($F(1, 36) = 12.665$, $p = 0.001$). There is a significant two-way interaction between RRD and RRO in the human condition, ($F(1, 19) = 15.092$, $p = 0.001$). However, there is a non significant two-way interaction between RRD and RRO ($F(1, 19) = 1.294$, $p = 0.271$) in the robot condition. There is a significant simple main effect of RRD in the human condition, ($F(1, 19) = 5.608$, $p = 0.029$). There is a significant simple main effect of RRO in the human condition, ($F(1, 19) = 32.589$, $p < 0.001$). Besides, there is a significant simple main effect of RRD in the robot condition, ($F(1, 17) = 11.018$, $p = 0.004$) and there is a significant simple main effect of RO in the robot condition, ($F(1, 17) = 104.171$, $p < 0.001$). See Table 3 for interaction effects, main effects, means and standard deviations. Outliers were not removed from the data. These results suggest that participants tend to reciprocate more towards Robot A when the robot started the game with a fair offer. Participants reciprocate on average 9 times during the game. Robot A used a Tit for Tat strategy and Reciprocal offers ($TfT \times RO$). Participants reciprocate on average 8.2 times towards Robot C ($TfT \times I - RO$). Robot C was reciprocating low offers with high offers. Robot C has the highest likeability score of the robots. See Table 3.

In the third research question *(Is participant's reciprocal offer (PRO) significantly affected by robot's reciprocal decision RRD, robot's reciprocal offer RRO and group G*

Table 2 Interaction effects, main effects, means and standard deviations of robot's likeability (RL)

Measurement	Three-way interaction	F(1, 36) =	Human*TfT*RO	Human*TfT*I–RO	Human*I–TfT*RO	Human*I–TfT*I–RO
RL	G*RRD*RRO	6.072, $p = 0.019$	3.66 (0.85)	4.12 (0.81)	3.61 (0.85)	3.51 (1.08)
			Robot*TfT*RO	Robo*TfT*I–RO	Robot*I–TfT*RO	Robot*I–TfT*I–RO
			4.01 (0.69)	3.97 (0.79)	3.16 (0.85)	3.49 (0.84)
RL Human starts	Two-way interaction	F(1, 19) =				
	RRD*RRO	4.452, $p = 0.048$				
	Main effects	F(1, 19) =				
RL Human starts	RRD	4.902, $p = 0.039$				
		F(1, 17) =				
RL Robot starts	RRD	10.742, $p = 0.004$				

G Group, RRO robot's reciprocal offer, RRD robot's reciprocal decision, TfT tit for tat, $I-TfT$ inverse tit for tat, RO reciprocal offer, $I-RO$ inverse reciprocal offer, RL robot likeability

Table 3 Interaction effects, main effects, means and standard deviations of participant's reciprocal decision (PRD)

Measurement	Three-way interaction	F(1, 36) =	Human*TfT*RO	Human*TfT*I–RO	Human*I–TfT*RO	Human*I–TfT*I–RO
PRD		12.665, $p = 0.001$	7.25 (2.17)	8.2 (2.04)	5.35 (1.73)	3.0 (1.65)
			Robot*TfT*RO	Robo*TfT*I–RO	Robot*I–TfT*RO	Robot*I–TfT*I–RO
			9 (0)	6.94 (2.6)	2.89 (2.14)	1.78 (1.9)
	Two-way Interaction effects	F(1, 19) =	TfT*RO	TfT*I–RO	I–TfT*RO	I–TfT*I–RO
PRD Human	RRD*RRO	15.092, $p = 0.001$	7.25 (2.17)	8.20 (2.04)	5.35 (1.73)	3.0 (1.65)
	Main effects	F(1, 19) =	RO	I–RO		
	RRO	32.589, $p < 0.001$	6.1 (2.825)	5 (3.36)		
			TfT	I–TfT		
	RRD	5.608, $p = 0.029$	7.8 (2.1)	3.3 (2.245)		

