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Aberrant reward processing to positive versus negative outcomes across psychotic disorders

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Abstract

Several studies of reward processing in schizophrenia have shown reduced sensitivity to positive, but not negative, outcomes although inconsistencies have been reported. In addition, few studies have investigated whether patients show a relative deficit to social versus nonsocial rewards, whether deficits occur across the spectrum of psychosis, or whether deficits relate to negative symptoms and functioning. This study examined probabilistic implicit learning via two visually distinctive slot machines for social and nonsocial rewards in 101 outpatients with diverse psychotic disorders and 48 community controls. The task consisted of two trial types: positive (optimal to choose a positive vs. neutral machine) and negative (optimal to choose a neutral vs. negative machine), with two reward conditions: social (faces) and nonsocial (money) reward conditions. A significant group X trial type interaction indicated that controls performed better on positive than negative trials, whereas patients showed the opposite pattern of better performance

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CRediT author statement

TPL: conceptualization, formal analysis, visualization, writing -original draft, writing -review and editing, MFG: conceptualization, supervision, resources, writing -review and editing, JL: conceptualization, methodology, data curation, writing -review and editing, PEC: writing -review and editing, AMJ: writing -review and editing, EAR: writing -review and editing, JKW: data curation, visualization, writing -review and editing, WPH: funding acquisition, conceptualization, investigation, project administration, writing -review and editing.

Declaration of competing interest

MFG has been a consultant or speaker for Biogen, Otsuka, Sumitomo Pharma, and Teva. WPH is Vice President of Clinical Science at WCG VeraSci. The rest of the authors report no biomedical financial interests or potential conflicts of interest.

Appendix A. Supplementary data

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on negative than positive trials. In addition, both groups performed better for social than nonsocial stimuli, despite lower overall task performance in patients. Within patients, worse performance on negative trials showed significant, small-to-moderate correlations with motivation and pleasure-related negative symptoms and social functioning. The current findings suggest reward processing disturbances, particularly decreased sensitivity to positive outcomes, extend beyond schizophrenia to a broader spectrum of psychotic disorders and relate to important clinical outcomes.

Keywords

Schizophrenia; Reward learning; Reinforcement learning; Social rewards; Reward sensitivity

1. Introduction

People with schizophrenia engage in motivated behaviors to obtain rewards and pleasurable outcomes less frequently than healthy controls do, even though patients show intact hedonic responses at subjective and physiological levels. Hence, functional deficits are thought to be partially attributable to the difficulty in translating reward information into goal-directed behavior (Strauss et al., 2014). Multiple reward processing abnormalities have been identified in schizophrenia (e.g., deficits in reward anticipation [Smucny et al., 2021] or effort valuation [Gold et al., 2013; Horan et al., 2015]). The focus of the current study was on sensitivity to positive outcomes, which refers to the degree to which an individual detects, pursues, learns from, and derives pleasure from reward-relevant stimuli, and sensitivity to negative outcomes, which refers to the degree to which an individual's behavior is inhibited by punishment-relevant stimuli (Kim et al., 2015). Separate studies have considered whether people with schizophrenia exhibit deficits primarily in processing positive outcomes versus negative outcomes (Fervaha et al., 2013; Gold et al., 2012), but the results have been inconsistent. Few studies have examined the key question of whether patients differ from controls in processing social vs. nonsocial rewards (Hanssen et al., 2020; Lee et al., 2019). Another unresolved issue concerns whether these reward processing disturbances extend to other illnesses along the psychosis-spectrum. It is also not clear whether these reward processing deficits are linked to negative symptoms and functioning. These are important issues to address as available treatments for motivational disturbances and poor functional outcomes in schizophrenia are marginally effective due to suboptimal understanding of underlying mechanisms, such as reward processing impairments. The present study investigated reward processing of positive and negative outcomes via performance on a probabilistic implicit learning task that also contrasted social and nonsocial stimuli in a diverse sample of people with psychotic disorders.

