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Relative risk of probabilistic category learning deficits in patients with schizophrenia and their siblings

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Abstract

Background—While patients with schizophrenia display an overall probabilistic category learning performance deficit, the extent to which this deficit occurs in unaffected siblings of patients with schizophrenia is unknown. There are also discrepant findings regarding probabilistic category learning acquisition rate and performance in patients with schizophrenia.

Methods—A probabilistic category learning test was administered to 108 patients with schizophrenia, 82 unaffected siblings, and 121 healthy participants.

Results—Patients with schizophrenia displayed significant differences from their unaffected siblings and healthy participants with respect to probabilistic category learning acquisition rates. Although siblings on the whole failed to differ from healthy participants on strategy and quantitative indices of overall performance and learning acquisition, application of a revised learning criterion enabling classification into good and poor learners based on individual learning curves revealed significant differences between percentages of sibling and healthy poor learners: healthy (13.2%), siblings (34.1%), patients (48.1%), yielding a moderate relative risk.

Conclusions—These results clarify previous discrepant findings pertaining to probabilistic category learning acquisition rate in schizophrenia and provide the first evidence for the relative risk of probabilistic category learning abnormalities in unaffected siblings of patients with schizophrenia, supporting genetic underpinnings of probabilistic category learning deficits in schizophrenia. These findings also raise questions regarding the contribution of antipsychotic medication to the probabilistic category learning deficit in schizophrenia. The distinction between good and poor learning may be used to inform genetic studies designed to detect schizophrenia risk alleles.

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Keywords

schizophrenia; relative risk; cognition; probability learning; caudate nucleus; antipsychotics

Probabilistic category learning involves a gradual learning of cue-outcome associations to some degree without conscious knowledge of the precise probabilistic frequencies determining those associations [1]. Previous studies of impaired probabilistic category learning acquisition rate using the “weather prediction” test in patients with striatal dysfunction suggest that this type of learning is related to striatum function [2-3]. Functional neuroimaging studies examining probabilistic category learning in healthy adults have reliably demonstrated activation of a neural network that includes caudate nucleus and prefrontal and parietal cortices [4-7].

Early “habit learning” studies demonstrated preserved striatal function in patients with schizophrenia [8-11]. These results have been questioned since the task used (different versions of the “Tower” test) has been shown to recruit executive function, problem solving, and working memory processes associated with prefrontal cortex function rather than relying primarily on basal ganglia function [12-16]. Recent studies of non-declarative learning and memory in patients with schizophrenia have produced more mixed results, especially with respect to serial reaction time tasks (see [17] for a review).

Previous probability learning studies (many using the weather prediction test) have shown a wide variation in their results with respect to differences between patients with schizophrenia and healthy adults: with some studies showing no acquisition rate or performance level differences [7,18-19], other studies showing overall performance level differences but no acquisition rate differences [7,20-23], and one study showing both acquisition rate and performance level differences [24]. Accordingly, the present study was designed to resolve the controversy in the literature regarding probabilistic category learning deficits in patients with schizophrenia by assessing the largest samples of patients with schizophrenia, their unaffected siblings, and healthy comparison participants to date using the widely used probabilistic category learning “weather prediction” test. Since relatively small sample sizes (used in previous studies of probabilistic category learning) may obscure the ability to detect significant differences of small effect or conversely, yield spurious significant effects, the larger sample size in the present study reduces the possibility of such undesirable outcomes.

While previous studies of probabilistic category learning examined mean group learning rate and performance levels, individual acquisition rates have been largely ignored (although [25] examined individual strategies). Individual learning scores explain individual differences that are independent of overall group differences and average learning [26]. Curve fitting to individual data is relevant for theoretical and methodological reasons and is helpful for distinguishing among different aspects of learning such as initial level of performance, rate of improvement, and final level of performance [26]. To characterize each of the groups more accurately with respect to the proportion of good and poor learners, a learning criterion was applied on an individual basis (see Methods for details). Using these revised learning criteria provides a clear picture of individual learning across all trials and enables a comparison of the frequencies of good and poor learners among groups. Other studies [7,27-31] have classified good and poor learners and [32] assessed whether siblings of patients with schizophrenia displayed a greater frequency of individuals with impaired cognition.

