ARCHIVAL REPORT

Decision-Making Impairments in the Context of Intact Reward Sensitivity in Schizophrenia

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Background: Deficits in motivated behavior and decision-making figure prominently in the behavioral syndrome that characterizes schizophrenia and are difficult both to treat and to understand. One explanation for these deficits is that schizophrenia decreases sensitivity to rewards in the environment. An alternate explanation is that sensitivity to rewards is intact but that poor integration of affective with cognitive information impairs the ability to use this information to guide behavior.

Methods: We tested reward sensitivity with a modified version of an existing signal detection task with asymmetric reinforcement and decision-making with a probabilistic decision-making task in 40 participants with schizophrenia and 26 healthy participants.

Results: Results showed normal sensitivity to reward in participants with schizophrenia but differences in choice patterns on the decision-making task. A logistic regression model of the decision-making data showed that participants with schizophrenia differed from healthy participants in the ability to weigh potential outcomes, specifically potential losses, when choosing between competing response options. Deficits in working memory ability accounted for group differences in ability to use potential outcomes during decision-making.

Conclusions: These results suggest that the implicit mechanisms that drive reward-based learning are surprisingly intact in schizophrenia but that poor ability to integrate cognitive and affective information when calculating the value of possible choices might hamper the ability to use such information during explicit decision-making.

Key Words: Decision-making, learning, reward sensitivity, schizophrenia

Many patients with schizophrenia (SC) demonstrate significant functional disability with prominent impairments in motivation and the ability to pursue long-term goals (1–6). In seeking to understand the origins of this disability, impairments in reward-processing and decision-making are logical candidate processes. For example, if SC muted the experience of rewards resulting from goal attainment, the failure to initiate and sustain goal-directed behavior would be understandable. Similarly, adaptive behavior deficits could be a consequence of deficient ability to learn from rewards (and/or punishments). The same sort of inertia and behavioral limitations could result from decision-making abnormalities. If patients have difficulty weighing the risks and benefits associated with different choices, impairments in adaptive behavior would inevitably result.

A review of the literature suggests that such simple formulations are probably inadequate. In the area of reward, there is replicated evidence that patients have surprisingly normative experiences of emotionally evocative stimuli (7–13) and that they successfully use rewards to guide learning in procedural learning tasks (14–17), although contrary findings exist (18,19). Despite evidence for spared reward-learning, patients show dramatic impairments in the ability to use feedback to guide behavior on tasks including the Wisconsin Card Sorting Test (20–23). Thus, it seems that the illness compromises some but not all aspects of reward processing.

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Received September 7, 2007; revised February 17, 2008; accepted February 22, 2008.

The literature on decision-making in SC is similarly complex. Although several reports show that patients make relatively normal choices (24–26), research often shows that they make "impulsive" decisions (27–30) and are more myopic with respect to future outcomes than healthy participants (31). These findings suggest that poor decision-making in SC likely occurs in the context of spared implicit reinforcement learning.

The explanation for this discrepancy might lie along the intersection of affect and cognition. Both the ability to adapt to rapid trial-to-trial alterations in reward contingencies and the ability to maintain the longer-term average reward value of a choice are critical to decision-making (16). In SC, it might be the case that cognitive impairments (e.g., working memory deficits) reduce the ability to use immediate reinforcements to shift behavior from trial-to-trial (32), despite adequate ability to acquire a stable response pattern based on a longer-term reinforcement history (16). This incongruity might manifest itself in poor performance early in a task, with later performance approximating normal levels (14,16). Cognitive/affective integration deficits might also explain low coherence between affective experience and motivated behavior when rewards must be maintained in working memory (13) and would predict difficulty in making decisions on the basis of subjective values of possible outcomes.

The subjective value of an outcome is important when choosing among competing response options (33–35). For example, it is likely that people choose options with higher subjective value, determined by a combination of the magnitude and valence (gain or loss) of an outcome, its likelihood of occurrence, and some affective preference weighting (36,37). Consistent with this idea many studies document, the involvement of reward circuitry in decision-making (38,39), especially when participants choose among uncertain or temporally distant outcomes (40–42).These studies suggest that prefrontal systems carrying both cognitive and reward information (dorsolateral prefrontal cortex and orbitofrontal cortex, respectively) are required to optimize task performance (43,44). In SC, poor integration of affective with cognitive information (45) might impair

0006-3223/08/$34.00
doi:10.1016/j.biopsych.2008.02.015

the ability to assign preference values to competing actions, particularly when actions are not immediately associated with reinforcement.

