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**Citation:** Hanssen, E., Fett, A-K., White, T-P., Caddy, C., Reimers, S. & Shergill, S. (2018). Cooperation and sensitivity to social feedback during group interactions in schizophrenia. *Schizophrenia Research*, 202, pp. 361-368. doi: 10.1016/j.schres.2018.06.065

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**Link to published version:** <https://doi.org/10.1016/j.schres.2018.06.065>

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1 **Cooperation and sensitivity to social feedback during group interactions in schizophrenia**

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30 **Keywords: Schizophrenia, Social interactions, Public Goods Paradigm, Social Feedback**

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32

33 **ABSTRACT**

34

35 Patients with schizophrenia show reduced cooperation and less sensitivity to social cues in  
36 pairwise interactions, however, it remains unclear whether these mechanisms are also present  
37 in interactions within social groups. We used a public goods game to investigate cooperation and  
38 sensitivity to social feedback in group interactions in 27 patients with schizophrenia and 27  
39 healthy controls. Participants played 20 trials in two conditions: 1) no fine: participants had the  
40 choice of investing into the public good (i.e. cooperating) or not (i.e. defecting), 2) fine:  
41 participants had the same choice but defectors could be punished by the other players. On the  
42 first trial, patients invested less in the public good than healthy controls. In the no fine condition,  
43 controls decreased their investments over time, but patients did not. The possibility of being  
44 fined for defecting and actually being fined led to significantly higher cooperation in both groups.  
45 This shows that the groups were equally sensitive to social feedback. Our findings suggest that  
46 patients tend to approach social group interactions with less cooperative behaviour, which could  
47 contribute to social dysfunction in daily-life. However, an intact sensitivity to social enforcement  
48 and feedback indicates that patients can adjust their behaviour accordingly within a group.

49

50 1. Introduction

51

52 Social cognitive skills are crucial for the development of cooperation and trust in interpersonal  
53 relationships (Fett et al., 2014; Kishida et al., 2010; Sutter and Kocher, 2007). There is ample  
54 evidence that patients with schizophrenia demonstrate impairments in social cognition (Couture  
55 et al., 2006; Fett et al., 2011; Green and Leitman, 2008; Green et al., 2008; Penn et al., 2008;  
56 Pinkham et al., 2003; Savla et al., 2012); and that these impact on illness outcomes (Couture et  
57 al., 2006; Fett et al., 2011; Penn et al., 1996). Social dysfunctions are also reflected in some of the  
58 key positive and negative symptoms of the disorder, such as paranoia, social withdrawal and lack  
59 of (social) motivation (Penn et al., 2008). In daily life, social interactions pose a challenge for  
60 patients (Billeke and Aboitiz, 2013; Couture et al., 2006; Penn et al., 1996), reflected in patients'  
61 difficulties maintaining relationships with family or friends (Burns and Patrick, 2007; Pinkham and

62 Penn, 2006). In studies using neuro-economic exchange games to examine social interactions  
63 directly, demonstrated that patients tend to show lower levels of trust towards others (i.e.  
64 cooperate less) (Fett et al., 2016; Fett et al., 2012; Gromann et al., 2013), compared to healthy  
65 individuals, and are less likely reciprocate in interactions (Berg et al., 1995; Sigmund, 2007, 2010).  
66 Lower levels of trust were associated with more severe psychotic symptoms in chronic psychosis  
67 (Fett et al., 2012; Gromann et al., 2013). Moreover, in these pair-wise interactions, patients did  
68 not adjust their behaviour after receiving information about the other player's trustworthiness  
69 (Fett et al., 2012), suggesting lower sensitivity to social feedback, which is in line with earlier data  
70 showing that patients are less sensitive to interpersonal cues (Corrigan and Green, 1993;  
71 Johannsen, 1961). While these two-person games can help to enhance the understanding of the  
72 dynamic nature of pairwise interactions, modelling social dilemmas in groups provides additional  
73 information because social interactions often occur among more than two individuals  
74 simultaneously (Archetti and Scheuring, 2012) and the signals of more people need to be  
75 interpreted simultaneously leading to a greater complexity in the social dynamics (Brandt et al.,  
76 2003; Sigmund, 2007).

