ORIGINAL RESEARCH

Neural Correlates of Cognitive Dysfunction in Conditional Reasoning in Schizophrenia: An Event-related Potential Study

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Purpose: Schizophrenia patients show impaired conditional reasoning. This study was to investigate event-related potential (ERP) characteristics of the conditional reasoning in schizophrenia.

Patients and methods: Participants included 24 schizophrenia patients and 30 normal controls (NCs), and the measurements of ERPs were conducted during the Wason selection task.

Results: Results showed that NCs consistently outperformed schizophrenia patients in terms of accuracy. Among the different rule types of the task, the precautionary type experiment yielded the highest accuracy rates. In contrast, both the descriptive and abstract type experiments resulted in lower accuracy. The RTs of the abstract type experiment were the shortest among the four experiments. In the abstract type of the Wason selection task, the NCs exhibited higher amplitudes for both the N1 and P2 components compared to the schizophrenia patients. At the parietal lobe, the N2 amplitudes were higher for the social contract type of the task compared to the precautionary version. At the frontal lobe, the N2 amplitudes were highest for the abstract type of the task. In the abstract type, the N2 amplitude at the parietal lobe was higher than that at the central lobe. The NCs displayed lower amplitudes for both the P3 and slow wave compared to the schizophrenia patients. Differences were observed between the NC and schizophrenia groups in terms of the latencies for N1, P2, N2, P3 and slow wave components across different experiment types and regions of interest.

Conclusion: In conclusion, the observed ERP patterns provide valuable insights into the neural mechanisms underlying the Wason selection task, highlighting the differences between NCs and patients with schizophrenia.

Keywords: event-related potential, wason selection task, schizophrenia, conditional reasoning, neural mechanism

Introduction

Schizophrenia is a multifaceted psychiatric disorder, and afflicts approximately 1% of the global population, impacting cognitive function, emotion, and behavior.[1] Its phenomenological profile is quite heterogeneous, comprising positive symptoms (hallucinations, delusions), negative symptoms (anhedonia, affective flattening), affective symptoms, cognitive impairments and impulsive aggression. Of all these clinical symptoms, cognitive dysfunctions have been in leading position because they are often linked to functional outcomes.[2] The cognitive deficits inherent in schizophrenia are frequently regarded as cardinal features, having pervasive impacts across multiple cognitive domains. These domains encompass neurocognitive impairments and social cognitive dysfunctions, including attention, memory, executive

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function, and social cognition, each reflecting distinctive yet interconnected impairments that significantly impede functional outcomes and quality of life.[3]

Conditioned reasoning is an important aspect of individual's neurocognitive function. Conditional reasoning (if p then q) is used very frequently in everyday situations. Disturbances in appropriate use of conditional reasoning could lead to errors with serious consequences.[4] The Wason selection task, a classic problem in the study of human reasoning, has been instrumental in understanding deductive reasoning processes. The Wason selection task is a standard test of conditional reasoning in which one flips cards to test a rule about the two faces.[5] There are four types of the Wason selection task: descriptive, abstract, social contract, and precautionary. The descriptive type describes one aspect of the world without telling people what to do. The abstract type is an abstract logical rule that applies to any situation and is expressed as: if p, then q. The social contract type contains a variety of specific social contracts, and the precautionary type is used to prevent the occurrence of hazards.[6] Many studies have been conducted on neural mechanisms of conditioned reasoning in normal individuals. The functional magnetic resonance imaging (fMRI) depicts changes in deoxyhemoglobin concentration consequent to task-induced or spontaneous modulation of neural metabolism, and it has been widely employed in investigations of cognition functions due to its high spatial resolution. A study using the social contract type of the Wason Selection task to investigate the neural bases of human reasoning about social rules with fMRI technology showed that the task activated the left frontoparietal network of deductive reasoning.[7] Another study using fMRI displayed that when participants performed a modified version of the classic Wason selection task, areas within the default-mode network showed a parametric deactivation with increases in relational complexity, and task-based connectivity between the striatum and the angular gyri, and between the thalamus and right temporal pole, increased as a function of relational complexity.[8] However, the disadvantage of fMRI is that it has low temporal resolution, so it cannot well investigate the changes in cognitive function during the Wason Selection task.

With the advent of neuroimaging techniques, the neural correlates of this task have been explored using event-related potentials (ERPs). ERPs offer a high temporal resolution, making them ideal for tracking the cognitive stages involved in the Wason selection task. A study which used ERPs to explore differences in spatiotemporal dynamics between modus ponens and modus tollens in the Wason selection task showed that modus ponens elicits a more positive P3b-like component than modus tollens from 400 to 800 milliseconds (ms), which suggests that modus tollens occupies more cognitive resources than modus ponens in the final stages of proposition testing.[9] Another study used ERPs to evaluate a modified Wason's selection task, ie, participants were provided with a proposition (hypothesis) and a card and they were asked to evaluate whether the card verified or falsified the given proposition, and results indicated that when the ERPs time-locked to the second side of each card showed that smaller amplitudes of P2 were elicited in backward falsification than in backward verification; a profound negative deflection was found in falsification conditions compared to verification conditions during the N2 time window; in comparison to verification conditions, falsification conditions evoked a decreased P3 component; and a late positive component (400–600 ms) was only triggered in the forward falsification condition.[10]

The previous study showed that impaired logical reasoning in schizophrenia is prominent, and patients with schizophrenia often jump to conclusions, and patients are too certain of their choices, even if they have too little information at their disposal.[11] Furthermore, the impaired logical reasoning has also been found in individuals with schizotypic characteristics in the general population.[12] A study showed patients with schizophrenia were significantly impaired on all conditional reasoning tasks compared to depressive patients and normal controls, and the social contract task and precautions tasks yielded better results than the descriptive tasks.[6] The results suggested that patients with schizophrenia could encounter difficulties understanding precaution rules and social contracts in real-life situations resulting in unwise risk-taking and misunderstandings in the social world.