In this article, we propose that decision-making difficulties in SC relate to the ability to assign subjective value to potential outcomes and not to general reward sensitivity deficits. We therefore predict that patients with SC will show normal responses to experienced rewards but worse ability to assign subjective value to response options, thereby affecting explicit decision-making.

We measured reward sensitivity with a signal detection task with asymmetric reinforcement. In signal detection tasks, participants report which of two stimuli was present on each trial by making one of two responses (46). By rewarding one stimulus more frequently than the other, it is possible to induce a response bias such that on trials where participants are uncertain about which stimulus they saw they tend to respond as though the more frequently rewarded stimulus was present (47). Pizzagalli *et al.* (48) used this paradigm to demonstrate that depressed individuals show reduced reward sensitivity compared with non-depressed individuals. Specifically, they found that non-depressed participants developed biased responding toward the frequently rewarded stimulus but depressed participants did not (48). If patients have intact reward sensitivity, they should develop a similar response bias as comparison participants.

A probabilistic decision-making task assessed how the value of a gamble related to participants' willingness to choose it (49). On each trial, participants chose one of two gambles that differed in reward magnitude, outcome (potential loss or no loss possible), and probability of winning. To understand how participants determined the subjective value of an outcome, we estimated the degree to which potential gains, losses, and uncertainty about outcomes contributed to decision-making.

Methods and Materials

Participants

Participants included 40 clinically stable outpatients with chronic SC and 26 healthy comparison participants (HC), matched on age and paternal education. Patient diagnoses were confirmed with the Structured Clinical Interview for DSM-IV (SCID) (50). All patients received antipsychotic medications, and none had had prescription changes during the month before participation. Patients were capable of providing informed consent, as documented by a set of standard probes. Symptom assessments included the Brief Psychiatric Rating Scale (BPRS) (51) and Scale for the Assessment of Negative Symptoms (SANS) (52). Comparison participants were free of psychiatric diagnoses, as indicated by the SCID, received no psychiatric medications, and had no family history of psychosis (see Table 1 for sample characteristics). Participants were free of substance abuse/dependence, except nicotine, for at least 6 months. After a complete description of study procedures, participants gave written informed consent. The University of Maryland's institutional review board approved the study.

Procedures

Reward Sensitivity Task. We used a line discrimination task, closely modeled after that reported in Pizzagalli *et al.* (48). At the start of each trial, participants viewed a fixation cross for 500 ms. A cartoon face with no mouth then appeared (Figure 1). After 500 ms, either a short (22 mm) or a long mouth (24 mm) appeared on the face and remained for 100 ms. The face, without the mouth, remained on the screen until participants responded. On feedback trials, participants saw feedback for 1750 ms. On trials without feedback, the screen was blank for 1750 ms before the start of the next trial. Participants responded with a left or right button press on a game-controller to indicate which mouth they had seen.

Table 1. Sample Characteristics and Neuropsychological Performance

	Healthy Participants (n = 26)	Participants with Schizophrenia (n = 40)	*p*
Age	48.26 (9.93)	45.8 (10.21)	.40
Age at Illness Onset	—	22.75 (7.26)	—
Participant Education	14.26 (1.97)	12.25 (1.96)	< .001
Paternal Education	12.64 (4.38)	12.47 (4.34)	.90
Gender (M:F)[a]	18:8	31:9	.45
Race[a]			.67
African American	9	11	
Caucasian	17	27	
Other	0	2	
Antipsychotic Medication			
Atypical	—	29	—
Typical	—	6	—
Typical + Atypical	—	5	—
Clinical Ratings			
BPRS	—	36.83 (8.46)	—
SANS	—	25.94 (14.11)	—
Neurocognitive Test Results			
Spatial Span	10.81 (3.06)	7.95 (3.23)	.001
Letter-Number Sequencing	16.22 (3.83)	11.70 (3.22)	< .001
Hopkins Verbal Learning Test	28.36 (4.08)	20.84 (5.19)	< .001
Wechsler Test of Adult Reading	106.78 (15.52)	95.27 (16.35)	.005

Table includes means and SDs. Except where noted, group differences tested with *t* tests. BPRS, Brief Psychiatric Rating Scale; SANS, Scales for the Assessment of Negative Symptoms.

[a]Comparison tested with χ^2.