Studying unaffected siblings of patients with schizophrenia may help to assess effects of antipsychotic medication upon probabilistic category learning deficits in a group that may share some risk genes for the abnormality and yet are not receiving antipsychotic medication.

Probabilistic category learning was also assessed to determine, for the first time, the relative risk of probabilistic category learning deficits in unaffected siblings of patients with schizophrenia and the frequency of probabilistic category learning abnormalities in patients, siblings, and healthy participants. Given the balance of previous studies showing normal acquisition rate in conjunction with impaired overall performance levels during probabilistic category learning in patients with schizophrenia, the hypothesis for the present study was that, relative to healthy adults, patients with schizophrenia would display an overall performance deficit in conjunction with a normal probabilistic category learning acquisition rate while unaffected siblings of patients with schizophrenia would display a level of performance that was intermediate between patients and healthy participants.

Method

Participants

Patients with schizophrenia—One hundred and eight patients, 77 males and 31 females, with a diagnosis of schizophrenia participated in this study. Two board-certified psychiatrists concurred on diagnosis by Structured Clinical Interview for the Diagnostic and Statistical Manual-fourth edition without knowledge of cognitive performance. Patients who received concurrent axis I psychiatric diagnoses other than schizophrenia, or had a history of current substance abuse, head injuries with concomitant loss of consciousness, seizures, central nervous system infection, diabetes, or hypertension, were excluded. Patients were all receiving doses of antipsychotic medication at the time of testing with the majority receiving second generation antipsychotics such as olanzapine or risperidone. Only 1 of these 108 patients had been administered the probabilistic category learning test previously, which has been reported elsewhere.

Unaffected siblings of patients with schizophrenia—Eighty-two unaffected siblings of patients with schizophrenia, 35 males and 47 females, participated in this study. Two board-certified psychiatrists concurred on all diagnoses by Structured Clinical Interview for the Diagnostic and Statistical Manual-fourth edition without knowledge of cognitive performance. These siblings had no current substance abuse, head injuries with concomitant loss of consciousness, seizures, central nervous system infection, diabetes, or hypertension; however, 23.2% had a diagnosis of major depression, in remission, 6.1% had a diagnosis of alcohol dependence, in remission, 4.9% had a diagnosis of anxiety disorder, in remission, and 1.2% had a diagnosis of substance dependence, in remission. No siblings had active mental disorders (including cluster A personality disorders or schizotypal symptomatology as determined by SCID II questionnaire for personality disorders followed by an interview by an experienced psychiatrist or psychologist) or were receiving medications at the time of assessment and none had been administered the probabilistic category learning test previously.

Healthy participants—One hundred and twenty-one healthy participants, 53 males and 68 females recruited through the National Institutes of Health Normal Volunteer Office, participated in this study. Healthy participants with a history of psychiatric disorders, current substance abuse, head injuries with concomitant loss of consciousness, seizures, central nervous system infection, diabetes, or hypertension were excluded. No healthy participants had been administered the probabilistic category learning test previously.

All participants provided informed written consent prior to participation in this study. The Institutional Review Board of the National Institute of Mental Health provided approval for this study.

Measure of General Intelligence

A four-subsection version of the Wechsler Adult Intelligence Scale-Revised (WAIS-R) was administered to all participants to obtain an estimate of current Full Scale Intelligence Quotient (FSIQ). The four-subsection version of the WAIS-R used to obtain estimated FSIQ was composed of Arithmetic, Similarities, Picture Completion, and Digit Symbol Substitution subsections [33].

Demographics and General Intelligence

See Table 1 for a summary of gender, ethnicity, mean age, and current WAIS-R estimated FSIQ for patients, siblings, and healthy participants. Separate one-way ANOVAs revealed a significant difference among groups with respect to age, $F(2, 283) = 4.62$, $p = .01$ and a significant difference among groups on the basis of WAIS-R estimated FSIQ, $F(2, 251) = 43.72$, $p < .001$. While siblings and healthy participants did not differ greatly in the ratio of males to females (see Table 1), the patient group was predominantly male. Results of a Chi-Square analysis of the number of males and females in each of the participant groups revealed significant differences among groups, $\chi^2(2) = 22.13$, $p < .001$. Thus, gender was entered as a grouping variable in the ANOVA (see Probabilistic Category Learning Analyses below).