Many studies have examined reward processing of positive and negative outcomes in schizophrenia using various reinforcement or reward learning paradigms (Abohamza et al., 2020). In a series of studies, Gold, Waltz, and colleagues (Gold et al., 2012; Strauss et al., 2011; Waltz et al., 2007) found consistent evidence that motivation impairments in schizophrenia were associated with reduced learning ability to positive outcomes (such as poor performance on a Go-learning task), but intact learning from negative, or loss, outcomes (NoGo--learning). Thus, people with schizophrenia may engage in fewer

motivated behaviors than healthy comparison participants because they are less sensitive or less able to learn how to obtain rewards but successful in knowing how to avoid losses or punishments (Strauss et al., 2014). Some studies have attempted to replicate and extend these findings, but with inconsistent results. For example, recent studies have found (Barch et al., 2017; Pratt et al., 2021) a generalized deficit in sensitivity involving both positive and negative outcomes on *explicit* learning tasks, but relatively intact sensitivity toward both positive and negative outcomes when using *implicit* learning tasks. These conflicting results raise questions about the precise deficits in reward processing in schizophrenia, particularly to sensitivity to positive and negative outcomes with implicit learning tasks.

Few studies have investigated aberrant social reward processing as a possible determinant of pervasive social dysfunction in schizophrenia (Hanssen et al., 2020). Using functional magnetic resonance imaging (fMRI), we (Lee et al., 2019) found reduced activation in areas involved with reward processing and value representation (e.g., ventral striatum, ventromedial prefrontal cortex, and anterior cingulate cortex) to social rewards but not nonsocial rewards in people with schizophrenia relative to controls. Interestingly, despite these neural differences, patients and controls exhibited similar behavioral performance across task conditions and comparable overall task performance. These findings highlight the importance of identifying and understanding distinct aspects of sensitivity to positive vs. negative outcomes, and with social vs. nonsocial rewards.

Little is known about reward processing deficits in other psychotic disorders beyond schizophrenia. People with different forms of psychosis (e.g., schizoaffective disorder, mood disorders with psychotic features) also experience difficulties with motivated behavior and processing reward information (Barch et al., 2017; Whitton et al., 2015). However, it is not clear whether the same pattern of impairments is present across psychotic disorders. Also, it is unclear whether different aspects of reward processing (e.g., sensitivity to negative outcomes, social, and nonsocial rewards) are related to negative symptoms and real-world functioning, although previous studies have considered correlations with negative symptoms (Gold et al., 2012; Strauss et al., 2011) and found that reduced sensitivity to positive outcomes was more pronounced in patients with greater motivation and pleasures negative symptoms. Such an approach is consistent with the NIMH's Research Domain Criteria (RDoC) program that emphasizes dimensional relationships between core behavioral dimensions and clinical symptoms and functioning across traditional diagnostic boundaries (Kozak and Cuthbert, 2016).

In this study, we examined reward processing via performance on a probabilistic implicit learning task, the One-Armed Bandit Task, in a diverse sample of people with psychotic disorders. The task consisted of two trial types: positive (optimal to choose a positive vs. neutral machine) and negative (optimal to choose a neutral vs. negative machine), with two reward conditions with an equal number of blocks: social (faces) and nonsocial (money) reward conditions. We expected that the people with psychotic disorders would show aberrant reward processing with reduced sensitivity to positive outcomes, and reduced sensitivity during social conditions, compared with controls. We also conducted exploratory comparisons between affective and nonaffective psychoses. Lastly, we examined the associations between performance metrics and negative symptoms and functioning.

2. Methods

2.1. Participants

The study sample included 101 clinically stable outpatients with psychosis and 48 healthy community controls. A broad recruitment strategy was used to enroll patients with any history of clinically significant primary psychotic symptoms (i.e., psychotic symptoms not secondary to illicit substance use or medical illness). Patients between 18 and 65 years old were recruited from outpatient clinics at the University of California Los Angeles (UCLA) and the Veterans Affairs Greater Los Angeles Healthcare System (VAGLA) and outpatient board and care facilities in the greater Los Angeles area. Psychiatric diagnosis was assessed with the Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (SCID-I/P; First et al., 1996) by interviewers trained according to established procedures (Ventura et al., 1998). The patient group consisted of those who met the criteria for schizophrenia ($n = 46$), an unspecified psychotic disorder ($n = 22$), bipolar I disorder with psychotic features ($n = 21$), schizoaffective disorder ($n = 8$), major depressive disorder with psychotic features ($n = 2$), schizophreniform disorder ($n = 1$), or brief psychotic disorder ($n = 1$). The patient group was clinically stable, with no medication changes in the past month and no psychiatric hospitalization in the past three months.