To date, no studies on ERP characteristics of the conditional reasoning in schizophrenia have been reported. Further investigating the ERP characteristics of the conditional reasoning in schizophrenia would be helpful in understanding the neural process of the conditional reasoning. Understanding the nuances of conditional reasoning deficits in schizophrenia could inform cognitive remediation strategies. Tailored interventions that specifically target reasoning skills might enhance the overall cognitive and functional outcomes for patients. Moreover, insights into the neural mechanisms underlying these deficits could provide novel targets for pharmacological and neuromodulatory treatments.

In present study, the participants included schizophrenia patients and normal controls, and the Wason selection task was used to investigate the neural process of the conditional reasoning and the measurements of ERPs during the Wason selection task. The purpose of the present study was to investigate the ERP characteristics of the conditional reasoning, and further explore the neural mechanism of the cognitive processing of the abnormal conditional reasoning in schizophrenia.

Materials and Methods

Participants

Participants included schizophrenia patients and normal controls. The diagnosis of schizophrenia met the Diagnostic and Statistical Manual of Mental Disorders, Fifth edition (DSM-5) schizophrenia criteria, and the age range of schizophrenia patients was 18–65 years.

The exclusion criteria comprised (1) had any physical illness as determined by clinical evaluations and medical records; (2) had any substance misuse or dependence; (3) had a history of modified electra convulsive therapy in the past 12 months. For normal controls, the inclusion criteria comprised (1) no diagnosis of psychiatric disorders according to DSM-5 criteria; (2) no current use of medications affecting cognitive function; (3) age range of 18–65 years.

Schizophrenia patients were selected from the Affiliated Mental Health Center of Jiangnan University, China. The normal controls were selected from a group of persons who lived in Wuxi City, Jiangsu Province, China through local residential community advertising recruitment. We used G*Power software to estimate the required sample size in this study. With $\alpha = 0.05$ for statistical significance in F-tests, a minimum of 18 persons per group was estimated to achieve high statistical power ($1-\beta = 0.95$). A total of 30 schizophrenia patients and 30 normal controls were included in this study. Three schizophrenia patients with poor electrode contacts and three schizophrenia patients with frequent blink artifacts or muscular artifacts were excluded from the subsequent analysis. Participants provided written informed consent before the experiment with the assessment procedures fully informed, however, for some of the schizophrenia patients with a compromised capacity to provide consent, we explained all experimental procedures to schizophrenia patients' next of kin, care takers or guardians, and they all consented on behalf of the schizophrenia patients whose capacity to consent was compromised.

This study was conducted from July 1, 2021, to July 31, 2023, and was approved by the Ethics Committee on Human Studies (WXMHCIRB2023LLky079), the Affiliated Mental Health Center of Jiangnan University, China and was carried out in accordance with the Declaration of Helsinki.

Clinical Assessments

All schizophrenia patients were evaluated by an associate chief psychiatrist and a psychiatric resident. The Positive and Negative Syndrome Scale (PANSS) was employed to assess psychopathology. The mean chlorpromazine-equivalent dose was calculated according to the previous report.[13] To evaluate the ability of cognitive processing regarding conditional reasoning, the Wason selection task was administered.

Stimuli and Task

Stimuli

Referred from the previous research, eight social contract, eight precautionary, and eight descriptive Wason selection tasks were used in the present study.[14] Experienced English-Chinese bilinguals translated all conditional rules into Chinese and localized some of the words, such as replacing Philadelphia with Wuxi. The number of Chinese characters of problems were closely matched (social contract: mean=18.33, standard deviation (SD)=1.99, range=15–21; precautionary: mean=18.53, SD=2.56, range=15–22; descriptive: mean=21.07, SD=1.75, range=19–25). We selected eight abstract Wason selection tasks for use in this study.[10]

Wason Selection Task

The experimental procedure referred from the methodology which was reported in a previous study.[15] As shown in Figure 1, in each trial, following a centrally presented fixation cross that lasted for 800–1000 ms randomly. After the fixation, a rule was displayed on the center of the screen for 5,000 ms (eg, "If you use the library, then you must pay the fee"). Then a card (eg, "Ming
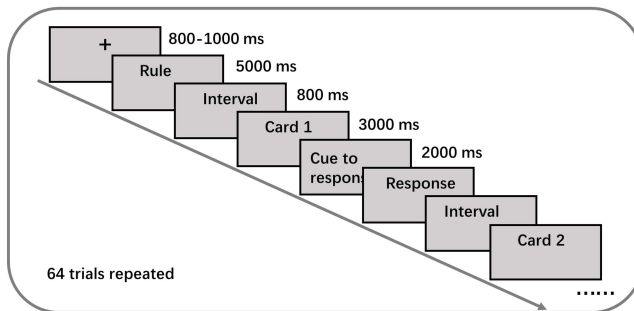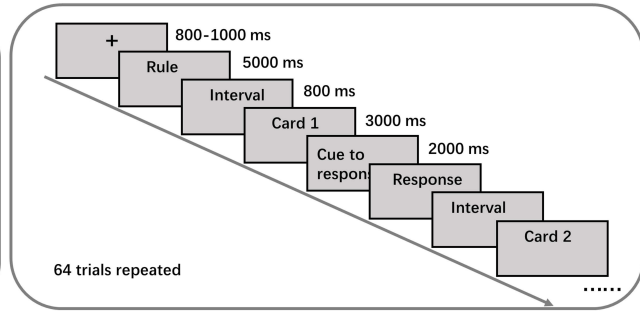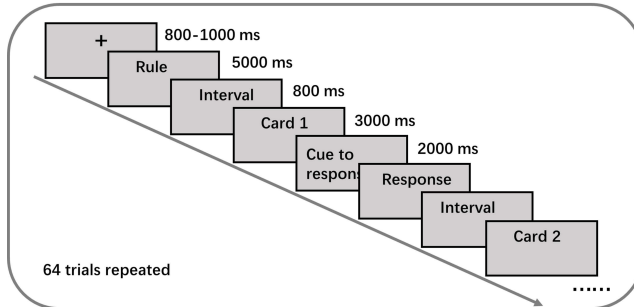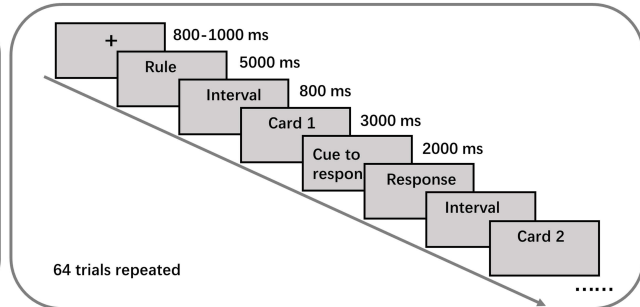
A The social contract type Wason Selection Task

