# Supplementary Information

# S2. Methods and Materials

## S2.1 Participants

## All participants were recruited from the San Francisco Bay Area. Additional exclusion criteria for healthy controls included: 1) SCID-IV confirmed diagnosis of an Axis I disorder within the last year or any lifetime history of a psychotic illness; 2) schizophrenia or other psychotic disorder in a first-degree relative.

## S2.3.1 Auction Game

We endowed participants with 100 game dollars (worth $5) at the start of the task. This amount changed depending on the outcome of each of 35 auction trials. Prior to the start of the task, we took a photograph of each participant’s face. This photograph was displayed on the screen throughout the task along with photographs of the virtual players. Before the task began, we placed a mock telephone call asking if the other five players were ready in order to enhance the believability of playing against other human players. Bidding behavior of the virtual players was based on bidding behavior of healthy human participants from a previous study (van den Bos et al., 2008). Participants sat approximately 60cm in front of a computer monitor throughout the task and were alone in the testing room during all trials. Participants entered bids using a keyboard. To increase salience of each trial outcome, a different sound was played depending on whether the participant won or lost the trial. The entire testing session lasted approximately 20 minutes. We divided final endowment by 20 to determine final payment in dollars. During an exit interview, we asked each participant a series of questions about their experience with the study tasks. We asked what they thought about the other players in the Auction Game and what they noticed about other players’ strategies during the task in order to assess whether they believed they were playing against real people. Participants who gave responses suggesting they did not believe the other players were real were excluded from analyses.

## S2.3.2 Devil’s Task

Ten standard playing cards, nine black and one red, were presented in a face-down stack. Participants selected a number of cards to turn over. Each black card revealed earned participants $0.30. However, if the red card was among the revealed cards, the participant received no money. We initially demonstrated two examples to ensure understanding of the task; participants then completed one trial. The task lasted approximately five minutes.

# *S2.4 Data Analysis*

## S2.4.1 Auction Game

## Multilevel linear model

We followed the steps presented in Bliese and Ployhart (2016), starting with a model with only fixed effects (step 1) and building it up by allowing for random factors (step 2 and 3). Finally, we accounted for autocorrelation and heteroscedasticity (step 4). All models were estimated using maximum likelihood algorithms. To find the best fitting and most parsimonious model, we compared the goodness of fit after each step by using -2 log likelihood values and the difference of degrees of freedom between the models. We specified our baseline model as:

where represents the bid factor of a participant, represents the intercept, and to represent the slopes of the respective variables that follow each coefficient. The within-subject factor was Trial (1 to 35, which was centered to the mean for the analysis) and between-subject factors were Drug (oxytocin and placebo) and Group (control and schizophrenia). To determine whether our model could be improved by adding a random term, we allowed the intercept to vary across participants and tested the effect of allowing for random slopes.

### Reinforcement Learning Model

The reinforcement learning model developed for this task has several adjustments specifically tailored to the auction environment; see van den Bos et al. (2013) for a full description. We hypothesized that social factors create value for winning and losing that is independent of the monetary outcomes of the task. As a result, winning becomes more valuable by some factor, which we call *,* and not winning the auction becomes aversive by some value :

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where is the amount won or lost by the winning bidder.

Next, following the logic of a classic reinforcement learning model we expect that, at the end of each trial, participants compute a prediction error based on the difference between the actual outcome (*U*) and the expected outcome (*V*) related to their bid factor:

The prediction error is then used to update the expected outcome of a bidding strategy *κ* using learning rate, :

Finally, decisions were generated by the model using a soft-max decision function, with a parameter, , that indicates response variability (i.e., the likelihood of chosing a suboptimal strategy):

The value function, *V*, was initialized to zero for all values of .

We estimated model parameters (, , ,and ) using a simplex optimization algorithm in Matlab. Finally, we compared the performance of the current model with several alternative models using Bayesian model comparisons. To test the null hypothesis that there are no social preferences, we compared the full model to one in which the and parameters were both removed. To further explore the role of , and , we also included reinforcement learning models with either and removed from the model.

### Trial-by-trial bidding behavior

We complemented the reinforcement learning model with a trial-by-trial analysis of the relationship between monetary outcome of the auction on trial and the change in bid factor from trial to trial (i.e., the bidding adjustment after winning or losing money). For each participant, we computed the average correlation between previous trial outcome and change in bid factor. We compared these correlations using a 2 (Drug: placebo versus oxytocin) x 2 (Group: controls versus schizophrenia) between-participants ANOVA.