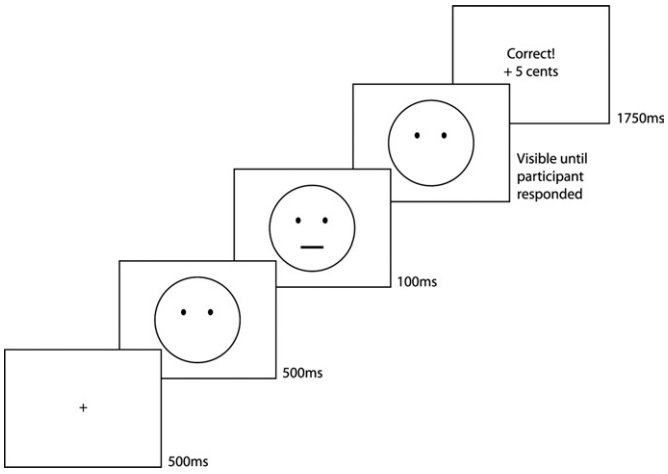

Figure 1. Trial timeline for a feedback trial on the reward sensitivity task.

Participants completed a practice block of 20 trials (10 short-mouth, in random order) to ensure that they understood task instructions. In the practice, participants saw the words "correct" or "incorrect" after each trial but received no bonus money. Neither group showed a preference for any stimulus after practice (all p values $>$ .43). During the task, participants completed three blocks of 100 trials. Each mouth was presented 50 times/block in pseudorandom order such that there were no more than four consecutive trials of the same mouth. Feedback ("Correct, +5 cents") appeared on 40 correct responses/block. Of the 40 rewards, 30 were provided to one of the mouths and 10 to the other. The more frequently rewarded mouth (short or long) and the response mappings (left and right buttons) were randomly determined for each participant before the task and remained consistent across all blocks. Reinforcements were pseudo-randomly scheduled such that no more than three trials in a row were reinforced. If participants responded incorrectly on a trial with scheduled reinforcement, the reinforcer was dispensed on the next correct identification of the same stimulus (48). The maximum bonus was $6.

Trials in which participants' reaction times were shorter than 300 ms and longer than 3000 ms were excluded from analyses. One HC participant was excluded for treating the task as a reaction-time task (>25% of trials faster than 300 ms). Across the task, we excluded .58% (SD = 1.14) of trials/HC participant and 4.10% (SD = 5.24) of trials/SC participant. We also excluded one SC participant who confused the response buttons. Debriefing confirmed that no SC participants and two HC participants were aware of the reinforcement asymmetry.

Probabilistic Decision-Making Task. We based our probabilistic choice task on one developed by Rogers *et al.* (49). In the task, participants chose between two simultaneously presented gambles involving hypothetical monetary rewards/penalties (for a comparison of actual and hypothetical rewards; see 53). Each gamble showed the possible reward, possible loss, and likelihood of winning the gamble (Figure 2). The two gambles varied in magnitude ($gamble_1$ randomly varied between $3 and $7; $gamble_2$ between $13 and $17). There were two outcome conditions. In the no-loss condition, losing the chosen gamble was worth $0. In the loss-possible condition, losing a gamble incurred a variable penalty of the same magnitude as the win ($gamble_1$: $3 to $7; $gamble_2$: $13 to $17). A second condition allowed us to determine how uncertainty about an outcome's likelihood affected behavior (54). In this condition, a mask over $gamble_2$ concealed the probability of winning. Participants completed 12 of each trial type, in random order.

At the start of the task, $gamble_1$ had high probabilities and $gamble_2$ had low probabilities of winning. To induce participants to choose the riskier $gamble_2$, we altered the probabilities of winning the gambles after each choice with an adaptive procedure. This was implemented such that if a participant chose $gamble_1$, the probability of winning $gamble_1$ on the next trial decreased by 10% and the probability of winning $gamble_2$ increased by 10%. With each choice reversal (e.g., the participant chose $gamble_1$ on $trial_{n-1}$ and $gamble_2$ on $trial_n$), the magnitude of the change in probability reduced by 20% and the direction of the change reversed (e.g., if the probability of winning $gamble_2$ had been increasing by 10%, it now decreased by 8%). Each trial type adapted independently. We chose an adaptive procedure, because these generate reliable estimates of performance in fewer trials than fixed stimulus sets (55). Groups did not differ in the number of reversals/condition [$Mean_{HC}$ = 4.68 (SD = .74), $Mean_{SC}$ = 4.78 (SD = 1.26); $F(1,62) = .43$, $p = .88$], the mean expected value difference required for a shift from $gamble_1$ to $gamble_2$ [$Mean_{HC}$ = 6.65 (SD = .51), $Mean_{SC}$ = 6.68 (SD = .63); $F(1,61) = .01$, $p = .94$], or the overall proportion of choices to $gamble_2$ [$Mean_{HC}$ = .40 (SD = .08), $Mean_{SC}$ = .42 (SD = .10); $F(1,62) = 1.13$, $p = .29$], suggesting that they treated the task similarly.