Probabilistic Category Learning Test

The weather prediction test was administered on a lap top computer as described in detail previously [2-3,23]. Participants learn the relationship between two equally occurring outcome variables (rain or shine) and combinations of four cue cards each composed of simple geometric shapes (see Figure S1 in Supplement 1). The probabilistic relationships among cue card combinations and outcome variables were predetermined (see Table 2).

Probabilistic Category Learning Analyses

Scoring followed that of previous studies [2-3,23]. Transformed scores for cumulative percent correct at every tenth trial were analyzed using a repeated-measures ANOVA with participant group (patient, sibling, healthy participant) and gender (male, female) as independent variables. Corrections for interdependencies among dependent variables were calculated using Greenhouse-Geisser and a Multivariate test for repeated measures. The difference between mean percent correct at trial 150 and trial 10 was analyzed to obtain a measure of acquisition rate that is relatively insensitive to absolute performance. Separate one-way ANOVAs were used to determine group differences with respect to trials on which no responses occurred.

Revised learning criteria—To compare frequencies of good and poor learners a learning criterion (positive difference score between cumulative percent correct at trial 150 and trial 10 and sustained cumulative percent correct equal to or greater than 65% across trials 100 to 150) was applied to all probabilistic category learning data on an individual basis. While the criterion chosen is somewhat arbitrary and dichotomizes a continuous variable into a categorical variable, this method can provide greater insight into the learning process and frequency of learning than the less informative mean acquisition rates of whole groups. See Table 3 for a summary of gender ratios, mean age, and current WAIS-R estimated FSIQ for patients, siblings, and healthy participants on the basis of learning status (good versus poor learners).

Relative risk—Relative risk was calculated by first obtaining the numbers of patients, unaffected siblings, and healthy participants who were classified as good and poor learners based on the revised learning criteria described above. A Chi Square analysis was used to test for a significance difference among the numbers of poor learners in each group. Moderate (2 - 4) to high (> 4) relative risk values suggest that the phenotype may be suitable for further

genetic analysis [34]. Here we used the calculation of relative risk for siblings used by [32]: the ratio of “affected” siblings to “affected” healthy participants.

Strategy analyses—Since previous work [25] suggests that probabilistic category learning strategy may influence performance, data from the present study were also analyzed (by MM) blind to group (patients, siblings, healthy participants) and learning status (good or poor learner) by using an improved strategy clustering analysis [35]. The frequency of each strategy used among groups was compared using a chi-square analysis to establish whether the groups utilized qualitatively different strategies. Other strategy related variables were analyzed by a series of one-way ANOVAs.

Results

Patients with schizophrenia were significantly different from their unaffected siblings and healthy participants with respect to probabilistic category learning acquisition rates. See Figure 1 for the probabilistic category learning acquisition curves for patients with schizophrenia, their unaffected siblings, and healthy participants. Results of a repeated-measures ANOVA with participant group (patient, sibling, healthy participant) and gender (male, female) as independent variables and cumulative percent correct at every tenth trial as the dependent variable with a Greenhouse-Geisser (G-G) adjustment for sphericity violations revealed a significant main effect of trial block, $G\text{-}G \text{ adjusted } \epsilon(2.3, 702.2) = 0.16, p < .001$, a significant trial block X participant group interaction, $G\text{-}G \text{ adjusted } \epsilon(4.6, 702.2) = 0.16, p = .05$, and no other significant main effects or interactions. Regarding the significant participant group X trial interaction, post hoc LSD tests revealed that the patients were significantly different from the siblings at trials 10 through 150, $p\text{'s} \leq .04$, and that the patients were significantly different from the healthy participants at trials 20 and 40 through 150, $p\text{'s} \leq .04$. Results of multivariate tests for repeated measures also yielded significant p values for the main effect of trial, $F(14, 292) = 57.07, p < .001$, and trial X participant group interaction, $F(28, 584) = 2.01, p = .002$.