Healthy comparison subjects between the ages of 18–65 were recruited through website advertisements and interviewed with the SCID-I and SCID-II for Personality Disorders (First et al., 1996). Inclusion criteria for healthy controls required no psychiatric history involving schizophrenia spectrum disorder, personality disorder (including avoidant, paranoid, schizotypal, schizoid, or borderline), or recurrent mood disorder, and no family history of a psychotic or bipolar disorder among first-degree relatives per self-report.

Additional exclusion criteria for all participants included: substance or alcohol dependence in the past month, estimated premorbid intelligence below 70 on the WRAT-4 (Wilkinson and Robertson, 2006), a current mood episode, clinically significant neurological diseases, or loss of consciousness due to head injury for more than 1 h. All participants had normal or corrected visual acuity and the ability to understand English. The research was approved by the institutional review boards at the VAGLA and UCLA, and all participants were evaluated for the capacity to give informed consent and provided written informed consent.

2.2. Clinical symptoms and functioning

Clinical characteristics of patients were assessed with the Brief Psychiatric Rating Scale, Expanded 24-item version (BPRS; Kopelowicz et al., 2008; Ventura et al., 1993) and Clinical Assessment Interview for Negative Symptoms (CAINS; Horan et al., 2011). The CAINS consists of 2 subscales: Motivation and Pleasure (MAP), reflecting diminished motivation and pleasure associated with negative symptoms (e.g., anhedonia, avolition, asociality), and Expression (EXP), reflecting diminished expressivity (e.g., blunted affect, alogia). The Role Functioning Scale (RFS; Goodman et al., 1993) assessed functional status for Work/School, Independent Living, Family, and Social Relations. All clinical interviewers were trained to a minimum intraclass correlation coefficient of 0.80.

2.3. Task

Participants completed a probabilistic implicit learning task, the One-Armed Bandit Task (Lee et al., 2019; Lin et al., 2012), to assess reward processing of positive and negative outcomes in contrasting social (faces) and nonsocial (monetary) feedback conditions.

Each trial began with the display of two visually distinctive slot machines: (1) a “good” slot machine paired with a “neutral” slot machine (i.e., high-payout trials related to positive outcomes) or (2) a “bad” slot machine paired with a “neutral” slot machine (i.e., low-payout trials related to negative outcomes; see Fig. 1a). A “good” slot machine had an 80% probability of a positive outcome and a 20% probability of a neutral outcome; a “bad” slot machine had an 80% probability of a negative outcome and a 20% probability of a neutral outcome; and a “neutral” slot machine had one-third probability of each positive, neutral, and negative outcomes. Participants had up to 2.5 s to select the slot machine that would give them the outcome they preferred by pressing a left or right button. Then, the reward outcome was presented for 1.5 s, followed by an inter-trial interval of a uniformly blank screen displayed for 1–5s (flat distribution). There were 100 trials: 50 high-payout trials and 50 low-payout trials for each of the social and nonsocial conditions. Thus, thus there were 200 trials overall for the task. Notably, participants were not told of the reward probabilities associated with each slot machine and had to learn them over the course of the task. Participants were not told that one machine was better than another and they were instructed to select the slot machine that they preferred.”

The One-Armed Bandit Task also contrasted social and nonsocial conditions (see Fig. 1b). The two condition types had identical trial structures of low-payout vs. high-payout with an equal number of social and non-social trials. The condition types were blocked and counterbalanced across participants. For the social condition, color photographs of six unfamiliar male faces from the NimStim collection (Tottenham et al., 2009) were used showing happy (positive outcome), angry (negative outcome), or neutral (neutral outcome) expressions. For the nonsocial condition, the stimuli included an image of a dollar bill (positive outcome), an image of a dollar bill crossed out (negative outcome), or an image of an empty black rectangle (neutral outcome). Participants did not receive actual monetary rewards after the task. The One-Armed Bandit Task was presented using E-Prime software 2.0 (Psychology Software Tools, Inc.).