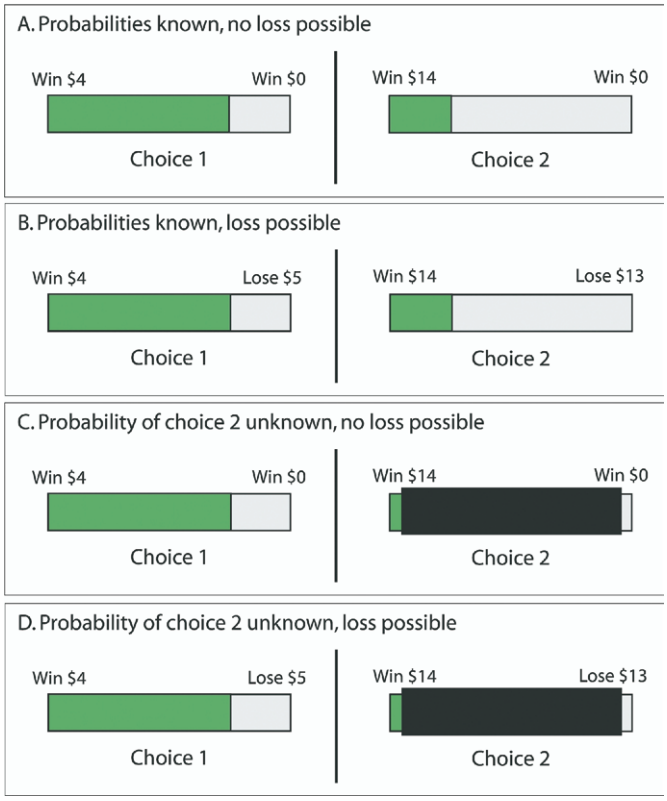

Figure 2. Example of each type of trial on the probabilistic choice task. Gamble 1 in each example depicts an 80% chance of winning $4 and a 20% chance of losing either $0 or $5. In one-half of the trials, the odds of winning gamble 2 were visible. The examples show a 30% chance of winning $14, versus a 70% chance of losing either $0 **(A)** or $16 **(B)**. In the remaining trials, the odds of winning gamble 2 were hidden from participants with a mask **(C and D)**. Participants chose gamble 1 with the left button of a game controller and gamble 2 with the right.

Additional Measures. Participants additionally completed working memory measures (spatial span and letter-number sequencing) (56), the Hopkins Verbal Learning Test (HVLT) (57), and the Wechsler Test of Adult Reading (WTAR) (58). Table 1 displays these scores. Because the working memory measures were highly correlated ($r = .53$, $p < .001$), we made a working memory composite score, by normalizing and averaging participants' scores.

Statistical Analysis

To assess task performance and reward sensitivity in the reward sensitivity task, we used a signal-detection theory approach. We indexed performance according to participants' ability to discriminate between the long and short mouths by calculating discrimination accuracy (d'[1]) (46). Participants' tendency to over-report seeing the frequently rewarded stimulus (bias[2]) served to measure reward sensitivity (47).

In the probabilistic decision-making task, we examined behavior in terms of both objective performance and subjective value. In objective terms, optimal decision-making involves choosing the gamble with the highest expected value. Expected value is the probability of winning multiplied by the amount of a win, minus the probability of losing multiplied by the amount of a loss (59). We calculated participants' proportion of optimal choices for each gamble.