Regarding differences in acquisition rates among the groups as measured by the difference score between trial 150 and 10, a separate one-way ANOVA revealed a trend toward a significant difference among groups, $F(2, 308) = 2.75, p = .07$, (patient mean acquisition rate = 11.9, $SEM = 1.8$; sibling mean acquisition rate = 14.8, $SEM = 1.4$; healthy participant mean acquisition rate = 16.8, $SEM = 1.4$). A follow-up post hoc t -test of acquisition rate in healthy participants and patients with schizophrenia based on the significant group X trial interaction from the repeated measures ANOVA revealed a significant difference in acquisition rate between healthy participants and patients with schizophrenia, $t(227) = 2.20, p = .03$. A small effect size of 0.2 was obtained with respect to acquisition rate differences between patients with schizophrenia and healthy participants.

Results of a separate one-way ANOVA for the number of trials on which no responses were made during probabilistic category learning revealed a significant difference among groups, $F(2, 311) = 21.56, p < .001$; post hoc LSD tests showed that patients with schizophrenia (mean = 7.0, $SEM = 1.1$) were significantly different from both siblings (mean = 1.5, $SEM = 0.3$) and healthy participants (mean = 1.6, $SEM = 0.2$), $p\text{'s} < .001$ with no other significant comparisons. However, the mean total number of omissions for patients was less than 5 percent of the total number of trials. Regarding antipsychotic medication effects on probabilistic category learning in patients, there were no strong, significant correlations among chlorpromazine equivalent dosage and probabilistic category learning mean percent correct difference scores ($r = -.06, p = .55$).

Given significant differences among groups on the basis of age, correlations were performed between age and probabilistic category learning mean cumulative percent correct difference

score between trials 150 and 10 (as a measure of acquisition rate). There were no strong, significant correlations among age and probabilistic category learning acquisition rate for each of the participant groups, patients: $r = .02$, $p = .85$, siblings: $r = .19$, $p = .13$, healthy participants: $r = .07$, $p = .49$ (for scatter plots see Figures S2-S4 in Supplement 1).

Given the expected significant differences among groups on the basis of general intelligence, correlation analyses were performed to determine the existence of any relationship between IQ and probabilistic category learning acquisition rates within each of the groups. There were no strong, significant correlations between IQ and probabilistic category learning acquisition rate in each of the groups (patients: $r = .08$, $p = .48$; siblings: $r = .07$, $p = .60$; healthy participants: $r = -.10$, $p = .32$). Inspection of the scatter plots (see Figures S5-S7 in Supplement 1) reveals no relationship between IQ and acquisition rate. Therefore, on the basis of these correlations age and IQ differences among groups were not considered further.

See Figure 2 for the different frequencies of good and poor learners obtained after applying the revised learning criteria, with patients displaying the lowest frequency and healthy participants displaying the highest frequency of good learners and siblings being intermediate. Relative risk for poor learning siblings was determined to be 2.6, $\chi^2(1) = 11.4$, $p < .001$. The relative risk for poor learning patients with schizophrenia was determined to be 3.6, $\chi^2(1) = 31.69$, $p < .001$.

Strategy analyses

Chi Square analyses for each trial block of 50 trials failed to display significant differences among the number of patients with schizophrenia, siblings, and healthy participants classified as good learners with respect to the type of strategy used (including random strategy) during the first trial block ($\chi^2(8) = 6.92$, $p = .55$), second trial block ($\chi^2(8) = 4.42$, $p = .82$), and third trial block ($\chi^2(8) = 3.02$, $p = .93$). Separate Chi Square analyses for each trial block of 50 trials failed to display significant differences among the number of patients with schizophrenia, siblings, and healthy participants classified as poor learners with respect to the type of strategy used (including random strategy) during the first trial block ($\chi^2(8) = 6.95$, $p = .54$), the second trial block ($\chi^2(8) = 7.60$, $p = .47$), and the third trial block ($\chi^2(8) = 8.18$, $p = .42$) (see Supplementary Material for details). Separate one-way ANOVAs comparing the groups on the basis of other strategy variables revealed no significant differences among groups (see Table 4).