B The precautionary type Wason Selection Task

C The descriptive type Wason Selection Task

D The abstract type Wason Selection Task

Figure 1 Schematic illustration of the Wason selection tasks: (**A**) social contract; (**B**) precautionary; (**C**) descriptive; and (**D**) abstract.

used the library") would be presented on the screen for 3,000 ms. When the card appeared on the screen, participants were asked to think logically, draw a conclusion about whether this card was a possible violation of the rule to complete the subsequent selection. Participants were asked to turn over the card by pressing "1" or pressing "2" if they decided not to turn over the card (half the participants had the opposite response keys to counterbalance this) without delay when the cue to respond appeared for 2,000 ms. Then after a duration fixation for 800 ms, the second card was presented. Breaks were given every 64 trials and the length of the break for each participant was based on individual preference. The Wason selection task was composed of one rule and four cards, for example, if the rule is "If P, then Q", the cards could be P, Q, not-P and not-Q. After fitting an EEG cap and reducing electrode impedance, the experimenter gave participants written instructions for the task. Participants were told to pretend to really have to investigate the situation described in the rules, then, for each card, ask themselves: "Would I need to see the information on the other side of this card in order to make a judgment?". If a sentence seems ambiguous, they were asked to use common sense – what we would really do if faced with this situation in real life. After participants read the instructions, the experimenter explained to the participants and asked them to do practice exercises. The explanations of experimenter are all the same to the extent that they do not interfere with the reasoning process of individuals. Then participants were given 16 practice trials of computer-based exercise which was given again if necessary. After the exercise, the formal experiment began. The four content types (social contract, precautionary, descriptive, and abstract) belong to experiment 1, experiment 2, experiment 3 and experiment 4, respectively. The eight rules (four trials for a type) went two rounds, and the corresponding cards were pseudorandom fixed in each experiment. During the whole experimental procedure, participants were instructed to remain still and to avoid head movements.

Reaction times (RTs) and accuracy were recorded for each trial in the four experiences. RT was defined as the time between the onset of the card and key pressing to select the answer. Accuracy was defined as the percentage of correct responses out of the total number of trials in each experience.

Electrophysiological Recording and Preprocessing

Electroencephalograms (EEGs, bandpass 0.05 Hertz (HZ) −100 HZ, digitized at 500 HZ) was recorded continuously with a 64-channel Ag-AgCl elastic cap based on the International 10/20 System using BioSemi Active Two system. The vertical electrooculogram (VEOG) was recorded with electrodes placed above and below the left eye and the horizontal electrooculogram (HEOG) with electrodes placed in the outer canthi of both eyes. The reference electrodes were the left

and right mastoids, and the ground electrodes were placed under the left clavicle site. All interelectrode impedances were maintained below 5 kΩ. In this study, the ERP waveforms were time-locked to the onset of each card. The epoch for ERP, including a 100 ms pre-card baseline, was 900 ms. After recording, data were processed offline using MatLab version 2020b (MathWorks, Inc.) with the EEGLAB toolbox. EEG data filtering including rejection and correction of atypical artifacts from eye movement, muscle, or cardiac components was done using independent component analysis (ICA).

Statistical Analyses

Statistical Program for Social Sciences software 22.0 (SPSS, IBM Corp., Armonk, NY, USA) was employed for the data statistical analysis. The comparisons of mean age (years), education (years), duration of illness (months) and age at onset were conducted between the schizophrenia patients and the normal controls with independent sample t-tests. The comparisons of handedness and sex ratio were conducted with the Pearson chi-squared test. A 2 Group (schizophrenia patient (SCZ) group vs normal control (NC) group) × 4 Experiment (experiment 1 vs experiment 2 vs experiment 3 vs experiment 4) repeated-measures analysis of variance (ANOVA) were employed to compare the accuracy and RTs. A three-way repeated-measures ANOVA were used to compare the mean amplitudes and the mean latencies of ERP components between the SCZ group and the NC group, using a Group (SCZ vs NC) × 4 Experiment (experiment 1 vs experiment 2 vs experiment 3 vs experiment 4) × 3 region of interest (ROI) (frontal lobe vs central lobe vs parietal lobe) as within-subject variables. The Greenhouse–Geisser method was used to correct the degrees of freedom of the F ratio. Effect sizes were also estimated using partial eta-squared (η^2). Bonferroni tests were performed as post hoc analyses if significant. The significance level was set at $p<0.05$.

Results

Demographic Characteristic Analysis of Participants

As shown in Table 1, there were no significant differences in mean age, mean education years, duration of illness or handedness between the schizophrenia patients and normal controls.

Table 1 Demographic Characteristics and Clinical Information

	SCZ (n=24)		NC (n=30)		Statistical Analysis	
	Mean	**SD**	**Mean**	**SD**	**t**	**p**
Age (years)	35.58	8.79	33.87	8.70	−0.71	0.48
Sex (M/F)	15/12		19/11		0.97 (χ^2)	0.33
Handedness (R/M/L)	7/8/7		10/8/12		0.86 (χ^2)	0.29
Education (years)	14.17	2.04	15.00	1.88	1.56	0.12
Age at onset (years)	24.33	6.77				
Duration of illness (months)	134.04	114.24				
Drug (mg/day, chlorpromazine equivalent)	301.27	192.79				
PANSS Positive scores	23.50	3.99				
PANSS Negative scores	20.63	5.89				
PANSS General scores	32.96	3.48				
PANSS Total scores	76.08	8.60				

Abbreviations: SCZ, schizophrenia patient group; NC, normal control group; SD, standard deviation; R, right; M, mixed; L, left; PANSS, Positive and Negative Syndrome Scale.