To examine relative contributions of wins, losses, and uncertainty to subjective value, we used a logistic regression model to estimate the degree to which each contributed to choice behavior. This model estimated each participant's conditional probability of choosing gamble_2, on the basis of potential outcomes (wins and losses) and the presence of uncertainty (mask over gamble_2), with maximum likelihood estimation. This technique allowed us to estimate how strongly each decision component contributed to decision-making. We used the logistic response function:

$$P_{\text{Gamble2}} = \exp(\theta)/(1 + \exp[\theta])$$

where P_{Gamble2} is a participant's probability of choosing gamble_2 given the linear term θ, which is based on potential outcomes. We estimated θ with the following equation:

$$\theta = \beta_1\left(V^+_2 + V^+_1\right) + \beta_2\left(V^-_2 + V^-_1\right) + \beta_3(U)$$

where V^+_1 is the probability of winning gamble_1 multiplied by the value of a win; V^+_2 is the probability of winning gamble_2 multiplied by the value of a win; V^-_1 and V^-_2 are the probabilities of losing gamble_1 and gamble_2, respectively, multiplied by the value of that gamble's loss; and U is presence/absence of the mask over gamble_2. The estimated βs are participants' subjective weightings of each variable (β_1: subjective-value of potential gains; β_2: subjective-value of potential losses; β_3: subjective-value of uncertainty). All post hoc comparisons are Bonferroni corrected.

[1]Formula for d': $d' = Z_{\text{CorrectFRS\_IDs}} - Z_{\text{IncorrectFRS\_IDs}}$ where $Z_{\text{CorrectFRS\_IDs}}$ is the z-transformed probability of correctly identifying the frequently rewarded stimulus (FRS) and $Z_{\text{IncorrectFRS\_IDs}}$ is the z-transformed probability of incorrectly identifying the FRS, meaning that participants erroneously responded as though the FRS was present; see (47).

[2]Formula for bias: $\text{bias} = 1/2(Z_{\text{CorrectFRS\_IDs}} + Z_{\text{IncorrectFRS\_Ids}})$ (formula notations as in Footnote 1; 47). Note that in this calculation, positive values of bias indicate that participants have developed a response strategy favoring the FRS. In signal detection notation, this formula gives Criterion.

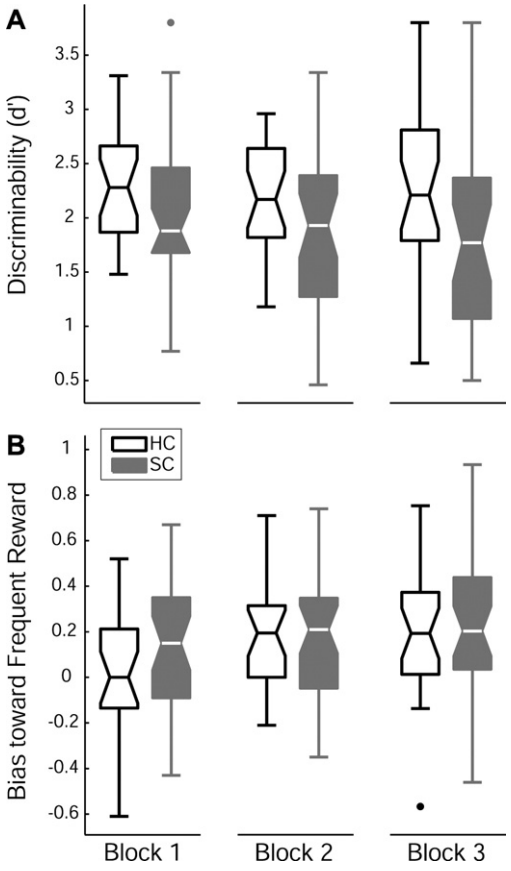

Figure 3. Reward sensitivity task results. Data are shown in Tukey box-plots. The middle line in each box shows the median, the box encloses 50% of the scores, and the whiskers show the full range of the data, excluding outliers. Outliers, depicted by dots, are data points that fall more than 2 SDs from the mean (76). **(A)** Healthy participants (HC) show slightly better ability to discriminate between the two stimuli (85% correct on average) than participants with schizophrenia (SC) (80% correct on average). **(B)** Both groups show similar development of response bias across the blocks. Note that positive values indicate bias toward the more frequently rewarded stimulus (scores of zero indicate no preference for either stimulus).

Results

Reward Sensitivity

Figure 3 shows results for the two mixed-model analyses of variance (ANOVAs) that examined group (HC, SC) differences in measures of discriminability (d') and bias across task blocks (1, 2, 3). Compared with HC participants, SC participants tended to have more difficulty discriminating between the short and long mouths (Table 2 shows ANOVA results). Neither the main-effect of block nor the group × block interaction approached significance for d'. However, despite slightly worse performance in the SC group, groups did not differ in the amount of bonus money earned [$\text{Mean}_{\text{HC}} = \$5.90$, SD = .20; $\text{Mean}_{\text{SC}} = \$5.95$, SD = .08; $t(64) = -1.14$, $p = .26$].