The primary dependent variable for behavioral performance in each condition was the proportion of trials in which the participant chose the optimal outcome (i.e., choosing a good machine over a neutral machine during the high-payout trials or choosing a neutral machine over a bad machine [i.e., avoiding loss] during the low-payout trials). For correlational analyses, we used scores within each cell of the 2-Trial Type x 2-Condition Type: (1) negative outcomes/nonsocial, (2) positive outcome/nonsocial, (3) negative outcome/social, and (4) positive outcome/social.

2.4. Statistical analyses

The analyses were conducted in four steps. First, we examined potential demographic differences between the psychosis and control groups. Second, we conducted a 2-Group

(between-subject: patient, control) x 2-Trial Type (within-subject: positive outcomes, negative outcomes) x 2-Condition Type (within-subject: social, nonsocial) repeated-measures analysis of variance (ANOVA). Partial-eta^2 (η_p^2) is reported as a measure of effect size. Significant effects were followed up with contrasts of marginal means. Third, an exploratory subgroup analysis was conducted to examine possible task performance differences between non-affective psychosis and affective psychosis (e.g., mood disorders with psychotic features). That analysis employed a 2-Patient Group (between-subject: non-affective psychosis, affective psychosis) x 2-Trial Type x 2-Condition Type repeated-measures ANOVA. Fourth, we sought to determine the degree to which individual differences in negative symptoms and functioning were associated with behavioral performance using Pearson's correlations within the psychosis patient group. Statistical significance for these correlations was adjusted for multiple testing using the Benjamini-Hochberg procedure (Benjamini and Hochberg, 1995). All analyses were two-tailed, and all variables were normally distributed (skew <1.5; kurtosis <2.0).

3. Results

Table 1 shows the demographic and clinical characteristics of the participants. Patients and controls were similar in age, ethnicity, race, and gender. Patients had lower levels of education than controls as expected but did not differ in parental education. Patients had higher BPRS-rated positive symptoms, depression/anxiety, and agitation/mania symptoms, and endorsed higher CAINS-rated negative symptoms, than controls.

3.1. Task data

Table 2 presents mean task performance (optimal choice proportion) for each Trial Type, Condition Type, and Group. The ANOVA (Table 3) yielded a significant main effect for Group such that controls performed better overall than patients ($\eta_p^2 = 0.7$). There was a significant main effect for Condition ($\eta_p^2 = 0.03$) such that both groups had greater optimal choice proportion in the social condition than in the nonsocial condition. The main effect for Trial Type (i.e., negative outcomes vs. positive outcomes) was not significant ($\eta_p^2 < 0.01$).

Regarding interactions, the Group x Trial Type interaction was significant ($\eta_p^2 = 0.03$; see Fig. 2). Controls performed numerically better (i. e., higher optimal choice proportion) in positive outcomes (i.e., high-payout) trials than in negative outcomes (i.e., low-payout) trials, but this comparison was not significant, $t(147)$ 1.14, $p = .26$. Patients exhibited the *opposite* pattern as patients performed better in the negative outcome trials compared to the positive outcome trials, $t(147) = -2.10$, $p < .05$. Regarding between-group effects, patients and controls did not show a significant difference in negative trials, $t(147) = -1.55$, $p = .12$, but showed a significant difference on task performance in positive trials, $t(147) = -3.50$, $p < .001$. See supplementary materials for a plot of the task data across trials to see the differences in implicit learning among patients with psychotic disorders and controls on negative outcomes and positive outcomes. The Group × Condition interaction was not significant ($\eta_p^2 = 0.2$).

The Condition x Trial Type interaction was also significant, $\eta_p^2 = 0.07$. Participants were performed better on negative outcome trials compared to positive outcome trials in the nonsocial condition ($t(147) = 2.36$, $p < .05$), but were better during positive trials relative to negative trials in the social condition, $t(147) = -2.21$, $p < .05$. Finally, the 3-way interaction involving Group x Condition x Trial was not significant, $\eta_p^2 = 0.001$.