77         One approach to examine group dynamics during cooperation and sensitivity to feedback  
78 from others is offered by the public goods game (PGG). In this paradigm, a social dilemma is  
79 given: participants have to make a choice between maximizing the benefits across a group at a  
80 cost to their personal payoff, or maximizing their personal payoff at the expense of the group.  
81 Players are given an initial endowment and have to make the decision whether to invest the  
82 money in a group account (cooperating/public good) to mutual benefit or whether to keep the  
83 money for themselves (defecting/private good) yet still benefit from the others contributions. A  
84 key variable underlying cooperation in the PGG is trust (Balliet and Van Lange, 2013). If a player  
85 chooses the private good, his return exceeds that of the players who invested into the public  
86 good (Fehr and Fischbacher, 2004); this represents "free riding" (Fehr and Schmidt, 1999;  
87 Wischniewski et al., 2009). When players are allowed to punish those who free ride, investments  
88 in the public good increase as cooperation is socially enforced (Brandt et al., 2003; Fehr and  
89 Gächter, 1999, 2002). While fining another player is mostly done out of anger or spite, there is a

90 cost attached to this - players have to pay to punish a defecting player, which makes this an  
91 altruistic act, a form of punishment at a personal cost (Brandt et al., 2003; Seymour et al., 2007).

92 To date, only one study has used the PGG to investigate group interactions in  
93 schizophrenia (Chung et al., 2013). They found higher levels of cooperation in patients compared  
94 to controls in a PGG without punishment (i.e. not examining social feedback). The authors  
95 concluded that patients played the game in a non-strategic way and demonstrate a reduced  
96 sensitivity to loss. However, the results are difficult to compare as the authors manipulated the  
97 utilized game to have 2 possible outcomes, group success or failure (success if 3 or more out of  
98 the 5 players in the game cooperated, otherwise failure), which enforced a higher rate of  
99 cooperation. More importantly, they did not include changes in cooperation over time. They also  
100 had groups exclusively of patients, which tends to amplify group differences. Therefore, their  
101 utilized PGG did not tap into the same processes as our PGG design.

102 We describe the first study to use a neuro-economic group interaction game to  
103 investigate behaviour in social groups in schizophrenia, using the PGG, incorporating a measure  
104 of sensitivity to social feedback. We were interested in three key elements: 1) baseline level of  
105 cooperation on the first trial, where participants do not have any information on the other  
106 players' behaviour, 2) behavioural change in response to others' behaviour, 3) behavioural  
107 change when players were able to punish other players – to investigate whether cooperation can  
108 be enforced and to examine sensitivity to social feedback. Based on expected illness reduced  
109 social cooperation, on some of the key symptoms of the disorder (e.g. paranoia and distrust) and  
110 on previous results from trust game studies we hypothesized that patients with schizophrenia  
111 would demonstrate: a) lower levels of baseline cooperation and lower mean cooperation in the  
112 PGG, b) less sensitivity to social feedback indicated by less difference in cooperation between  
113 conditions (i.e. social enforcement) and less adjustment in behaviour after being fined in the  
114 preceding trial as compared to controls (i.e. sensitivity to social feedback). We hypothesized a  
115 negative association between symptoms (positive and negative), cooperation and sensitivity to  
116 social feedback in patients. Positive symptoms are related to social abnormalities and deficits in  
117 social decision making and trust. Negative symptoms such as social withdrawal, isolation, social  
118 anhedonia, social amotivation have strong social components.

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## 2. Methods

### 2.1 Subjects

Twenty-seven outpatients with schizophrenia and twenty-seven healthy controls were included in the study. Patients were recruited from the South London and Maudsley NHS Foundation Trust and healthy controls subjects were recruited through local advertising. Demographic information is displayed in Table 1. Inclusion criteria for all participants were 1) age between 18-55 years old, 2) sufficient understanding of the English language to successfully perform the task and to understand the informed consent, 3) no learning disabilities, 4) absence of a neurological condition, 5) no alcohol/drug dependence within the last six months, 6) absence of a major physical illness or motor, hearing or speech difficulties. For the schizophrenia group additional inclusion criteria were 1) a diagnosis of schizophrenia, schizoaffective disorder or psychotic disorder according to the ICD-10 criteria, 2) stable under their current treatment (> 6 weeks). The patients who were included had the following diagnoses without any comorbidity: 20 schizophrenia, 5 schizoaffective disorder, 1 psychotic disorder, 1 polymorphic psychosis with schizophrenia. All patients were medicated, with 85% treated with atypical antipsychotics.