Analysis of Behavioral Data

Mean RTs and accuracy rate were calculated for each of the four experiments are shown in Table 2. The repeated measures ANOVA with 2 group (SCZ vs NC) as the between-subjects factor × 4 experiment (experiment 1 vs experiment 2 vs experiment 3 vs experiment 4) as the within-subjects factor showed a significant main effect of group for accuracy ($F_{(1, 52)}$=7.232, p=0.010, η^2=0.122). The accuracy in the NC group was higher than that in the SCZ group. There was also a significant main effect of experiment type for accuracy ($F_{(2, 115)}$=9.715, p<0.001, η^2=0.157). The accuracy in experiment 2 was substantially higher than that in experiments 3 and 4.

For RTs of target stimuli, the main effect of group was not significant ($F_{(1, 52)}$=0.029, p=0.865, η^2=0.001). The significant main effect of experiment was observed in RTs ($F_{(3, 137)}$=9.068, p<0.001, η^2=0.148). RTs in experiment 4 was shorter than that in experiments 1, 2, and 3.

Analysis of ERP Data

The average number of trials for ERP analyzing in experiment as shown in Table 3. There were no significant differences in experiments 1, 2, 3, and 4 between the SCZ and NC groups, respectively.

We selected frontal lobe site (F3, Fz, F4), central lobe site (C3, Cz, C4), and parietal lobe site (P3, Pz, P4) for the analysis. The grand average ERPs at frontal, central, and parietal regions are presented in Figure 2, and the grand averaged topographical distribution are presented in Figure 3. According to the grand average ERPs and referred from the previous reports,[15,16] the following components were analyzed: N1 (70–150 ms), P2 (150–250 ms), N2 (250–450 ms), P3 (450–600 ms), Slow wave (600–800 ms). Using the ERP components above as dependent variables, a series of 2 group (SCZ vs NC) × 4 experiment (experiment 1 vs experiment 2 vs experiment 3 vs experiment 4) × 3 ROI (frontal lobe vs central lobe vs parietal lobe) repeated-measures ANOVA was performed on mean amplitudes and latencies.

N1 Amplitudes

There was a significant interaction for group × experiment × ROI (Greenhouse–Geisser corrected, $F_{(2.976, 154.736)}$ =4.455, p=0.019, η^2=0.062). Further analysis showed at experiment 4 level, a significant simple effect for group was observed ($F_{(1, 52)}$=46.153, p<0.001, η^2=0.47), and post hoc tests revealed that in experiment 4, N1 amplitudes in NC group were higher than that in the SCZ group, while no group differences were observed in experiments 1, 2, or 3.

Table 2 Mean RTs and Accuracy Rate Were Calculated for Each of the Four Experiments (Mean ±SD)

	Experiment 1		Experiment 2		Experiment 3		Experiment 4	
	SCZ	**NC**	**SCZ**	**NC**	**SCZ**	**NC**	**SCZ**	**NC**
Accuracy	0.48±0.13	0.58±0.17	0.52±0.17	0.65±0.27	0.44±0.11	0.51±0.21	0.42±0.11	0.55±0.19
RTs (ms)	660±157	633±178	612±160	585±171	598±166	613±183	571±181	540±173

Abbreviations: SCZ, schizophrenia patient group; NC, normal control group; SD, standard deviation.

Table 3 The Average Number of Trials for ERP Analyzing

	SCZ		NC		Statistical Analysis	
	Mean	**SD**	**Mean**	**SD**	**t**	**p**
Experiment 1	50.79	14.40	54.90	8.58	1.234	0.225
Experiment 2	51.08	8.91	50.93	10.45	−0.056	0.096
Experiment 3	53.29	13.59	51.23	9.83	−0.646	0.521
Experiment 4	49.00	12.70	51.20	13.04	0.623	0.536

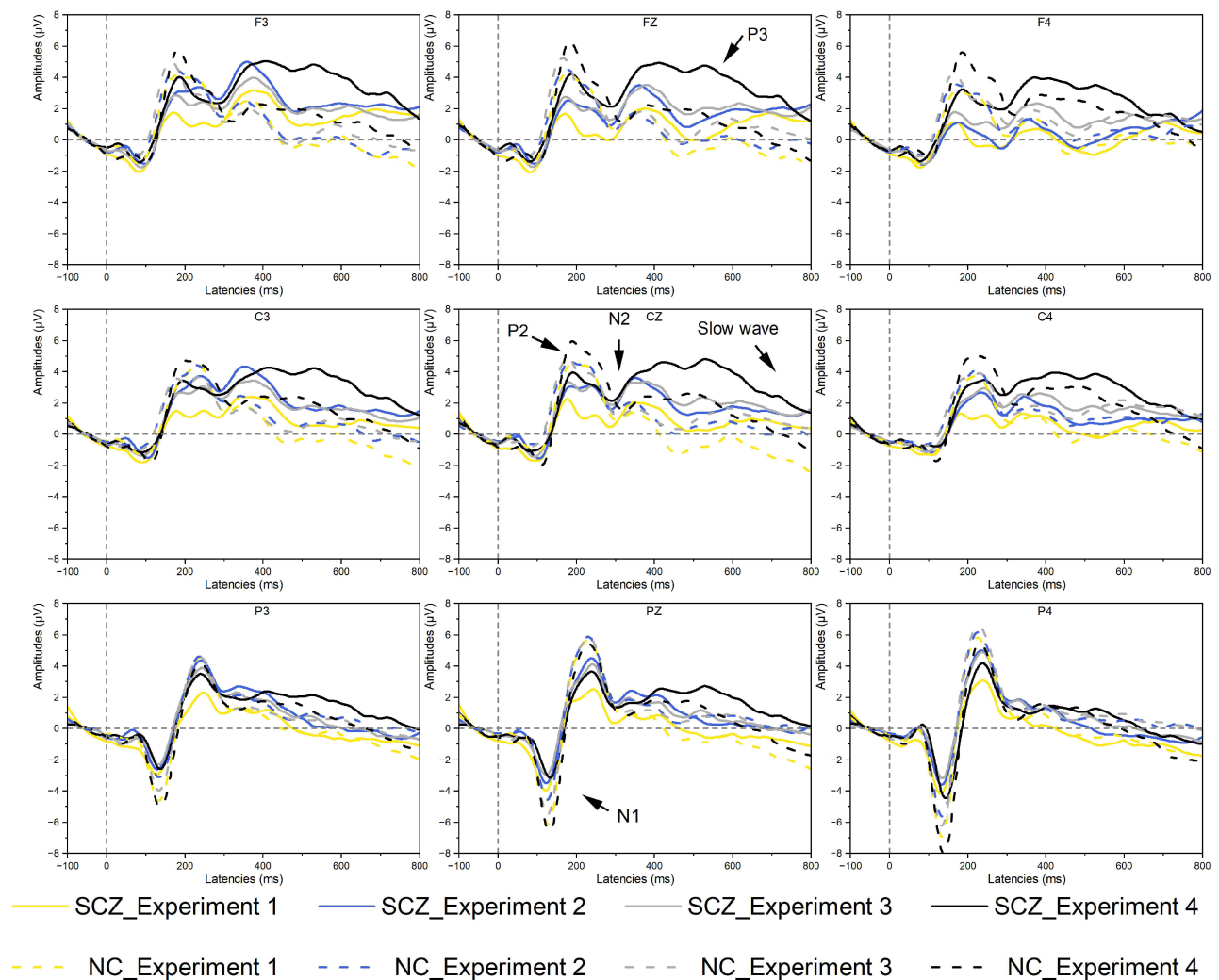**Abbreviations**: SCZ, schizophrenia patient group; NC, normal control group; SD, standard deviation.