Consistent with hypotheses, we did not find group differences in the development of bias (see Table 2). As Figure 3B illustrates, both groups showed similar development of a reward-seeking response bias, with more pronounced bias in later blocks compared with the first (p values $< .04$). Bias did not differ between blocks 2 and 3 ($p = .91$). Neither the effect of group nor the block × group interaction was significant. These results suggest intact sensitivity to reward in SC.

Table 2. Task Results

	df	*F*	*p*	Effect Size (η^2_p)
Reward Sensitivity				
Bias[a]				
Block (1, 2 or 3)[b]	2, 55	4.08	.04	.08
Group (HC or SC)	1, 55	.15	.70	.003
Group × Block	2, 55	.55	.46	.01
Discriminability				
Block (1, 2, or 3)	2, 58	1.46	.24	.03
Group (HC or SC)	1, 58	3.68	.06	.07
Group × Block	2, 58	.71	.50	.01
Probabilistic Choice				
Subjective weightings				
Potential gains (β_1)	1, 62	.37	.54	.006
Potential losses (β_2)[b]	1, 62	7.02	.01	.11
Uncertainty (β_3)	1, 62	.56	.46	.009
Proportion of optimal choices				
Gamble (1 or 2)[b]	1, 62	84.72	< .001	.59
Group (HC or SC)[b]	1, 62	7.23	.009	.13
Gamble × Group[b]	1, 62	9.27	.003	.11

Table shows analysis of variance results with effect sizes.
[a]Three SC participants did not make errors in one or more task blocks. Bias cannot be calculated in errorless blocks, so the missing data excluded these participants from this analysis.
[b]Superscript notation indicates significant differences.

To determine how results related to neurocognitive measures, we examined correlations between cognitive measures, bias, and d' (each averaged across task blocks). There was no relationship between bias and any neurocognitive measure in either group (all *p* values >.16). However, in both groups, d' was significantly related to working memory (HC: $r = .49$, $p = .01$; SC: $r = .47$, $p = .005$). Among SC participants, d' did not relate to other variables (all *p* values >.19). Among HC participants, d' related to HVLT ($r = .45$, $p = .03$) and WTAR ($r = .51$, $p = .01$). These results suggest that cognitive ability, particularly working memory, relates to task performance but is independent of reward sensitivity.

Probabilistic Decision-Making

The probabilistic decision-making task allowed us to estimate participants' subjective weightings of several decision components (potential gains and losses and uncertainty) on the basis of their decision-making behavior. We subjected our estimates of participants' decision-component weightings (the βs from our logistic regression model) to multivariate ANOVA. As Figure 4A shows, groups did not differ in the degree to which they weighted potential gains or uncertainty in their decisions (Table 2). However, SC participants gave potential losses significantly less weight than HC participants. That is, the possibility of losing had less influence on SC participants' choices than on HC participants' choices.

Recent economic models of decision-making suggest that people's subjective weightings of decision-components influence propensity to choose optimally (33,60). We therefore examined optimal decision-making with a mixed-model ANOVA (group [HC, SC] × gamble [1,2]). The HC participants made more optimal choices overall (see Table 2 for results). There was a significant main effect of gamble showing that all participants made more optimal gamble_1 than gamble_2 choices (see Figure 4B). There was also a significant group × gamble interaction such that when gamble_1 was optimal HC participants chose it more frequently but when the higher-stakes gamble_2 was optimal groups chose it with similar frequency. To understand this interaction, we examined participants' cross-gamble difference in optimal choices (optimal gamble_2 − optimal gamble_1 choices). Relative to gamble_1 behavior, HC participants reduced their optimal gamble_2 choices to a greater degree than SC participants [$\text{Mean}_{HC} = -.29$, SD = .25; $\text{Mean}_{SC} = -.16$, SD = .24; $t(64) = -2.08$, $p = .04$], suggesting that gamble_2 was subjectively worse for HC participants.

To understand whether subjective weightings of potential outcomes explained group differences in optimal decision-making, we conducted a hierarchical multiple regression with participants' total optimal choices as the criterion variable. We entered participants' subjective weightings of potential gains, losses, and uncertainty at step one of the model. Subjective weightings explained significant variance in optimal choice behavior ($\Delta R^2 = .35$, $p < .001$). Examination of the regression coefficients showed that subjective weightings of gains ($p = .01$) and losses ($p = .02$) related to optimal choice behavior but weighting of uncertainty did not ($p = .14$). The entry of group (HC, SC) at step two of the model did not significantly account for variance over and above participants' subjective weightings ($\Delta R^2 = .03$, $p = .18$). This finding suggests that subjective weightings of decision components relate to how participants choose among competing options.