### 2.2 Measures

*Symptoms* - To assess symptom severity in patients the Positive and Negative Syndrome Scale (PANSS) (Kay et al., 1987) was used. The PANSS is a semi-structured interview that assesses symptoms over a two-week period prior to the testing session. Thirty items are scored to evaluate the severity of psychopathology: 1 = absent, 2 = minimal, 3 = mild, 4 = moderate, 5 = moderate to severe, 6 = severe to 7 = extreme. In the current study, the PANSS subscale scores were used to get estimate of positive symptom severity (range 7-49) and negative symptom severity (range 7-49). The positive and negative scale have good concurrent validity and good internal reliability (respectively Cronbach's  $\alpha = 0.62-0.73$  and  $\alpha = 0.83-0.92$  (Kay et al., 1987; Peralta and Cuesta, 1994)).

148 *2.3 Estimated cognitive ability* - To control for possible influence of cognitive ability on group  
149 differences in behaviour in the PGG, an estimation of cognitive ability was assessed with the  
150 vocabulary subtest of the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999).  
151 The Vocabulary subtest has a total of 42 items, where subjects are required to define and  
152 describe the words best to their knowledge. Words are presented orally and visually. The WASI  
153 vocabulary test gives a good estimate of overall intelligence scores, the vocabulary subtest  
154 showing a 0.87 correlation with the full WAIS III (Axelrod, 2002). T-scores were converted to  
155 scaled WASI scores (range 20-80).

156

#### 157 *2.4 Experimental design*

158 A binary public goods paradigm was used to investigate cooperation and sensitivity to others'  
159 social feedback in a group setting. Subjects participated in two three-player games involving one  
160 of two conditions; 20 trials in the no fine and 20 trials in the fine condition. Before the start of  
161 the game, participants were informed that they were playing all 40 trials with the same two  
162 opponents who were participating on computers that were connected via the Internet. In reality,  
163 they were playing computers (player 2 and player 3) that were programmed with stochastic  
164 algorithms that mimicked human choices. The study was coded in Adobe Flash (see (Reimers and  
165 Stewart, 2015), and was adapted from a version of the PGG in which participants genuinely  
166 played against other real player over the internet. As such, plausibility of playing with other real  
167 people was kept high. In the no fine condition, player 2 was programmed to play a tit-for-tat  
168 strategy (see, e.g., Axelrod, 1980); meaning player 2 would cooperate on all trials, except  
169 immediately following a trial on which the other two players did not cooperate. Player 3 was  
170 programmed to play a locally self-interested strategy, defecting on all trials. In the fine condition,  
171 players 2 and 3 used the same strategies as in the no fine condition. Both player 2 and 3  
172 cooperated if they were punished in the preceding trial. Player 2 punished any player that  
173 defected on two consecutive trials. Player 3 never punished other players. To make the strategies  
174 used by the virtual players less transparent, players played their dominant strategy 80% of the  
175 time and a random 20% of the time the opposite strategy.

176           In the *no fine condition*, participants received an initial endowment of £3. They then had  
177 to make a choice whether to keep the money for themselves (invest in the private good; i.e. free  
178 riding) or to put their £3 in a public good (invest in the public good; i.e. cooperation). They made  
179 this choice before seeing the other players' decisions. At the end of the trial, the contribution of  
180 each player was revealed, and the money contributed by the three players was summed then  
181 doubled and the total amount was divided equally among all players, regardless of whether they  
182 cooperated or not. The next trial started again with £3 for each player.

183           The *fine condition* was identical to the no fine condition, however, after participants made  
184 their choice and had been informed about how the other players had invested, they were then  
185 given the option to punish the players who did not cooperate. To punish another player was  
186 costly, since £1 was deducted from their own total amount and £2 was deducted from the total  
187 of the fined player. So, punishing another player was only possible at a cost to themselves.