Figure 2 Grand averaged ERPs of both SCZ and Normal control groups under different experiments (experiment 1, 2, 3, and 4) of the pooling electrodes site (frontal lobe site (F3, Fz, F4), central lobe site (C3, Cz, C4), and parietal lobe site (P3, Pz, P4)). As signed at Cz site, the N1 time window range are from 70 to 150 milliseconds (ms); the N2 time window range is 250–450 ms, the P3 time window range is 450–600 ms, the slow wave time window range is 600–800 ms. SCZ, schizophrenia group; NC, normal control group. Experiment 1, social contract type Wason selection task; Experiment 2, precautionary type Wason selection task; Experiment 3, descriptive type Wason selection task; Experiment 4, abstract type Wason selection task.

N1 Latencies

There was a significant interaction for group × ROI (Greenhouse–Geisser corrected, $F_{(1.559, 81.056)}$=4.455, p=0.022, η^2=0.079). Further analysis showed that no simple effect for group was observed, however, at group level, the simple effect for ROI was significant (for NC group: $F_{(2, 51)}$=47.855, p<0.001, η^2=0.652; for SCZ group: $F_{(2, 51)}$=15.673, p<0.001, η^2=0.381). Post hoc analyses revealed that for both NC group and SCZ group, N1 latencies in parietal lobe were longer than that in frontal lobes and in central lobes.

P2 Amplitudes

There was not significant interaction for group × experiment × ROI (Greenhouse–Geisser corrected, $F_{(3.007, 156.380)}$=0.328, p=0.806, η^2=0.006). However, there was a main effect for group ($F_{(1, 52)}$=6.313, p=0.015, η^2=0.108). Post hoc analyses showed that the amplitudes in the NC group was higher than that in the SCZ group.

P2 Latencies

There was a significant interaction for group × experiment ($F_{(3, 156)}$=3.773, p=0.012, η^2=0.068). Further analyses showed that at group level, the simple effect of experiment was significant ($F_{(3, 50)}$=3.709, p=0.017, η^2=0.182) in the NC group,
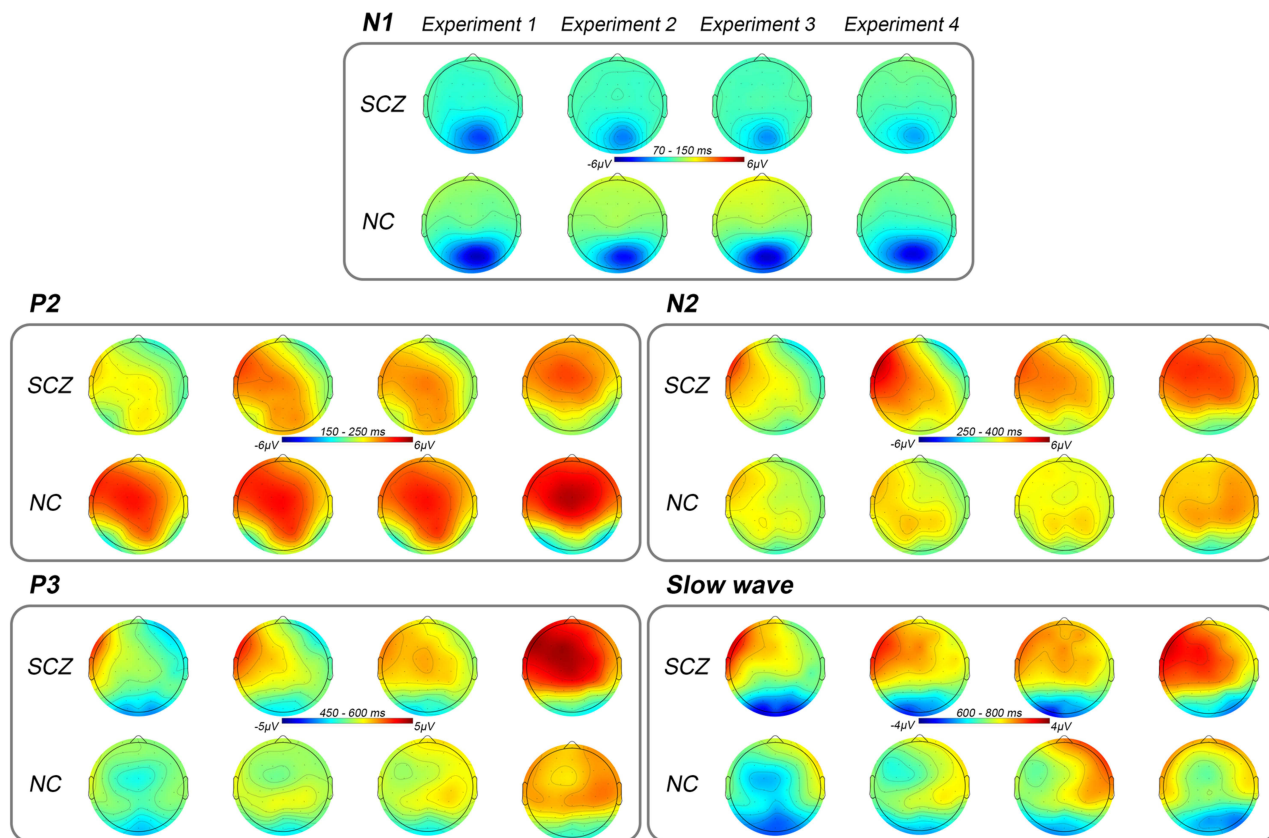
Figure 3 Topographical distribution of grand averaged N1, P2, N2, P3, and slow wave within a time window of 70–150 ms (N1), 150–250 ms (P2), 250–450 ms (N2), 450–600 ms (P3), and 600–800 ms (slow wave) post-stimuli under different experiments. SCZ, schizophrenia group; NC, normal control group. Experiment 1, social contract type Wason selection task; Experiment 2, precautionary type Wason selection task; Experiment 3, descriptive type Wason selection task; Experiment 4, abstract type Wason selection task.