Patients with non-affective psychosis ($n = 70$) were compared to patients with affective psychosis ($n = 23$), which included patients with bipolar I disorder and major depressive disorder (see Footnote1). The ANOVA yielded a main effect of Condition Type (i.e., better performance for social vs. nonsocial) with a pattern consistent with the above analysis, $F(1, 91) = 14.09$, $p < .001$, $\eta_p^2 < 0.13$. The main effect for Trial Type was significant ($F(1, 91) = 4.99$, $p < .05$, $\eta_p^2 = 0.05$) as both patient groups performed better in the negative outcome trials than in the positive outcome trials. Of note, the main effect of the patient groups (nonaffective vs. affective psychosis) and *all* interactions involving the patient groups were not significant, Fs < 3.16, ps > .08, $\eta_p^2 < 0.035$. See supplementary materials for a table that summarizes the results of the statistical analysis for affective vs. nonaffective psychosis.

3.2. Correlations between task performance and negative symptoms and functioning

Table 4 presents correlations among negative symptoms and functioning with the scores within each cell of the 2-Trial Type x 2-Condition Type. CAINS MAP scores were significantly associated with poorer performance across the negative outcome Trial Types. RFS Family and RFS Social Relations were associated with poorer performance across the negative outcome Trial Types and social reward conditions. RFS Work/School was linked with performance on the negative Trial Type specifically in the nonsocial Condition Type. CAINS EXP and RFS Independent Living were not significantly associated with task performance metrics. All statistically significant correlations survived the Benjamini & Hochberg procedure. See supplementary materials for correlations of task performance with CAINS MAP scores by patient group.

4. Discussion

In this study, we examined several distinct aspects of reward processing in a diverse sample of people with psychotic disorders. There were three major findings. First, consistent with our expectations, people with psychotic disorders performed better on negative outcome trials (i.e., avoiding loss) than on positive outcome trials (i.e., obtaining rewards). Second, patients and controls showed a similar tendency to select better outcomes for social stimuli than for monetary stimuli, despite lower overall task performance in patients. Third, within the psychosis group, worse performance on negative trials showed significant, small-to-moderate correlations with motivation and pleasure-related negative symptoms and social functioning. These findings suggest reward processing disturbances, particularly decreased sensitivity to positive outcomes, extend beyond schizophrenia to a broader spectrum of psychotic disorders and relate to important clinical outcomes.

[1]It is unclear whether schizoaffective disorder belongs to the affective psychosis group or the non-affective psychosis group. Therefore, patients with schizoaffective disorder were not included in this specific analysis.

Our results are consistent with previous reports (Strauss et al., 2011; Waltz et al., 2007) that found reduced sensitivity to positive outcomes on reinforcement learning paradigms and neurophysiological indicators of diminished approach motivation (Horan et al., 2014) in schizophrenia. Further, consistent with findings from Barch et al. (2017), no statistically significant differences in task performance were observed among the psychotic disorder subgroups (i.e., affective vs nonaffective psychosis), indicating that reward processing abnormalities extend beyond schizophrenia to other schizophrenia spectrum and affective psychotic disorders. However, this finding should be interpreted with some caution given the small sample size of the affective psychosis group and the relatively high percentage of unspecified psychosis in the nonaffective psychosis group in the current study. These patterns of results suggest that diminished desire for, pursuit of, and persistence in goal-directed activities that could lead to potentially beneficial or successful outcomes may stem in part from a reduced sensitivity or potential ability to learn from prior positive outcomes.

A modest effect size ($\eta_p^2 = .07$) was observed for the Group x Trial Type (i.e., positive vs. negative trials) interaction in the current study. Thus, the current findings suggest that it is important to consider multiple reward processes beyond impaired sensitivity to positive outcomes to fully understand motivational factors that hold people with schizophrenia back from pursuing personally meaningful, goal-directed behaviors. Future studies can also evaluate potential mechanisms underlying impaired sensitivity to positive outcomes in psychotic disorders, for example, by investigating whether these impairments stem from positive prediction errors or failures to precisely represent the value of the alternative responses during decision making (Gold et al., 2012), or how deficits in positive outcome sensitivity may relate to anticipated motivation and pleasure in daily activities (Moran et al., 2019).