188           The task was presented in an animated way, presenting 3 players seated around a table,  
189 the procedure of the game is visually shown in Figure 1.

190

## 191 *2.5 Procedure*

192 All participants were invited to the Institute of Psychiatry, Psychology and Neuroscience, where  
193 testing took place. Trained MSc level researchers carried out the testing session and a research  
194 nurse administered the PANSS interview. Prior to participation subjects were given written  
195 information about the content of the study and what would be expected from them. It was  
196 emphasized that their participation was voluntary and they had the opportunity to withdraw at  
197 any moment without any consequences. The study was approved by the Bromley Research Ethics  
198 Committee. All participants signed informed consent before testing.

199           After completing a questionnaire on demographic information, participants played the  
200 PGG (the no fine condition first, followed by the fine condition) on a laptop in a web browser,  
201 which initially showed a loading message and a connecting message for the other players. After  
202 a few connection attempts, the system displayed that all players were connected and the task  
203 was launched. Plausible variable delays were used for the responses of the other players, so that they  
204 did not necessarily appear immediately after the participant made a choice. After completing the

205 experimental task the PANSS interview was conducted. At the end of the session, subjects  
206 received an incentive of £10 for participation in the study.

207

## 208 *2.6 Statistical analyses*

209 Statistical analyses were performed using STATA version 14 (StataCorp, 2015). We examined  
210 group differences in demographics using t-tests and chi square tests. Logistic regression analyses  
211 were performed to investigate the differences between groups in baseline cooperation  
212 (investment on the first trial) and multilevel mixed effects logistic regression analyses to  
213 investigate the differences in mean cooperation, changes in cooperation over trials, punishment  
214 (i.e. frequency of fining other players) and social sensitivity to punishment (i.e. change in  
215 behaviour after being fined) between groups and between symptoms and cooperation within the  
216 patient group, taking into account possible effects of a-priori confounders (gender and age). The  
217 same analyses were run to investigate within group effects of condition in baseline cooperation  
218 and mean cooperation (i.e. representing social enforcement). Separate analyses were conducted  
219 to investigate group differences within each condition and the condition effect within each  
220 group, as the full model omitted essential variables due to dichotomous outcome and predictor  
221 variables.

222

## 223 3. Results

224

### 225 *3.1 Demographics*

226 Demographic information and clinical characteristics are shown in Table 1. There were no  
227 significant differences between groups in age and gender. There was a trend towards significant  
228 differences between groups in estimated cognitive ability, with patients having a lower estimated  
229 cognitive ability than healthy control subjects.

230

### 231 *3.2 Group differences on baseline and mean cooperation by condition*

232 Task performance per group and condition is shown in Table 2 and are displayed in Figure 2. In  
233 the no fine condition, there was a significant difference in first-trial cooperation between groups

234 with patients showing lower cooperation, OR = 0.18, 95% CI (0.04; 0.89),  $p = .04$ , but no significant  
235 difference in mean levels of cooperation ( $p = .23$ ). In the fine condition, there was a similar trend  
236 effect towards a difference in cooperation between groups, OR = 0.20, 95% CI (0.03; 1.19),  $p =$   
237  $.077$ , but mean levels of cooperation throughout the game did not differ ( $p = .53$ ).

238

### 239 *3.3 Changes in cooperation over trials*

240 PGG performance changes over repeated trials are shown in Figures 3a (no fine condition) and  
241 3b (fine condition). There was a trend towards group differences in change in cooperation over  
242 trials in the no fine condition, as indicated by the interaction between trial number and group,  
243 OR = 1.05, 95% CI (1.00; 1.10),  $p = .065$ . Analyses by group showed a significant change in  
244 cooperation in the healthy control group (OR = .94, 95% CI (0.91; 0.97),  $p < .001$ ), but not in the  
245 patient group ( $p = .34$ ).

246 In the fine condition the change in cooperation over time was not different between  
247 groups, as indicated by the non-significant interaction between trial number and group ( $p = .86$ ).  
248 In the model without the interaction, the main effect of group on cooperation was also non-  
249 significant ( $p = .43$ ), however, there was a significant main effect of change of cooperation over  
250 trials (OR = 0.96, 95% CI (0.94; 0.98),  $p = .002$ ).