Discussion

Patients with schizophrenia were significantly different from their unaffected siblings and healthy participants during probabilistic category learning with respect to acquisition rates; however, there were no significant differences between siblings and healthy participants. Although these results did not support our hypothesis, the results support previous work [24] showing impaired probabilistic category learning acquisition rates in patients with schizophrenia relative to healthy participants. Although the present result supports the previous finding [24], an impaired acquisition rate is in contradistinction to other studies that have failed to demonstrate impaired probabilistic learning acquisition rate in schizophrenia [18,20, 22-23]. The ability to identify an impaired acquisition rate in the present study may have been due to use of a relatively large sample size that allowed differentiation of a relatively small effect among groups. Thus, these results suggest that an impaired acquisition rate is characteristic of patients with schizophrenia.

Although siblings on the whole failed to differ from healthy participants on strategy and quantitative indices of overall performance and learning acquisition, application of the revised learning criteria revealed that patients display the lowest frequency and healthy participants

display the highest frequency of good learners while siblings were intermediate. The sibling group displayed a moderate relative risk for probabilistic category learning impairment. This suggests that there is only a subset of siblings who express genetic risk for probabilistic category learning impairment. The distinction between good and poor probabilistic category learning may aid in the detection of people who may be susceptible to developing schizophrenia; however, further work examining probabilistic learning with people in the prodromal stage would need to be conducted.

The pattern of brain activity during probabilistic category learning in siblings of patients with schizophrenia has not been demonstrated. Determining the pattern of brain activity in poor learning siblings of patients with schizophrenia would be of interest since similar to their siblings with schizophrenia these unaffected siblings may possess a genetic variant that codes for some aspect of dopamine system function that may influence reinforcement learning; however, unlike their siblings with the illness, these unaffected siblings have not experienced a history of antipsychotic medication treatment that could adversely impact caudate structure and function. While a recent functional MRI study of probability learning has shown decreased prefrontal cortex and striatal activity in schizophrenia [7], “good learning,” based on a positive acquisition rate and sustained performance, in patients with schizophrenia appears to involve compensatory extra-striatal circuitry consisting of a more rostral portion of the dorsolateral prefrontal, cingulate, parahippocampal, and parietal cortices [7]. This compensatory network may not be available, or as strongly recruited, in patients and siblings who are classified as poor learners.

There are some potential limitations of this study. Use of the term “unaffected” in the siblings is meant to refer primarily to psychosis and siblings with a psychotic related diagnosis were excluded; however, many siblings had other diagnoses in remission or may have possessed some cluster A personality traits although an effort was made to exclude siblings with these traits. The inverse gender ratio in patients with schizophrenia relative to healthy participants and siblings may have influenced the results. Analysis of the effect of gender on probabilistic learning failed to reveal a significant effect of gender. Significant differences among the groups with respect to age and IQ may be seen as potential confounding variables; however, a closer examination of the relationships among probabilistic category learning acquisition rate, age and IQ within each of the groups revealed no strong, significant correlations. Inspection of the scatter plots (Supplementary Material) shows an absence of any relationship among probabilistic category learning, age and intelligence. Weickert et al. [23] previously reported no strong, significant correlations between probabilistic category learning and IQ in smaller, independent samples of patients and healthy participants.

Another potential limitation pertains to antipsychotic medication effects on striatal function in patients. Increased striatal dopamine receptor binding has been shown in patients with schizophrenia [36-41], administration of dopamine D2 receptor antagonists yield symptom reduction [42-46], and previous studies have shown an abnormal relationship between markers of dorsolateral prefrontal cortex function and abnormal striatal preynaptic dopamine in patients with schizophrenia [47-51]. There is also evidence of frontal lobe physiological abnormalities and caudate hypometabolism in treatment resistant patients with schizophrenia relative to healthy participants [52-54] and significantly lower relative glucose metabolism in the caudate of patients with schizophrenia [55]. Abnormal caudate nucleus volumes (generally increases) have also been reported in patients with schizophrenia relative to healthy participants [56-61]; and these differences appear to be related to antipsychotic treatment. While [62] found that first generation antipsychotic treatment impaired probabilistic category learning in schizophrenia, second generation antipsychotic treatment in an independent group of patients did not appear to negatively influence probabilistic category learning. In contrast to the results of [62], the present study shows that probabilistic category learning acquisition is impaired in