Similar to our previous findings (Lee et al., 2019), we did not find that patients had a unique behavioral impairment in processing social rewards relative to controls, suggesting that any reduced sensitivity to social rewards may be subtle and better detected with neurophysiological methods. Contrary to expectations, our results suggest that both patients and controls had enhanced performance for social than nonsocial stimuli. The current findings are consistent with those from Catalano et al. (2021) using a neurophysiological measure (event-related potentials) who observed that patients with schizophrenia oriented their attention equally to social and nonsocial stimuli (N1pc) and showed greater sustained attention to social than nonsocial stimuli (i.e., larger contingent negative variation) and others (Horan et al., 2012; Jang et al., 2016) that found patients with schizophrenia showed a reflexive orientation toward emotional stimuli (i.e., emotional faces) compared to neutral stimuli. Thus, additional research is needed to understand the precise deficits in social reward processing in patients with psychotic disorders. Alternative recent approaches to investigate aberrant social reward processing have included examining subjective valuation or preference of social reward (see Catalano et al., 2018) and effort exertion in the context of live social encouragement (see Fulford et al., 2018).

We found that higher motivation and pleasure negative symptoms (i.e., experiential negative symptoms) were associated with worse performance on negative trials. We also observed that social functioning deficits were associated with reduced sensitivity to negative outcomes

and social rewards. While some studies have found reduced sensitivity to positive outcomes among people with schizophrenia with greater motivational negative symptoms (Gold et al., 2012; Moran et al., 2019), others (Barch et al., 2017) found more generalized associations between negative symptoms and abnormalities in sensitivity to both positive and negative outcomes. There are several possible explanations for the lack of association between positive outcomes and motivation and pleasure deficits. The paradigm used in the current study captures implicit learning that is stimulus-driven, whereas negative symptoms reflect more goal-driven or deliberate efforts toward rewarding stimuli. Alternatively, negative symptoms were assessed using a clinician-rated interview, which provides a cross-sectional snapshot of motivation and pleasure symptoms based on retrospective self-report, thus limiting its ecological validity. Digital phenotyping of negative symptoms via smartphones (Cohen et al., 2021; Raugh et al., 2021) that collects data of real-world behaviors and experiences that may be more related to performance metrics from a laboratory-based implicit reward learning task. Adding to the sparse literature on reward processing in psychotic disorders, we found that individual differences in performance across negative trials and social reward conditions were largely associated with specific functional deficits in the social domain but not with independent living or vocational domains.

Regarding treatment implications, psychosocial interventions can specifically target reward processing impairments for people with psychotic disorders. For example, it may be necessary to incorporate cues and provide frequent, repeated positive reinforcers (e.g., verbal praise, credit list, stickers, tokens) to facilitate goal-directed behaviors (Gholipour et al., 2012; Grant et al., 2012). It may also be useful to take advantage of recent advancements in mobile health (mHealth) technology for psychosocial treatment to present frequent, selective cues. Mobile apps may be well-suited for delivering cues, reinforcers, and reminders designed to promote behavioral activation and savoring techniques (Arevian et al., 2020; Depp et al., 2019). Specifically, clinicians could use mHealth apps to send reminders for patients to engage in specific activities and have apps deliver customized positive or negative feedback concerning patient responses.

Several limitations are worth mentioning. First, this cross-sectional study was mostly composed of chronically ill patients and whose average ages were in the late forties. Thus, this study cannot determine whether these patterns of reward processing deficits precede the onset of psychosis or are the sequela of living with a severe mental illness. While few studies have demonstrated various reward processing deficits, such as explicit reward processing of positive outcomes (Cheng et al., 2022) and cognitive effort decision-making abnormalities (Chang et al., 2020), in first-episode psychosis, little is known about different aspects of reward processing in adolescents or young adults with early psychosis or at clinical high-risk for psychosis. Second, this study used emotional faces as rewarding stimuli in the social condition. It may be that emotional faces have greater intrinsic reward value to the participants than pictures of money, which may hold little intrinsic reward value. It is unclear whether similar effects would be observed for other forms of social rewards (e.g., dynamic social video stimuli, social affiliative contact). Third, the patients were receiving antipsychotic medications at clinically determined dosages, which could have impacted performance on the probabilistic implicit learning task. However, none of the correlations between antipsychotic dose (i.e., chlorpromazine-equivalent) and task performance metrics

were significant. Fourth, neurocognitive ability, which was not assessed in the current study, and positive symptoms may have also impacted performance on the probabilistic implicit learning task.