We have suggested that cognitive impairments might affect the ability to formulate subjective value. We examined this idea with hierarchical multiple regression with average weighting of potential gains and losses (the decision components related to optimal choice) as the criterion variable. At step one of the model, we entered the cognitive measures (working memory, HVLT, and WTAR). These accounted for a significant portion of the variance in participants' weightings of potential outcomes ($\Delta R^2 = .27$, $p < .001$). The regression coefficients at this step showed that working memory made a significant contribution to the model ($p = .01$) but neither HVLT ($p = .16$) nor WTAR ($p = .75$) did so. We entered group (HC, SC) at step two in the model. Working memory entirely accounted for group differences in participants' subjective valuations of potential outcomes ($\Delta R^2 = .02$, $p = .28$).

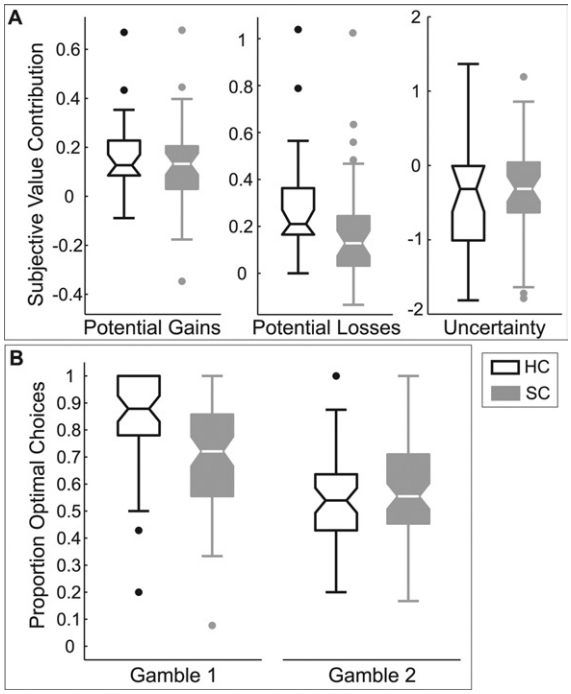

Figure 4. Probabilistic decision-making task results. Data are shown in Tukey box-plots. The middle line in each box shows the median, the box encloses 50% of the scores, and the whiskers show the full range of the data, excluding outliers. Outliers, depicted by dots, are data points that fall more than 2 SDs from the mean (76). **(A)** Participants with schizophrenia (SC) weighted potential gains and uncertainty similarly to healthy participants (HC) when deciding between two uncertain outcomes. However, SC participants, compared with HC participants, gave potential losses significantly less weight when making decisions. **(B)** The HC participants made more optimal choices overall, although the gamble × group interaction shows that HC participants made more optimal choices of $gamble_1$ than SC participants, but groups did not differ on $gamble_2$ choices.

Symptom Correlations

In the SC group, we explored the relationships between symptom ratings and task measures (bias, d', subjective weighting of potential outcomes). The d' showed a nonsignificant, inverse relationship with SANS total ($r = -.33$, $p = .06$). No other relationships emerged (all p values $>.19$).

Discussion

Consistent with expectations, patients with SC showed normal sensitivity to rewarding stimuli on a task in which rewards implicitly biased behavior. They also showed altered decision-making relative to healthy participants and relatively worse ability to use subjective valuations of potential outcomes, particularly losses, in their decisions. Deficits in working memory seemed to account for this alteration in subjective valuation. These findings suggest two important ideas. First, when assessed with implicit learning measures, the experience of reward and ability to learn from reinforcement are surprisingly intact in SC. The fact that patients developed a reward-seeking response bias is evidence of this idea. Second, degraded working memory in SC compromises the ability to weigh potential outcomes effectively during decision-making, which in turn limits decision quality. This idea is in keeping with a recent report showing that limbic activity might modulate working memory capacity (61). Together, these ideas have implications for understanding the functional impairments associated with SC.