PRD participant's reciprocal offer, RRO robot's reciprocal offer, RRD robot's reciprocal decision, TfT tit for tat, $I-TfT$ inverse tit for tat, RO reciprocal offer, $I-RO$ inverse reciprocal offer, RL robot likeability

individually or interactively?), we investigate whether RRD, RRO and G affects participant's reciprocal offer (PRO). We found that there is not an significant three-way interaction effect (F(1, 36) = 0.824, $p = 0.370$). There is a statistically significant main effect of RRO, (F(1, 36) = 4.151, $p = 0.049$), a statistically significant main effect of the RDD, (F(1, 36) = 8.775, $p = 0.005$) and a between subject main significant effect of G, (F(1, 36) = 8.137$p = 0.007$). There are not interaction effect but we can observe that the participant's reciprocal offer (PRO) is independently aligned with with the pure reciprocal offer RO of the robot, the pure reciprocal robot's strategy (TfT), and the G (robot/human starter). The highest number of participant's reciprocal offer (PRO) happened when the robot started the interaction and the second highest number of participant's reciprocal offers happened when the robot used RO offers. See Table 4 for the means and standard deviations.

The fourth research question *(Is participant profit (PP) significantly affected by the RRD, RRO and G individually or interactively?)*, searchs for the strategies that affect participant's profit (PP). There is not a statistically significant three-way interaction between strategy, offer and group, (F(1, 36) = 0.053, $p = 0.819$). Outliers were not removed from the data. However, there is a statistically significant two-way interaction between RRD and RRO, (F(1, 36) = 34.006, $p < 0.001$). Statistically significant main effects (F(1, 36) = 76.536$p < 0.001$) of RRD were found. In addition, RRO present a significant main effect (F(1, 36) = 66.515, $p < 0.001$). We can observe that the combination of RRO and RRD affects participant's profit. Robot C provides the highest profits to the participant (1219.21 hypothetical dollars) being reciprocal and accepting low offers paying them high ($TfTxI-RO$). The second most profitable interaction $PP = 752.63$ happened with

Table 4 Interaction effects, main effects, means and standard deviations of participant's reciprocal offer (PRO)

PRO	Main effects	F(1, 36) =	RO	I–RO
	RRO	4.151, $p = 0.049$	2.7 (2.49)	1.6 (1.96)
			TfT	I–TfT
	RRD	8.775, $p = 0$ .005	2.4 (2.733)	1.9 (1.763)
			Human	Robot
	G	8.137 $p = 0.007$	1.575 (1.833)	2.79 (2.6)

Table 5 Interaction effects, main effects, means and standard deviations of participant's profit (PP)

Measurement	Two-way interaction effects	F(1, 36) =	TfT*RO	TfT*I–RO	I–TfT*RO	I–TfT*I–RO
PP	RRD*RRO	34.006, $p < 0.001$	752.63 (251.93)	1219.21 (387.05)	567.63 (97.24)	707.89 (122.48)
	Main effects	F(1, 36) =	RO	I–RO		
	RRO	66.515 $p < 0.001$	660.1 (211.297)	963.6 (384.106)		
			TfT	I–TfT		
	RRD	76.536 $p < 0.001$	985.9 (400.46)	637.8 (130.57)		

Robot A using a pure reciprocal strategy of ($TfT \times RO$). See Table 5 for the means and standard deviations.

In order to answer our fifth research question *(What is the correlation between robot likeability RL and participant's reciprocal decision PRD, participant's reciprocal offer PRO, and participant's profit PP?)*, we determine the Spearman's correlation between the PRD, PRO, PP and RL. Preliminary analysis showed the relationships to be monotonic, as assessed by visual inspection of the scatterplots. There was a positive moderate correlation between PP and PRD, rho (152) $= 0.513$, $p < 0.0001$ and a positive moderate correlation between RL and PRD, rho (152) $= 0.308$, $p < 0.0001$. Similarly, there was a weak positive correlation between RL and PP, rho (152) $= 0.226$, $p < 0.005$ and a negative weak correlation between RL and PRO, rs(152) $= -0.225$, $p < 0.005$. These correlations led us to speculate that robot's likeability is affected by the profits obtained by the participants and participant's reciprocal decisions. In other words, the robot is more likeable when the interaction leads to higher profits and higher number of participant's reciprocal decisions but negatively correlated with the participant's reciprocal offer. Participant's reciprocal decision (PRD) and profit are correlated when the participants figure out the reciprocal patterns. However, these correlations are not significant and it is not possible to draw generalised conclusions from this analysis. See Table 6.