Overall, the current findings provide further evidence of the specificity of reward processing deficits, particularly sensitivity to positive outcomes, in illnesses on the psychosis spectrum. Further, these findings provide evidence for a relationship between the severity of motivation and pleasure negative symptoms, social functioning deficits, and impaired processing of negative outcomes and social rewards, which is consistent with the social isolation and community disengagement is seen across psychotic disorders (Green et al., 2018; Le et al., 2018).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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A.

		Positive	Neutral	Negative
Good		80%	20%	0%
Bad		0%	20%	80%
Neutral		33%	33%	33%

B.

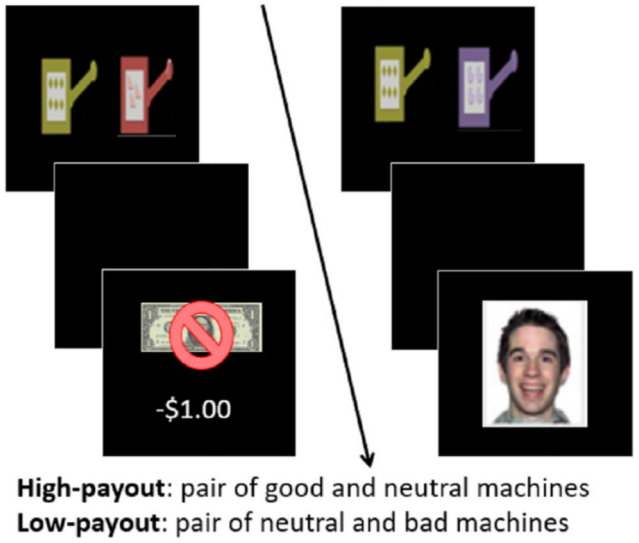

Fig. 1.

A schematic diagram of the One-Armed Bandit Task. (A) There are 3 types of slot machines. A “good” slot machine had an 80% probability of a positive outcome and a 20% probability of a neutral outcome; a “bad” slot machine had an 80% probability of a negative outcome and a 20% probability of a neutral outcome; and a “neutral” slot machine had a one-third probability of each positive, neutral, and negative outcomes. (B) Each reward condition (nonsocial vs. social) with an identical trial structure consisted of the 2 trial types: a high-payout trial and a low-payout trial. For the high-payout trial, a good slot machine was paired with a neutral slot machine. For the low-payout trial, a bad slot machine was paired with a neutral slot machine.

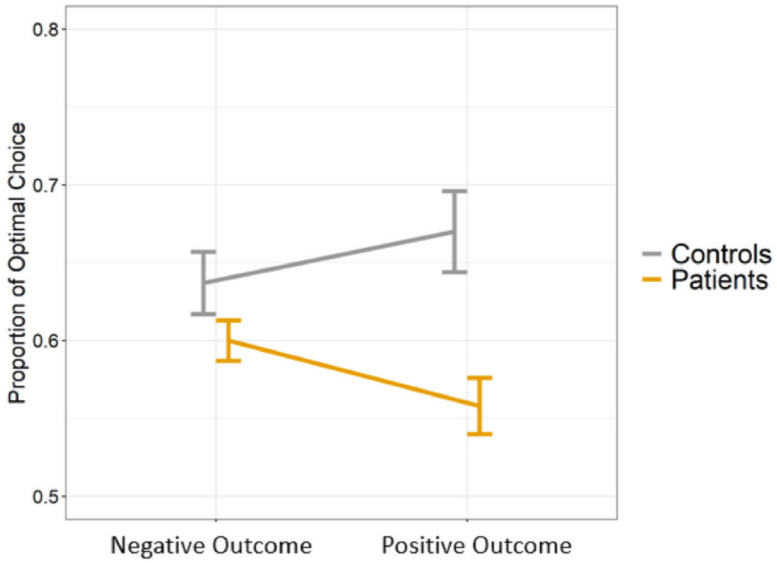

Fig. 2.