Post hoc analyses showed that P2 latencies both in experiments 1 and 4 were longer than that in experiment 3. However, the simple effect of group was not significant (all $p>0.05$).

N2 Amplitudes

There was not significant interaction for group × experiment × ROI ($F_{(3.271, 170.093)}=0.444$, $p=0.738$, $\eta^2=0.008$). However, there was a significant interaction for experiment × ROI ($F_{(3.271, 170.093)}=7.972$, $p<0.001$, $\eta^2=0.133$), and further analyses showed that at ROI level, the simple effect of experiment were significant (for frontal lobe: $F_{(3, 50)}=6.729$, $p=0.001$, $\eta^2=0.288$; for central lobe: $F_{(3, 50)}=6.145$, $p=0.001$, $\eta^2=0.269$; for parietal lobe: $F_{(3, 50)}=3.002$, $p=0.039$, $\eta^2=0.153$), and post hoc analyses showed that at parietal lobe, the N2 amplitudes in experiment 1 were higher than that in experiment 2 ($p=0.048$); at frontal lobe, N2 amplitude in experiment 1 ($p<0.001$), experiment 2 ($p=0.003$) and experiment 3 ($p=0.015$) was higher than that in experiment 4. At experiment level, the simple effect of ROI was significant (for experiment 1: $F_{(2, 51)}=0.453$, $p=0.638$, $\eta^2=0.017$; for experiment 2: $F_{(2, 51)}=4.195$, $p=0.021$, $\eta^2=0.141$; for experiment 3: $F_{(2, 51)}=3.230$, $p=0.048$, $\eta^2=0.112$; for experiment 4: $F_{(2, 51)}=11.324$, $p<0.001$, $\eta^2=0.308$), and post hoc analyses showed that in experiment 4, N2 amplitudes in parietal lobe were higher than that in central lobe ($p=0.001$).

N2 Latencies

There was a significant interaction for group × experiment (Greenhouse–Geisser corrected, $F_{(2.225, 115.725)}=11.120$, $p<0.001$, $\eta^2=0.176$). Further analysis revealed that the simple effect of NC group was significant ($F_{(3, 50)}=15.089$, $p<0.001$, $\eta^2=0.475$), and the simple effect of SCZ group was significant ($F_{(3, 50)}=2.821$, $p=0.048$, $\eta^2=0.145$). Post hoc analyses revealed that at group level for NC group, the latencies in experiment 1 were longer than that in experiments 2, 3, and 4 respectively (all $p<0.001$), and for SCZ group, the latencies in experiment 4 were longer than that in experiment 2 ($p=0.042$); At experiment

level, the latencies in NC group were longer than that in SCZ group for experiment 1 (p=0.010); the latencies in NC group were lower than that in SCZ group for experiments 2, 3, and 4 (p=0.009, 0.011, 0.002).

The interaction for group × ROI was significant (Greenhouse–Geisser corrected, $F_{(1.417, 73.665)}$=4.925, p=0.019, η^2=0.087). Further analyses revealed that at ROI level, the simple effect of group was significant in the frontal lobe ($F_{(1, 52)}$=8.459, p=0.005, η^2=0.140), and the central lobe ($F_{(1, 52)}$=6.203, p=0.016, η^2=0.107), but not the parietal lobe ($F_{(1, 52)}$=0.005, p=0.946, η^2=0.000), and post hoc analyses showed that the latencies in the NC group were shorter than in the SCZ group in the frontal lobe and central lobe. At group level, the simple effect of ROI was significant (for NC group: $F_{(2, 51)}$=4.603, p=0.015, η^2=0.153; for SCZ group: $F_{(2, 51)}$=19.115, p<0.001, η^2=0.428). In NC group, N2 latency was shorter in parietal lobe than that in frontal (p=0.01) and central lobes (p=0.044). In SCZ group, N2 latencies were shorter in parietal lobe than that in frontal and central lobes.

P3 Amplitudes

There was not significant interaction for group × experiment × ROI (Greenhouse–Geisser corrected, $F_{(3.399, 176.747)}$=0.444, p=0.762, η^2=0.008). The main effect of group was significant (Greenhouse–Geisser corrected, $F_{(1, 52)}$=4.556, p=0.038, η^2=0.081). Post hoc analyses revealed that the amplitude was lower in the NC group than that in the SCZ group.

P3 Latencies

There was not significant interaction for group × experiment × ROI (Greenhouse–Geisser corrected, $F_{(4.345, 225.954)}$=1.320, p=0.261, η^2=0.025). There was main effect for ROI (Greenhouse–Geisser corrected, $F_{(1.527, 79.404)}$=7.041, p=0.004, η^2=0.119), and post hoc analyses revealed that the latencies in parietal lobe were lower than that in frontal and central lobes.