patients with schizophrenia who were primarily treated with second generation antipsychotic medication. Impaired probabilistic category learning acquisition rate from the present study supports earlier work (24) also showing impaired acquisition rate in patients with schizophrenia administered second generation antipsychotic medication. Probabilistic category learning acquisition rate may be negatively influenced in patients with schizophrenia by both illness and antipsychotic treatment; however, in the present study there was no relationship between chlorpromazine equivalent dose and probabilistic category learning. Conversely, antipsychotic treatment in patients with schizophrenia may to some extent normalize disease related probabilistic category learning acquisition rate impairment since approximately 50% of the patients were classified as good learners in the present study. Results from the present study would suggest that shared genes related to schizophrenia (rather than antipsychotic treatment which was not a factor in siblings) may contribute to the larger proportions of siblings who were classified as poor learners. There is also some support for abnormal striatal activity during probabilistic learning in first episode psychotic patients who were not receiving antipsychotic medication [19].

The Ser-9-Gly polymorphism of the dopamine D3 receptor has been associated with probabilistic category learning deficits in schizophrenia [22]. However, previous studies suggest that there is no clear association between the Ser-9-Gly polymorphism and schizophrenia [63-64]. Furthermore, dopamine D3 receptors are restricted mainly to the ventral striatum and the islands of Calleja based on postmortem brain studies [65-67], while radioligand binding in all other regions of the caudate/putamen represents exclusive binding to dopamine D2 receptors [68] and evidence suggests that probabilistic category learning does not rely solely on ventral striatum processing [2-3,4-7]. Thus, it is presently unclear whether dopamine D3 receptor binding would play a role in probabilistic category learning or schizophrenia.

Conversely, [69] has shown that polymorphisms of the DARPP-32 and dopamine D2 receptor genes (associated with striatal function in healthy adults) predicts greater probabilistic reward learning and the ability to avoid choices probabilistically associated with negative outcomes. Also, [70] has shown that a combination of dopaminergic polymorphisms (including genes for the dopamine transporter, catechol-O-methyltransferase, and vesicular monoamine transporter-member 2) increase the risk for schizophrenia. Thus, further studies of other candidate genes (polymorphisms of DARPP-32, dopamine D2 receptor, and dopamine transporter genes) related to striatal function and probabilistic category learning in schizophrenia would be warranted.

In summary, patients with schizophrenia were significantly different from their unaffected siblings and healthy participants with respect to probabilistic category learning acquisition rates. Application of a revised learning criteria based on individual data revealed that patients displayed the lowest frequency and healthy participants displayed the highest frequency of good learners while siblings were intermediate. The present results 1) represent the largest set of probabilistic category learning data in patients with schizophrenia to date, 2) appear to clarify discrepant findings regarding probabilistic category learning acquisition rate in schizophrenia (use of larger samples enabled detection of significant acquisition rate differences of relatively small effect), and 3) provides the first evidence for a moderate relative risk of probabilistic category learning abnormalities in unaffected siblings of patients with schizophrenia, supporting a genetic contribution to probabilistic category learning deficits in schizophrenia and brings the effects of antipsychotic medication on probabilistic category learning into question since increased numbers of siblings also showed impairment but were not receiving antipsychotic medications.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Figure 1.

Probabilistic category learning acquisition curves for patients with schizophrenia, their unaffected siblings, and healthy participants. * Patients were significantly different from the siblings at trials 10 through 150, $p's \leq .04$, and + patients were significantly different from the healthy participants at trials 20 and 40 through 150, $p's \leq .04$ based on post hoc LSD tests.

Figure 2.

Percentages of good and poor learners during probabilistic category learning in patients with schizophrenia, their unaffected siblings, and healthy participants classified on the basis of revised learning criteria.