Finally, for the sixth question *(Do participants rank the robots differently depending on the robot's factors and is this difference significant?)*, in order to determinate the favourite robots, we asked the participants to rank them. We conducted a chi-square goodness-of-fit test to determine whether participants ranked one of the four robots significantly higher than the other robots. The minimum expected frequencies were 9.5 for the general ranking, 5 for the Human starter group and 4.5 for the Robot starter group. The robot A using $TfT \times RO$ (pure reciprocal) was ranked highest followed by robot C using $TfT \times I_R O$ as reciprocal strategy. All chi-square values for the four different robots are not significant. However, these rankings could suggest that the Norm of Reciprocity is accomplished for reciprocal robots and generous robots under this experimental setup. However, more studies are required to generalise these conclusions. See Table 7.

Table 6 There are significant moderate and weak correlations among robot's likeability (RL), participant's reciprocal decision (PRD), participant's reciprocal offer (PRO), and participant's profit (PP)

$p < 0.02$	PRD	PRO	PP
RL	0.308	−0.225	0.226
PRD			0.513

6 Discussion and Conclusions

The robot's likeability (RL) is affected by the three-way interaction effect consisting of who starts the interaction (G), robot's reciprocal decision (RRD), and robot's reciprocal offer (RRO). Hence, a two-way ANOVA was performed by separated groups. A two-way interaction effect between RRO and RRD was found. The robots displaying a reciprocal decision TfT were rated higher in likeability than the robots using a inverse reciprocal offer $I - TFT$. Indeed, the robot in the TfT and $I - RO$ condition had a higher likeability score than the other robots in the human condition. In this case $I - RO$ is beneficial for the robot in the TfT condition (Robot C) but not for the robot A in TfT and RO condition (pure reciprocal). In the case of the robot starter

Table 7 Ranking of robot reciprocal conditions $TfT \times RO$ and $I - TfT \times RO$ received the best rankings due to probably the consistent reciprocal strategy and the economic reward received by the participant respectively

Favourite	1st	2nd	3rd	4th
General ranking of the robots				
$TfT \times RO$	13	13	7	5
$TfT \times I - RO$	9	9	9	11
$I - TfT \times RO$	8	9	11	10
$I - TfT \times I - RO$	8	7	11	12
Human starter of ARUG				
$TfT \times RO$	5	8	3	4
$TfT \times I - RO$	5	5	6	4
$I - TfT \times RO$	5	5	5	5
$I - TfT \times I - RO$	5	2	6	7
Robot starter of ARUG				
$TfT \times RO$	8	5	4	1
$TfT \times I - RO$	4	4	3	7
$I - TfT \times RO$	3	5	5	5
$I - TfT \times I - RO$	3	4	6	5

condition, there is a main effect of RRD such that TFT (M = 3.98, SD = 0.73) lead to higher scores of likeability than $I - TfT$ (M = 3.32, SD = 0.85). In the robot starter group the robot in the TfT and $I - RO$ (Robot C) condition also had higher scores. The likeability of the robot due to the TfT and $I - RO$ could be explained by the unexpected behaviour of the robots towards the participants and the nature of $I - TfT$ that reciprocate low offers with higher offers as is explained in the next paragraph.

The study performed in [15] shows similar results in terms of the likeability of robots performing unexpected behaviours even when these behaviours were breaking social rules. Moreover, these results slightly match with the results of the ranking of the robots after all the experimental sessions. The favourite robots in the ranking were firstly the robot in TfT and RO (pure reciprocal) condition and then TfT and $I - RO$ condition. Probably the robot in TfT and $I - RO$ was perceived as a generous robot and that is why people liked it. They didn't expect that offering low pays being rewarded with higher pays from the robot during the $ARUG$. Participants liked the unexpected financial benefit and "nice" behaviour of the robot. On the other hand the pure reciprocal could be perceived as easier to understand. This knowledge can be useful for the design of future robot behaviours, offering unexpected robot behaviours and benefits to the users (low or high rewards) in order to keep to the user engaged with the interaction.