251

### 252 *3.4 Effect of social enforcement on cooperation within groups*

253 Within the healthy control group there was no significant difference in the percentage  
254 cooperation on the first trial between conditions,  $p = 1.00$ . However, controls showed a  
255 significant difference in mean levels of cooperation between conditions, with cooperation being  
256 higher in the fine than no fine condition, OR = 1.60, 95% CI (1.22; 2.10),  $p = .001$ .

257 In the patient group, there was no significant difference in percentage baseline  
258 cooperation between conditions,  $p = .55$ . Similar to healthy controls, patients showed a  
259 significant difference in the mean levels of cooperation throughout the game between  
260 conditions, with cooperation being higher in the fine than no fine condition, OR = 1.84, 95% CI  
261 (1.39; 2.44),  $p < .001$ .

262

263 *3.5 Sensitivity to social feedback and punishing behaviour*

264 The likelihood of cooperation after being punished by another player for free riding did not differ  
265 between groups,  $p = .58$ , see Table 2 for percentages of cooperation. Groups also did not show  
266 any differences between cooperation after defecting but not being fined by another player ( $p =$   
267  $.67$ ) and no differences in cooperation after cooperating in the previous trial ( $p = .52$ ). Healthy  
268 controls and patients did not differ in the frequency of punishments given to other players,  $p =$   
269  $.74$ .

270

271 *3.6 Correlations between (baseline) cooperation and symptoms within the patient group*

272 No significant association between positive and negative symptoms and baseline cooperation  
273 was present in either condition (no fine condition:  $p = .38$   $p = .59$ , fine condition:  $p = .57$  and OR  
274  $p = .90$ , respectively).

275 There was a significant interaction between positive symptoms and change in cooperative  
276 behaviour over trials in the no fine condition (OR = 1.01, 95% CI (1.00; 1.02),  $p = .05$ ). To examine  
277 the interaction in more detail, we divided the patients into three groups based on the positive  
278 symptom severity (PANSS Group 1;  $N = 9$ ,  $M = 12.33$ ,  $SD = 1.76$ , PANSS Group 2:  $N = 7$ ,  $M = 15.57$ ,  
279  $SD = 0.5$  and PANSS Group 3:  $N = 7$ ,  $M = 21.29$ ,  $SD = 2.97$ ). These results are plotted in Figure 4,  
280 demonstrating that patients with the most severe positive symptoms (PANSS Group 3) increased  
281 their level of cooperation throughout the game compared to healthy controls and patients in the  
282 PANSS Groups 1 and 2. This interaction effect was not found in the fine condition,  $p = .95$ , and  
283 also no main effect of positive symptoms in the model without the interaction ( $p = .26$ ), but there  
284 was a main effect of cooperation over trials (OR = 0.96, 95% CI (0.93; 1.00),  $p = .05$ ).

285 There was no significant interaction between negative symptoms and trial number on the  
286 likelihood of cooperation in the no fine condition and the fine condition, respectively  $p = .63$  and  
287  $p = .31$ . There was no main effect of negative symptoms in the no fine condition ( $p = .99$ ), nor in  
288 the fine condition ( $p = .51$ ). There was no main effect of cooperation over trials in the no fine  
289 condition (OR = 0.99, 95% CI (0.95; 1.02),  $p = .42$ ), but this was significant in the fine condition  
290 (OR = 0.96, 95% CI (0.93; 1.00),  $p = .05$ ).

291

292 All analyses were repeated with IQ as a covariate in the model. Due to many missing values in IQ,  
293 we used a multiple imputation-based procedure to re-create the individual missing scores. This  
294 yielded slightly different parameter results, however, significance did not change and the  
295 direction of the effect remained the same.

296

#### 297 4. Discussion

298

299 This study examined cooperation and sensitivity to social feedback in schizophrenia in a PGG, to  
300 measure the dynamics of social group interactions. Our findings on baseline cooperation show  
301 that patients are less cooperative at task onset. However, patients did not differ from controls in  
302 their reaction to social enforcement or sensitivity to social feedback (i.e. punishment).