A longstanding explanation for the motivational and behavioral deficits characteristic of SC is that the illness dampens the experience of reward (62,63). The present finding—that patients developed normal bias toward a frequently rewarded stimulus—adds to a growing body of literature suggesting spared response to pleasurable stimuli in SC (10,12,13). Moreover, the magnitude of the bias our participants showed is similar to that of Pizagalli *et al.*'s (48) control participants, suggesting that this result cannot simply be explained by atypical task performance in our sample. These results demonstrate that patients are sensitive to reward contingencies and can modify responses on the basis of reinforcement, despite absence of explicit awareness of reward contingencies. This implies that reward-based implicit learning systems are largely functional in SC.

In contrast, and consistent with previous reports (30,31,64), patients showed a pattern of altered decision-making that suggests they have difficulty using affective information to guide decision-making. Specifically, patients had more difficulty than healthy participants in choosing a low-risk gamble optimally, although groups did not differ in optimal choices to a high-risk gamble. At first glance, this finding implies a riskier choice strategy among patients (26,27,29); however, our analysis of participants' relative weightings of decision components suggests otherwise. We found no group difference in participants' valuations of potential gains or uncertainty, suggesting that patients are neither overly sensitive to gains nor insensitive to outcome likelihood. Instead, patients gave potential losses less weight in their decisions than healthy participants, suggesting that "risky" decision-making in SC relates to the relative undervaluation of potential losses. Working memory significantly related to participants' ability to weigh both types of potential outcomes in their decisions.

Together, results from both tasks suggest an interesting picture of the decision-making deficits so prominent in SC. To understand this, we examine differences in the tasks themselves, which are important in understanding the relationship of affect and cognition in decision-making. On each trial of the reward sensitivity task, we asked participants to decide which of two stimuli they had seen, implicitly shaping their preference for one stimulus with a series of small reinforcers. On each trial of the decision-making task, participants decided which of two choices they preferred by integrating cognitive (objective value) and affective information (subjective value). Discrimination accuracy in the reward sensitivity task related to working memory, although implicit preference for the frequently rewarded stimulus did not. Conversely, on the probabilistic decision task, working memory was an important determinant of participants' explicit preferences, as evidenced by robust correlations between working memory and task performance. Results suggest that patients are sensitive to immediately present reinforcers but have difficulty formulating preferences on the basis of potential outcomes and/or incorporating these into their choices. In essence, patients have difficulty integrating an affective preference into a cognitive representation that supports optimal decision-making.

In terms of the functional impairments associated with SC, results imply that deficits in motivated behavior might arise as rewards become more temporally remote (31) or require integration of cognition and affect (28,45,65). Whereas one might know that working brings a paycheck and exercise improves health, the gap between knowledge and motivation might simply be too large to bridge. Conversely, when rewards are immediately and consistently present in the environment, behavioral deficits might diminish (14,16,66). Indeed, evidence from token

economy studies suggests that making rewards salient aspects of the environment ameliorates some of the motivational deficits associated with SC (67–69). Taken together, this implies that consistent and tangible reinforcements might shape motivated behavior in a way that more complex or temporally remote rewards lack the power to do.

This research has several limitations. First, although we found group differences in subjective weightings of potential losses, we did not directly test responses to experienced punishments. Although previous findings show that patients report normal experiences of unpleasant stimuli (7,10,13), punishments might have less salience (23), thereby diminishing their subjective weightings. Second, the external validity of these tasks is unknown. Laboratory tasks are only a proxy for real-world reward sensitivity and decision-making. Moreover, although previous research suggests that participants respond similarly to real and hypothetical rewards (53), our use of hypothetical rewards in the decision-making task might have caused participants to behave differently than if they had played for real prizes. Third, our sample includes more men than women, and it might be the case that women treat affective stimuli differently (70–74), although this is not necessarily the case in reward-related decision-making (75). Finally, all our patients received antipsychotic therapy. Although our results likely generalize to the average treated outpatient with SC, we do not know whether results would be similar in unmedicated or medication-naïve populations.

Conclusions

The present findings demonstrate altered decision-making in the context of intact reward sensitivity in SC. Patients' decision-making alterations related to their ability to formulate subjective preferences, which itself related to working-memory. These results suggest that implicit learning systems, which rely on long-term reinforcement history, might be intact in SC but that cognitive deficits impinge on the ability to use affective experience in decision-making. Thus, making rewards immediate and salient aspects of the environment might partly mediate the deficits in motivated behavior that characterize SC.

A Grant (to JMG) from the National Institute of Mental Health (#1 R24 MH72647-01A1) made this work possible. We wish to thank Sharon August, Rebecca Wilbur, and Maria Wydra for their invaluable assistance with data collection.

We have no conflicts of interest, biomedical, financial, or otherwise, to declare.

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