In terms of participant's reciprocal decision (PRD), a significant three-way interaction effect existed. Then, a two-way ANOVA was performed for each group. A two-way interaction effect between RRO and RRD was found. Participants reciprocated more towards the robots in the TfT condition than in the $I - TfT$ in the human group. See Table 3 for means and standard deviations. Participants reciprocated more towards the robot in the TfT and $I - RO$ condition in the same group. These results are in line with our results in previous studies [15] in terms that the Norm of Reciprocity [30] applies in HRI. People tend to reciprocate towards robots that show evident reciprocal behaviours. Furthermore, they naturally reciprocate more towards the robot in TfT and $I - RO$ because it offers higher financial benefits: the robot made higher offers when the participant offered little money. No cases of humans offering high amounts of money to receive little money from the robot appeared during the experiment. In the case of the robot starter group, RD had a main effect in the decisions of the participants. They reciprocate more to the robot in TfT condition, (M = 7.97, SD = 2.09) than the robot in $I - TfT$ (M = 2.3, SD = 2.07). Similarly, RO had an impact in PRD in the robot group. Participants reciprocate more frequently when the robot used a reciprocal offer in RO condition (M = 5.94, SD = 3.44), than when the robot was using $I - RO$ (M = 4.36, SD = 3.44). Similarly to the human group, reciprocal strategies play a role that lead us to think that the Norm of Reciprocity rules the reciprocal behaviours in HRI. Moreover, the use of simultaneous reciprocal different strategies has a very defined outcome in terms of PRD and RL. In this case, these interactive behaviour could be attributed to the easy identification of a reciprocal pattern along the 20 rounds of the $ARUG$. These patterns are easy for the participant to comprehend, allowing for easy prediction and manipulation of future benefits in the game.

In terms of participant's reciprocal offer (PRO) there are no interaction effects at all. There is a main effect of RO. Participants reciprocated the offer of the robot more frequently in RO (M = 2.7, SD = 2.49) than in $I - RO$ (M = 1.6, SD = 1.96). There is also a main effect of RD; participants reciprocate the robot's offer more often in the TfT condition (M = 2.4, SD = 2.733) than in the $I - TfT$, (M = 1.9, p = 1.763). We also found that the initiator, makes a significant difference in PRO. Participants reciprocate the offer less (M = 1.575, SD = 1.833) when they start the $ARUG$ than when is the robot who starts the game, (M = 2.79, SD = 2.6). Apparently, the robot is capable of establishing a reciprocal pattern when it starts the game that is easily followed by the participant. These findings suggest that, ideally, robots starting an interaction can establish the patterns of interaction in an understandable way for the user.

There was not a three-way interaction effect affecting participant's profit (PP). However, there is a two-way interaction effect between RRO and RRD that can be explained with the main effects. In RRO condition participants had a higher profit with the robot in the $I - RO$ condition

(M = 963.6, SD = 384.106) than in the RO condition, (M = 660.1, SD = 211.297). Similarly in RRD, participants had a higher profit with the robot in TfT condition, (M = 985.9, SD = 400.46) than with the robot in $I-TfT$, (M = 637.8, SD = 130.57). In other words, the combination of TfT and $I-RO$ are the most profitable for the participant. The combination of the reciprocal movements and low reciprocal offers made the participant quickly notice that they can obtain higher profit if they keep making negative reciprocal offers (low offers) because the robot will offer high offers in the next round. The main effect of the RRO made more profitable the strategies that imply more RRD. For instance, a higher reciprocal offer coming from the robot made it easier for the participant to accept it and do a reciprocal movement in the next round. Hence, it is possible to claim that humans would prefer to receive higher benefits from the robot compared to what they offer it in other kinds of interaction. This is comparable to what happens in human–human interaction when a person provides a service to another.

In terms of the correlations between robot's likeability (RL), participant's reciprocal decision (PRD), participant's reciprocal offer (PRO), and participant's profit (PP), further studies are required due to the moderate and weak nature of the correlations.