# S3. Results

## S3.1 Auction Game

## Trial-by-trial bidding behavior

Trial-by-trial analysis revealed a Group X Drug interaction, *F*(1, 75) = 162.35, *p* < 0.001, *ηp2* = 0.68 in bidding adjustment after winning or losing money; see Figure S1.To better understand this interaction, we examined the effect of drug in each group separately. In participants with schizophrenia, we found that the correlation between monetary outcome from trial and bid factor in trial was significantly different between the placebo and oxytocin conditions, *t*(30) = 17.02, *p* < 0.001, *d* > 1. While there was a positive correlation between outcome on trial *t – 1* and bid factor in trial *t* in the placebo condition (*M* = 0.42, *SD* = 0.16), there was a negative correlation between the two (*M* = -0.50, *SD* = 0.13) in the oxytocin condition. That is, for participants with schizophrenia who received placebo, monetary losses in a given trial led to reduced bids in the subsequent trial. For those administered oxytocin, however, monetary losses actually led to increased bids. This finding, which suggests a strategy to win the auction despite losing money, is consistent with the higher seen among participants with schizophrenia in the oxytocin condition. We found no difference between drug conditions for controls, *t*(45) = -0.04, *p* = 0.97.

**Figure S1.** Correlation between previous trial outcome and bid factor change in the Auction Game, shown by group (HC = healthy controls, SZ = patients with schizophrenia) for the placebo (PL) and oxytocin (OT) conditions.



## S3.2 Devil’s Task

We found no significant effects of Group, *F*(1, 72) = 0.02, *p* = 0.9, or Drug, *F*(1, 72) = 0.39, *p* = 0.54, or a significant Group x Drug interaction, *F*(1, 72) = 1.03, *p* = 0.31; see Figure S2.

**Figure S2.** Card selection in the Devil’s Task, shown by group (HC = healthy controls, SZ = patients with schizophrenia) for the placebo (PL) and oxytocin (OT) conditions. See main text for details.



### S3.3 Predictors of Auction Game bidding behavior in schizophrenia

## To address the possibility that cognition influenced bidding behavior, we included years of education (as a proxy for cognition) in a multilevel model. There was no significant four-way drug x group x trial x education interaction (p = 0.26), drug x trial x education interaction (p = 0.078), or group x trial x education interaction (p = 0.20). There was no significant main effect of education on bid factor (p = 0.11). The two-way education x trial interaction significantly affected bid factor (b = -6e-04 , t = -2.51, p = 0.012), regardless of group or drug, such that participants with high levels of education (mean education years + 1 standard deviation = 14.5) significantly decreased their bids over time (b = -0.0085 , t = -4.96, p = 7.6e-07) whereas participants with low levels of education (mean education years – 1 standard deviation = 4.32) did not (b = -0.0023 , t = -1.32, p = 0.19). As years of education did not interact with either group or drug, it is unlikely that differences in educational attainment explain our main findings. We also examined whether educational attainment correlated with the social motivation to win the Auction Game, . We found no correlation between years of education and (estimate = -0.14, t = -1.27, p = 0.21).

## **Figure S3. Interaction between anti-dopaminergic medication dosage and Auction Game bidding.** Medication dosages of patients with schizophrenia are shown as chlorpromazine equivalents (CPZ) for the placebo (PL) and oxytocin (OT) conditions. While oxytocin did not affect bidding behavior for patients taking mean dosages of anti-dopaminergic medications (panel A), it did affect bidding for those taking high dosages (panel B).



## **Table S1**. **Effect of drug on bidding behavior by CPZ and trial.** Participants on high dosages of antidopaminergic medications bid more on oxytocin than on placebo at trial 35, but not at trial 1. Participants on low dosages of antidopaminergic medications bid similarly on oxytocin and placebo at trials 1 and 35.

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| Chlorpromazine equivalents (CPZ) | At Trial 1 | At Trial 35 |
| ***b*** | ***t*-value** | ***p*-value** | ***b*** | ***t-*value** | ***p*-value** |
| 0 | -0.036 | -0.18 | 0.86 | -0.20 | -0.99 | 0.33 |
| 400 | 0.095 | 0.38 | 0.70 | 0.77 | 3.18 | 0.0033 |
| 800 | 0.23 | 0.39 | 0.70 | 1.74 | 3.10 | 0.0041 |

**References**

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