Slow Wave Amplitudes

There was significant interaction for group × ROI (Greenhouse–Geisser corrected, $F_{(1.180, 61.383)}$=4.712, p=0.028, η^2=0.083). Further analyses showed that at ROI level, the simple effect of group was significant in the frontal lobe ($F_{(1, 52)}$=9.338, p=0.004, η^2=0.152), and the central lobe ($F_{(1, 52)}$=8.117, p=0.006, η^2=0.135), but not in the parietal lobe ($F_{(1, 52)}$=0.413, p=0.523, η^2=0.008). Post hoc analyses showed that the amplitude in the NC group was lower than that in the SCZ group.

Slow Wave Latencies

There was nonsignificant interaction between group, experiment and ROI (Greenhouse–Geisser corrected, $F_{(2.681, 139.405)}$=0.868, p=0.449, η^2=0.016). The interaction between group and experiment was not significant (Greenhouse–Geisser corrected, $F_{(2.300, 119.609)}$=1.427, p=0.243, η^2=0.027). The interaction between experiment and ROI (Greenhouse–Geisser corrected, $F_{(2.681, 139.405)}$=2.478, p=0.071, η^2=0.045). The interaction between group and ROI was not significant (Greenhouse–Geisser corrected, $F_{(1.547, 80.438)}$=0.069, p=0.891, η^2=0.001).

Discussion

This study is the first to investigate ERP characteristics of the conditional reasoning in schizophrenia patients. The Wason selection task, a cornerstone in cognitive psychology, serves as a tool to investigate deductive reasoning processes. In our study, performance metrics such as accuracy and RTs were analyzed to understand the differences between normal controls and schizophrenia patients across various rule types of the task. Results showed that normal controls consistently outperformed schizophrenia patients in terms of accuracy. This suggests that healthy individuals may have a more efficient or intact reasoning process when tackling the Wason selection task compared to those with schizophrenia. In addition, among the different types of the task, the precautionary type experiment yielded the highest accuracy rates. In contrast, both the descriptive and abstract type experiments resulted in lower accuracy. This indicates that the nature or context of the task can significantly influence reasoning performance, with precautionary scenarios potentially being more intuitive or relatable for participants. When considering RTs for target stimuli, the abstract type experiment stood out, with participants registering the shortest RTs among the four experiments. This suggests that, despite its potentially challenging nature, the abstract type of the task might prompt quicker decision-making or response initiation.

The observed performance patterns in the Wason selection task underscore the cognitive differences between normal controls and schizophrenia patients. Furthermore, the variations in accuracy and RTs across different task types highlight

the influence of task context on reasoning processes. Such findings contribute to our understanding of the cognitive mechanisms underlying deductive reasoning and the potential impact of psychiatric conditions like schizophrenia on these processes.

Numerous studies have demonstrated that individuals with schizophrenia often exhibit impairments in conditional reasoning tasks compared to healthy controls. This deficit persists even when controlling for general cognitive decline. For example, a study investigated the counterfactual thinking in schizophrenia patients, and results indicated that patients present the reasoning of mental representations of alternatives to past factual events even when they are in symptomatic remission.[17] Another study using an exploratory approach examined the counterfactual thinking for the first time in a sample of nonpsychotic first-degree relatives of schizophrenia patients, and results suggested that nonpsychotic first-degree relatives of schizophrenia patients displayed a subtle disruption of global counterfactual thinking.[18] Moreover, there is evidence that the nature and severity of delusions in schizophrenia might influence conditional reasoning performance. For instance, patients with more bizarre delusions tend to make more reasoning errors.[19] In addition, a previous study indicated that healthy people perform poorly on the descriptive or abstract type Wason selection task, but they perform well on the social contract or precautionary type Wason selection task.[20]

Compared with previous studies, our study not only analyzed the behavioral data of the participants when they performed The Wason selection task, but also analyzed the ERP data in detail. Consistent with extant literature,[17–20] our empirical analysis on the accuracy of behavioral outcomes indicated that the control group exhibited proficiency in precautionary type tasks, yet their performance was notably deficient in tasks of a descriptive and abstract nature. Parallel findings were observed in schizophrenia patients, who also demonstrated compromised conditional reasoning abilities in both descriptive and abstract variants of the Wason selection task, thereby corroborating the patterns documented in previous scholarly investigations.[6,11,12]

In healthy individuals, ERP studies on the Wason selection task have illuminated the neural dynamics underlying this classic reasoning problem. By capturing the temporal progression of cognitive processes, these studies offer a window into the brain's mechanisms for deductive reasoning.[9,10,15] In this study, distinct ERP patterns were observed between NC and SCZ groups across different experiment types of the Wason selection task. In the abstract rule type of the Wason selection task, the NC group exhibited higher amplitudes for both the N1 and P2 components compared to the SCZ group. This suggests that the initial processing and attentional engagement might differ between the two groups during abstract reasoning. At the parietal lobe, the N2 amplitude was higher for the social contract type of the task compared to the precautionary version. In contrast, at the frontal lobe, the N2 amplitude was highest for the abstract type of the task. Furthermore, in the abstract type, the N2 amplitude at the parietal lobe was higher than that at the central lobe. This indicates that the neural processing of different task variations might be region-specific and highlights the role of the parietal and frontal regions in different reasoning contexts. The NC group displayed lower amplitudes for both the P3 and slow wave components compared to the SCZ group. These components, reflecting sustained processing of the cognitive process, often associated with decision-making and cognitive evaluation, suggest potential differences in the cognitive strategies or processing efficiency between the two groups.

Significant differences were observed between the NC and SCZ groups in terms of the latencies for N1, P2, N2, P3, and slow wave components across different experiment types and regions of interest. These latency differences underscore the temporal disparities in cognitive processing between the two groups.