Reward processing of positive and negative outcomes in patients with psychotic disorders and controls on the One-Armed Bandit Task, collapsing across condition types (i.e., social vs nonsocial stimuli). The y-axis represents the proportion of trials with the optimal outcome (i.e., choosing a neutral machine over a bad machine during the low-payout trials or choosing a good machine over a neural machine during the high payout trials). Error bars ± 1 SE.

Table 1

Summary of demographic information and clinical data (N = 149).

Variable	Controls (n = 48)	Psychosis Patients (n = 101)	Statistic
	M (SD) or %	*M (SD) or %*	
Demographics			
Gender (% identified male)	69%	71%	χ^2=.02
Race			χ^2=.02
American Indian/Alaskan	–	.9%	
African American/Black	25.0%	34.3%	
Asian	10.4%	6.5%	
Caucasian	56.3%	48.1%	
Hawaiian/Pacific Islander	2.1%	1.9%	
More than one race	4.2%	8.3%	
Ethnicity			χ^2=3.29
Hispanic	15%	16%	
Age	47.9 (9.5)	48.1 (11.8)	t = .10
Education (years)	14.9 (1.9)	13.6 (2.0)	t = − 3.67 *
Parental Education (years)	14.8 (3.1)	14.2 (3.4)	t = −.87
BPRS symptoms			
Positive Symptoms	1.14 (.21)	1.86 (.79)	t = 8.59 *
Depression/Anxiety	1.20 (.25)	2.06 (.94)	t = 6.62 *
Agitation/Mania	1.06 (.10)	1.24 (.45)	t = 3.77 *
CAINS negative symptoms			
Motivation and Pleasure	.81 (.76)	1.44 (.81)	t = 4.53 *
Expressivity	.18 (.29)	.79 (.82)	t = 6.76 *

Note.

* p < .001; BPRS = Brief Psychiatric Rating Scale, CAINS = Clinical Assessment Interview for Negative Symptoms.

Table 2

Summary of One-Armed Bandit Task performance across trial type and condition by group.

	Controls (n = 48)		Patients (n = 101)	
	Mean	*SD*	*Mean*	*SD*
Trial Type				
Negative Outcome	.64	.13	.60	.14
Positive Outcome	.67	.20	.56	.17
Condition Type				
Nonsocial	.65	.17	.56	.12
Social	.66	.17	.60	.14

Note. Numbers indicate the proportion of optimal responses.

Table 3

Repeated measures analysis of variance for One-Armed Bandit Task performance.

	***F* value**	***df***	***p* value**	η_p^2
Group	11.42	1, 147	<.001	.07
Condition Type	3.91	1, 147	.04	.03
Trial Type	.65	1, 147	.80	<.01
Group x Condition Type	2.52	1, 147	.12	.02
Group x Trial Type	4.53	1, 147	.04	.03
Condition Type x Trial Type	11.48	1, 147	<.001	.07
Group x Condition Type x Trial Type	.22	1, 147	.64	.001

Note. Condition Type = Nonsocial vs. Social, Trial Type = Negative Outcome vs. Positive Outcome.

Table 4

Correlations of study variables in the psychosis patient group (n = 101).

	Negative Outcome/Nonsocial	Positive Outcome/Nonsocial	Negative Outcome/Social	Positive Outcome/Social
CAINS MAP	−.20*	.03	−.25*	−.08
CAINS EXP	−.16	.10	−.02	−.10
RFS Work/School	.27**	−.09	.01	.15
RFS Independent Living	.08	−.02	−.10	.19
RFS Family	.32**	.12	.23*	.21*
RFS Social Relations	.30**	.02	.32**	.21*

* $p < .05$

** $p < .01$; all statistically significant correlations remained significant after Benjamini & Hochberg procedure.

Note. CAINS = Clinical Assessment Interview for Negative Symptoms (lower scores on CAINS reflect less severe negative symptoms), RFS = Role Functioning Scale (higher scores on RFS reflect better functioning).