303 Patients have lower initial inclination to cooperate in social groups, as indicated by a lower  
304 level of baseline investments into the public good compared to healthy controls. This finding is  
305 in line with evidence from pairwise interactions, where patients show less basic trust (Fett et al.,  
306 2012; Gromann et al., 2013). To engage in social interactions, one has to trust the other person's  
307 willingness to cooperate, which seems to be a key precursor in the development of cooperation  
308 in a public goods dilemma (De Cremer, 1999). Patients may choose more selfishly in a PGG  
309 compared to healthy controls, because they are less trusting due to negative beliefs about other  
310 individuals. Another possible explanation is that patients with schizophrenia are more self-  
311 oriented, due to a reduced ability to take the perspective of others (Sprong et al., 2007).

312 Change in behaviour over trials was different between groups in the condition without  
313 fining, but not in the condition where cooperation was socially enforced. Healthy controls started  
314 out with high levels of cooperation and then decreased their cooperation over trials, which is in  
315 line with previous findings on cooperation in a public goods paradigm, cooperation in multi-shot  
316 public goods games tends to be high initially and then declines throughout the game (Andreoni,  
317 1988; Fehr and Fischbacher, 2003; Fischbacher et al., 2001; Ledyard, 1995). This can be explained  
318 by a game-theoretic view: the allocation of the public good is equal no matter what amount each  
319 individual invests, thus, to maximize one's own profit, the dominant long-term strategy is to  
320 defect (Andreoni, 1988). A possible explanation for decreasing cooperation could be that  
321 participants are reluctant to invest into the public good because of fear that others are not going

322 to contribute as well. This is called inequity aversion. In the beginning of the game, healthy  
323 participants may be more willing to take a risk, or are more trusting in others' good will compared  
324 to patients. However, when their contributions are not routinely reciprocated, this feeling of  
325 inequity overrides the willingness to cooperate (De Cremer, 1999; Kurzban et al., 2001). The  
326 decline may also be related to a self-serving bias (Fischbacher et al., 2001). Patients' motivation  
327 to defect may be based on a lack of trust due to fear of uncooperative behaviour of others.  
328 Another possible explanation could be that patients value monetary reward in a different way  
329 than controls do, which could be related to impulsive choices (Heerey et al., 2007) and  
330 amotivation (Fervaha et al., 2013).

331 Adding the option of punishing another player for free riding increased the likelihood of  
332 cooperation within both groups compared to the condition where fining was not allowed.  
333 Although this is in line with previous findings in healthy subjects, who tend to increase  
334 cooperation when the punishing of free riders is allowed (Brandt et al., 2003; Fehr and Gächter,  
335 2002), this was in contrast to our expectations in the patient group. We anticipated that patients  
336 would be less sensitive to social enforcement by introducing the possibility of fining others, due  
337 to patients' deficits in processing social information. The findings suggest that patients are  
338 sensitive to social enforcement. Moreover, there was an increase in cooperation after defecting  
339 and being fined for it: in healthy controls from 12.80% to 45.10% and in patients from 13.72% to  
340 44.83%. This change in behaviour was similar in both groups, indicating that patients did not  
341 show the expected reduced sensitivity to social feedback. There is some evidence from other  
342 studies for unimpaired sensitivity to punishment in schizophrenia (Cheng et al., 2012). In pairwise  
343 encounters a reduced sensitivity, i.e. no changes in trust, was shown after providing information  
344 about the trustworthiness of the other player (i.e. top-down processing) (Fett et al., 2012). In our  
345 study patients had to use bottom-up processing to deduct the social information (i.e. learning  
346 trial-to-trial in the game). It might be that problems arise when patients have to use top-down  
347 processing of social information specifically (integration of *a priori* information) and not when  
348 patients use bottom-up processing of social feedback that is data-driven.

349 Patients and controls demonstrated the same amount of punishing behaviour, which is in  
350 line with results in pairwise interactions in dictator game with punishments (Wischniewski and

351 Brüne, 2011). These findings suggest that patients are sensitive to social rules and willing to  
352 altruistically punish other players to reinforce social norms at the same level as healthy control  
353 subjects.