Finally, participants ranked the robots at the end of the experiment. They had a general view of all the possible behaviours of the robots and freely decided their favourite robot in their own terms as we can note in their final comments. Although the chi-square analysis does not offer significant results, the ranking gives some clue for future studies. People ranked $TfT \times RO$ as their favourite reciprocal strategy and $TfT \times I-RO$ as their second favourite. In the case of $TfT \times RO$, the pure reciprocal robot, this could be explained due to the fact that they could detect a reciprocal pattern easily compared to the other robots which had more unexpected behaviour as we explained before. For Robot C ($TfT \times I-RO$), we observed a reciprocal pattern perceived as generous due to the higher reciprocal offer of the $TfT \times I-RO$ strategy when the participant made a low offer. This reciprocal strategy of Robot C gave to the participants who noticed it early more money compared to the other strategies.

6.1 Conclusions

This study suggests that humans accomplish the Norm of Reciprocity proposed by Gouldner [30] in the domain of HRI in terms of robot's likeability, participant's reciprocal decision, participant's reciprocal offers, and participant's profits. We found that participants liked the pure reciprocal robot strategy with $TFT \times RO$ and $TfT \times I-RO$ conditions and obtained more benefits from the combination of these strategies. TfT and $I-RO$ robot was likeable due to the unexpected behaviour bringing economic benefits to the participant.

This study is in line with the results of previous studies [11] and [15]. It is possible to say that the Norm of Reciprocity rules the interaction of decision games in HRI in terms of simultaneous use of reciprocal strategies in $ARUG$ which is a relatively complex interactive scenario. When the human starts the interaction, participants reciprocate towards the robot that shows evident reciprocal behaviours, specifically with the robot in the TfT and $I-RO$ condition due to the higher economic benefits(the participant offers little money to the robot and the robot made higher offers).

When the robot starts the interaction, participants reciprocate the offer (PRO) and the decision, (PRD) in the TfT and RO conditions; more often than when the human starts the interaction due to the robot establishing a pattern which is easy to follow. Furthermore, if the robot starts the interaction with a 50%:50% offer, it could be perceived as a fair offer. This perception could be the cause of the significantly higher reciprocation towards this robot. These findings could be useful in the future for designing complex reciprocal behaviours for different social applications such as health-care, education or entertainment. Moreover, different layers of reciprocal behaviours could work together in order to keep the attention of the user and provide benefits by different means.

Besides, the participant's profit (PP) is affected simultaneously by RRD, and RRO as main effects. Consequently participants obtain a higher profit with the robot in the TfT and $I-RO$ condition. Although this high profit, our analysis of correlations in the fifth question, shows a weak correlation between PP and RL. In other words, Profit and Likeability are not strongly correlated in Human Robot Interaction.

Although the people received a higher profit from the Robot C using TfT and $I-RO$ strategy they ranked Robot A; the pure reciprocal robot (TfT and RO), higher when they compare all the robots. This is likely because this robot offered easily comprehensible and predictable outputs during the $ARUG$. However, in the experimental session participants found more likeable the TfT and $I-RO$ robot condition. In other words, a likeable robot as Robot C would not necessarily be the favourite robot when it is compared with other robots in a ranking. However, robots showing in some reciprocity; such as the Robot A ($TfT \times RO$) and ($TfT \times I-RO$) would be more beneficial for the users than those that do not so. Again looks like reciprocal robots are more likeable that generous robots when they are compared with other robots showing less obvious reciprocal behaviours.

These findings should be considered for the future design of interactive behaviours in social robots. More investigation is required to these findings to real interactive scenarios. However, We expect that in the near future these interactive patterns based in games can be useful in more complex human–robot interactions.

6.2 Limitations and Future Work

Considering the complexity of the reciprocal behaviors this scenario presented, further studies are required in order to determinate stronger correlations between likeability and reciprocity. Besides, future scenarios in the real world will offer more challenging conditions for robot designers, requiring them to create even more complex robot behaviours. In addition, the measurement and analysis of other items in the Godspeed scale as well as other psychological measurements could be added to the study and to similar experiments.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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