Limitations

Our research has some limitations that need to be noted. First, the outcome of this study is preliminary because of the modest sample size. Second, due to the small sample size of our study, it is not conducive to include factors such as patients' clinical status, course of disease and medication regimen for comparison and interpretation of statistical results. In the future, it is necessary to use large samples, use the same parameters, and take into account the above factors for the analysis of results. Third, there is a potential practice effect when subjects perform different experiments. In the future, the four experiments of conditional reasoning need to apply random methods to develop experimental procedures to eliminate this practical effect and further validate the results of this study. Fourth, due to the deficient spatial resolution of

ERPs, further studies with other neuroimaging techniques should be conducted to clarify the neural mechanism of cognitive processing deficits of conditional reasoning in schizophrenia.

Conclusion

In conclusion, the observed ERP patterns provide valuable insights into the neural mechanisms underlying the Wason selection task, highlighting the differences between normal controls and individuals with schizophrenia. The distinct ERP components and their variations across task types and brain regions emphasize the intricate interplay between cognitive processes, task demands, and neural activity. Conditional reasoning deficits in schizophrenia offer a window into the cognitive disturbances experienced by these patients. Unraveling the mechanisms and manifestations of such deficits could pave the way for improved treatments and better quality of life for individuals with schizophrenia. In other words, by performing the Wason selection task on patients with schizophrenia, this study proved that the conditioned reasoning function deficit in patients with schizophrenia has a neural basis, that is, the cerebral cortical function deficit. It is suggested that treatment methods to improve cerebral cortex function, such as repeated transcranial magnetic stimulation, should be used to intervene in schizophrenia. As the field advances, it will be exciting to see how newer techniques and paradigms further refine our understanding of the neural basis of the Wason selection task.

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Disclosure

The authors report no conflicts of interest in this work.

References

1. Kahn RS, Sommer IE, Murray RM, et al. Schizophrenia. *Nat Rev Dis Primers*. 2015;1:15067. doi:10.1038/nrdp.2015.67
2. Gebreegziabhere Y, Habatmu K, Mihretu A, et al. Cognitive impairment in people with schizophrenia: an umbrella review. *Eur Arch Psychiatry Clin Neurosci*. 2022;272(7):1139–1155. doi:10.1007/s00406-022-01416-6
3. Wang M, Yan H, Tian X, et al. Neuroimaging and multiomics reveal cross-scale circuit abnormalities in schizophrenia. *Nat Mental Health*. 2023;1:633–654. doi:10.1038/s44220-023-00110-3
4. Gazzo Castañeda LE, Sklarek B, Dal Mas DE, et al. Probabilistic and deductive reasoning in the human brain. *Neuroimage*. 2023;275:120180. doi:10.1016/j.neuroimage.2023.120180
5. Boissonnade R, Tartas V, Guidetti M. Toward a cultural-historical perspective on the selection task. *Integr Psychol Behav*. 2014;48(3):341–364. doi:10.1007/s12124-014-9256-4
6. Kornreich C, Delle-Vigne D, Brevers D, et al. Conditional reasoning in schizophrenic patients. *Evol Psychol*. 2017;36(2):321–330. doi:10.1177/1474704917721713
7. Canessa N, Pantaleo G, Crespi C, et al. The impact of egocentric vs. allocentric agency attributions on the neural bases of reasoning about social rules. *Brain Res*. 2014;1581:40–50. doi:10.1016/j.brainres.2014.06.001
8. Hearne L, Cocchi L, Zalesky A, et al. Interactions between default mode and control networks as a function of increasing cognitive reasoning complexity. *Hum Brain Mapp*. 2015;36(7):2719–2731. doi:10.1002/hbm.22802
9. Li B, Zhang M, Luo J, et al. The difference in spatiotemporal dynamics between modus ponens and modus tollens in the Wason selection task: an event-related potential study. *Neuroscience*. 2014;270:177–182. doi:10.1016/j.neuroscience.2014.04.007
10. Cai X, Li F, Wang Y, et al. Electrophysiological correlates of hypothesis evaluation: revealed with a modified Wason's selection task. *Brain Res*. 2011;1408:17–1426. doi:10.1016/j.brainres.2011.06.056
11. Moritz S, Woodward TS, Hausmann D. Incautious reasoning as a pathogenetic factor for the development of psychotic symptoms in schizophrenia. *Schizophr Bull*. 2006;32:327–331. doi:10.1016/j.brainres.2011.06.056
12. Sellen JL, Oaksford M, Gray NS. Schizotypy and conditional reasoning. *Schizophr Bull*. 2005;31:105–116. doi:10.1093/schbul/sbi012
13. Thippaiah SM, Rachel E, Fargason B. Switching antipsychotics: a guide to dose equivalents. *Curr Psychiatry*. 2021;20(4):13–14.
14. Ermer E, Guerin SA, Cosmides L, et al. Theory of mind broad and narrow: reasoning about social exchange engages ToM areas, precautionary reasoning does not. *Soc Neurosci*. 2006;1(3–4):196–219. doi:10.1080/17470910600989771
15. Cutmore TR, Halford GS, Wang Y, et al. Neural correlates of deductive reasoning: an ERP study with the wason selection task. *Int J Psychophysiol*. 2015;98(3 Pt 1):381–388. doi:10.1016/j.ijpsycho.2015.07.004
16. Luck SJ. *An Introduction to the Event-Related Potential Technique*. Boston: MIT Press; 2005:pp388.
17. Albacete A, Contreras F, Bosque C. Symptomatic Remission and Counterfactual Reasoning in Schizophrenia. *Front Psychol*. 2017;7:2048. doi:10.3389/fpsyg.2016.02048
18. Albacete A, Contreras F, Bosque C. Counterfactual reasoning in non-psychotic first-degree relatives of people with schizophrenia. *Front Psychol*. 2016;7:665. doi:10.3389/fpsyg.2016.00665

19. Simpson J, Done DJ. Analogical reasoning in schizophrenic delusions. *Eur Psychiatry.* 2004;19(6):344–348. doi:10.1016/j.eurpsy.2004.05.009

20. Cosmides L, Tooby J. Neurocognitive adaptations designed for social exchange. In: Buss DM, editor. *Handbook of Evolutionary Psychology.* Hoboken, NJ: John Wiley & Sons; 2005:pp584–627.