354 Interestingly, positive symptoms were only associated with the level of cooperation over  
355 trials in the no fine condition. Patients with more severe positive symptoms showed an increase  
356 in cooperation over time, compared to reduced cooperation in the lower symptom groups and  
357 the healthy control group. An inability to estimate the risk of loss (Pedersen et al., 2016; Shurman  
358 et al., 2005) and reduced sensitivity to unfairness (Agay et al., 2008; Csukly et al., 2011) might  
359 explain why patients in the highest symptom group in our study increase their level of  
360 cooperation instead of decreasing this behaviour. It is possible that the higher level of  
361 cooperation in our study is related to making choices without fully contemplating the best  
362 strategy. In accordance with previous studies these abnormalities in behaviour in the PGG may  
363 reflect aberrant reward processing (Juckel et al., 2006a; Juckel et al., 2006b; Nielsen et al., 2012;  
364 Schlagenhaut et al., 2008) and reward learning (Gold et al., 2008; Murray et al., 2008; Strauss et  
365 al., 2014; Waltz et al., 2013). This should be interpreted with caution due to the small sample  
366 sizes in the three symptom groups. However, the possibility of being punished resulted in an  
367 appropriate behavioural adjustment in patients with more severe positive symptoms. It is not  
368 possible to be definitive about the reason for this aberrant behaviour without social  
369 enforcement, which may be contributed by a lower sensitivity to other people's choices or lack  
370 of cognitive flexibility. It would therefore be interesting to investigate this association with  
371 specific clusters of symptoms and cooperation in group interactions in future studies.

372 There are limitations in this study. First, the PGG in this study was a binary 3-player game,  
373 this choice was made for task simplicity, either an investment in the private or the public good;  
374 incorporating continuous investment opportunities may have made the game more sensitive to  
375 changes in social enforcement and feedback. Second, the punishment in our study was  
376 potentially low; a free riding player punished by a cooperating player would still receive £3 (i.e.  
377 the initial endowment) if the other 2 players cooperated; a flexible level of punishment could  
378 have greater influence on behaviour. Last, we did not differentiate between medication type,

379 although the majority of patients were on atypical antipsychotics. Future studies have to  
380 systematically investigate the possible roles of medication and stage of the illness are.

381 This study is the first to investigate cooperation, social enforcement and sensitivity to  
382 social feedback in group interactions in schizophrenia. Although all effect sizes were small, our  
383 findings suggest that patients demonstrate a tendency to initiate social group interactions with  
384 less cooperative behaviour, which may set a negative tone in social settings, potentially  
385 contributing to social difficulties in initiating interactions in real life functioning. However, the  
386 results clearly suggest that social enforcement and sensitivity to social feedback are intact, which  
387 indicates that it may be possible for patients adjust their social behaviour accordingly during  
388 repeated social interactions. This may be particularly important for interventions that target  
389 social skills and suggests that group-based interventions may be particularly helpful. The study  
390 would benefit from replication, since this is the first study to investigate cooperation and  
391 sensitivity to social feedback in this manner. It would be interesting to extend this work into social  
392 group interactions in real time and to use neuroimaging, to test the underlying neural  
393 mechanisms.

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524

525 **Figure legends**

526

527 *Figure 1.* Schematic representation of the binary public goods game: a) no fine condition and a+b)  
528 fine condition; a) participants could cooperate (black arrows) or free ride (light grey arrow), a  
529 choice made without knowing the other players' decisions. The amount in the public good was  
530 doubled and split equally among all players (grey arrows), b) The players who cooperated could  
531 fine (punish; grey arrows) the players who free rode after receiving information on the other  
532 players' decisions. Costing the fining player £1, but deducting £2 from the free riding player.

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535 *Figure 2.* Group and condition comparisons for baseline cooperation and overall mean  
536 cooperation in the multi-round binary public goods game. The error bars depict the dispersion of  
537 cooperation over all trials within groups and conditions. †  $p < 0.08$ , \*  $p < .05$ , \*\*  $p \leq .001$

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540 *Figure 3:* Cooperation per trial in the multi-round binary public goods game in the a) no fine  
541 condition, and the b) fine condition.

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544 *Figure 4.* To visualize the interaction effect found between positive symptoms and change in  
545 cooperation over trials within the patient group, 3 groups for symptom severity were made.  
546 Change of cooperation over trials by positive symptom severity are plotted in the no fine  
547 condition.

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