Table 1
Gender, ethnicity, mean age and current IQ estimate for patients with schizophrenia, their unaffected siblings, and healthy participants

	patients with schizophrenia	unaffected siblings	healthy adults	χ^2	F	p
number	108	82	121			
male : female ratio	2.5 : 1.0	0.7 : 1.0	0.8 : 1.0	22.13	---	< .001
ethnicity (%)						
Caucasian	76.4	89.3	81.2			
African American	07.3	02.4	04.3			
Asian	04.5	01.2	03.4			
Hispanic	01.8	01.2	00.9			
Native American	01.8	02.4	00.0			
Mixed	08.2	03.6	10.3			
age (years)	36.1 (1.1)	36.7 (1.1)	32.8 (0.9)	---	4.62	.01 ^a
WAIS-R FSIQ	92.5 (1.2)	104.4 (1.3)	105.7 (0.9)	---	43.72	< .001 ^b

^a healthy adults significantly different from siblings and patients, post hoc LSD p's = .02.
^b patients significantly different from siblings and healthy adults, post hoc LSD p's < .001.

notes: standard error in parentheses. Wechsler Adult Intelligence Scale-Revised Full Scale Intelligence Quotient (WAIS-R FSIQ) estimate based on four subtests.

Table 2
Probability Structure of Probabilistic Learning (Weather Prediction) Task

Cue Pattern	Cue				P(cue combination)	P(outcome)
	1	2	3	4		
1	0	0	0	1	.133	.150
2	0	0	1	0	.087	.385
3	0	0	1	1	.080	.083
4	0	1	0	0	.087	.615
5	0	1	0	1	.067	.200
6	0	1	1	0	.040	.500
7	0	1	1	1	.047	.143
8	1	0	0	0	.133	.850
9	1	0	0	1	.067	.500
10	1	0	1	0	.067	.800
11	1	0	1	1	.033	.400
12	1	1	0	0	.080	.917
13	1	1	0	1	.033	.600
14	1	1	1	0	.047	.857

Note. For any given trial, 1 of the 14 possible cue pattern combinations displayed above appeared on the computer screen with a probability indicated as: $P(\text{cue combination})$. As shown above, the probability of the cue combinations to predict “sunshine” (outcome 1) was set at $P(\text{outcome 1})$ was set at $P(\text{outcome})$. Conversely, the probability of the above cue combinations to predict “rain” (or outcome 2) was equal to $1 - P$.

Table 3
Gender ratios, mean age, and current WAIS-R estimated FSIQ for patients, siblings, and healthy participants on the basis of learning status (good versus poor learners)

	patients with schizophrenia		unaffected siblings		healthy adults	
	good	poor	good	poor	good	poor
male : female	2.1 : 1.0	3.3 : 1.0	0.8 : 1.0	0.8 : 1.0	0.7 : 1.0	1.3 : 1.0
age (years)	36.6 (1.4)	38.5 (1.8)	37.1 (1.5)	38.0 (2.1)	32.7 (1.1)	30.1 (3.1)
WAIS-R IQ	94.0 (1.4)	89.2 (1.9)	105.0 (1.5)	104.5 (2.2)	105.3 (1.1)	104.0 (3.2)

Note. Standard error in parentheses.

Table 4
Mean trial number at which the first strategy switch occurred, total number of strategy switches during the first half of trials, number of strategy switches during the second half of trials, and number of trials correctly fitted to a strategy for patients with schizophrenia, their unaffected siblings, and healthy participants

	patients with schizophrenia	unaffected siblings	healthy participants	F	p
trial of 1 st strategy switch	35.6 (4.1)	35.8 (4.1)	35.5 (3.1)	0.00	1.00
number of strategy switches	5.4 (0.3)	5.4 (0.3)	5.6 (0.2)	0.13	.88
switches in 1 st half of trials	3.2 (0.2)	2.8 (0.2)	3.1 (0.2)	0.74	.48
switches in 2 nd half of trials	2.2 (0.2)	2.5 (0.2)	2.5 (0.1)	1.34	.26
trials correctly fitted	53.3 (3.5)	52.6 (3.5)	51.7 (2.9)	0.07	.94

notes: standard error in parentheses.