Response randomization of one- and two-person Rock–Paper–Scissors games in individuals with schizophrenia

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ABSTRACT

Randomization among successive choices is important in adaptive decision-making, particularly for strategic interactions in which the optimal strategy is a mixed strategy. Patients with schizophrenia have been reported to have deficits in random sequential behaviors arising from impaired executive function. However, whether schizophrenic patients exhibit distinct behaviors for response randomization in one- and two-person games requiring different behavioral strategies is not known. The aim of this study was to examine the response randomization of 48 schizophrenic patients and 50 healthy subjects in one- and two-person Rock–Paper–Scissors games. Here we found that the schizophrenic patients exhibited non-random biases distinct from those of the healthy subjects (i.e., stereotypic switching in the one-person game and the tendency to choose the best response against the opponent's previous choice in the two-person game). The entropy of the choice sequences was prominently decreased in the schizophrenic patients for both games, thereby indicating an overall disturbance in the behavioral randomization in adaptive decision-making. These results suggest that the impairment of response randomization in schizophrenic patients manifests differently in interactive and non-interactive situations, which may be useful for the diagnosis and quantification of the severity of the disease.

1. Introduction

Decision-making is a complex process that requires various cognitive functions such as working memory, cognitive–behavioral flexibility, adaptive learning, and executive control. In addition, decision-making in interpersonal settings engages aspects of social cognition such as theory of mind. Because schizophrenia is characterized by psychotic (i.e., positive and negative) symptoms and overall cognitive deficits including dysfunction in social interactions and poor executive function (Yudofsky and Hales, 2008), impaired decision-making is a major problem in schizophrenic patients that restricts social and occupational functioning (Kim et al., 2007). Patients with schizophrenia have been specifically reported to suffer from difficulties in strategic decision-making in social games (Agay et al., 2008; Chung et al., 2011), because the outcome is dependent not only on the individual's own choice but also on the opponent's choice and social interactions during the games.

Game theory has provided a theoretical framework in which such a strategic interaction between multiple agents can be rigorously analyzed. According to game theory, randomization among successive choices (i.e., a mixed strategy) is often the optimal strategy for each player in competitive settings. The Rock–Paper–Scissors (RPS) game is a well-known example of such games. In the RPS game, if both players choose randomly among rock, paper, and scissors with the same probability of 1/3, neither of the two players can increase the probability of winning by a change in strategy because the winning probability of every choice is equal (i.e., 1/3). However, if an individual deviates from the mixed strategy where rock, paper, and scissors are chosen with equal probability, the opponent can exploit it. Thus, the players must randomize their choices to make it difficult to predict their choice from their previous play.

However, even healthy subjects show poor performance in response randomization. In this type of game, the players are asked to generate a sequence of responses that is as random as possible by button press, or in verbal or written form. Human players tend to perform too few repetitions of the same choice and too many shifts among consequent responses (Wagenaar, 1972). Response randomization has been suggested to be associated with various executive functions, including the inhibition of prepotent responses. 'Random number generation' experiments with healthy subjects and various neuropsychiatric populations have shown that intact executive function and working memory are important for the

randomization of responses, and patients with brain lesions, dementia, and schizophrenia therefore show impaired random number generation compared with healthy subjects (Spatt and Goldenberg, 1993; Brugger et al., 1996; Salamé et al., 1998; Peters et al., 2007; Salamé and Danion, 2007). In particular, schizophrenic patients show stereotypic responses that are often characterized by nonrandom, sequential responses in order (Morrens et al., 2006).

Interestingly, randomization behavior in competitive games has been found to be distinct from the randomization behavior during instructed response randomization tasks (Rapoport and Budescu, 1992; Budescu and Rapoport, 1994). Individuals generate more random sequences of choice when they are trying to maximize their gain in the competitive games than when they are intentionally generating a sequence of random choices, which implies that the cognitive processes underlying randomization behaviors in multi-agent competitive games (e.g., two-person games) and in a one-person random response generation task differ. The one-person game, i.e., a random response generation task, requires executive function and working memory to adjust the current choice against the sequence of the previous choices (Budescu and Rapoport, 1994; Rapoport and Budescu, 1997). In contrast, the strategic interaction in two-person, competitive games requires adaptive learning and the mentalization of the opponent's state of mind to predict the next choice of the opponent (Hampton et al., 2008).

Few studies have addressed the impairment in schizophrenic patients performing adaptive decision-making tasks, and the randomization behavior of the schizophrenic patients has not yet been investigated in the context of one- and two-person games. Paulus et al. (1994, 1999a, 1999b, 2002) examined the behavioral complexity and temporal correlations in choice sequences of schizophrenic patients using a two-choice prediction. In that task, the subjects were asked to predict the location of stimuli (i.e., left or right) which was randomly determined by a computer. However, there was no incentive for the randomization in this task because it was not a competitive game with the adaptive opponents. Another study used the matching penny game (Kim et al., 2007) to focus on the updating of the strategy depending on the outcome, but it was conducted with a computer opponent. The different magnitudes of risk in the two alternatives may be a complicating factor in schizophrenic patients with limited cognitive capacity. Additionally, there was no parallel one-person game task.

Here, we aimed to investigate the cognitive deficits in schizophrenic patients that limit optimal decision making, i.e., response randomization in competitive games, using the one- and two-person Rock–Paper–Scissors (RPS) games. The one-person RPS game consists of response randomization among rock, paper and scissors, and the two-person RPS game is a conventional two-person competitive RPS game. RPS is a familiar game, which

should thus prevent any confounding effect related to the learning of a new task. We hypothesized that the randomization behaviors in the RPS game would be disturbed in schizophrenic patients when compared with healthy subjects in the one-person game and the two-person game because of deficits in executive function and impaired mentalizing, respectively. If our results support our hypothesis, the one- and two-person RPS games may be a simple tool for the measurement of executive function and social cognition in schizophrenic patients.

2. Methods

2.1. Subjects

Forty-eight schizophrenic patients and 50 healthy subjects participated in this study. The patients were recruited from Bugok National Hospital, and the healthy subjects were from the local community. The patients and healthy subjects in this study had no history of neurological disorders such as seizure, stroke, head injury, or substance use other than caffeine or nicotine. Table 1 provides the demographic and clinical characteristics of the two groups. There were no significant differences between the two groups in terms of age, gender, and years of education. All participants provided informed consent prior to their participation in this study and were paid a certain honorarium. The entire experimental procedure was conducted under a protocol approved by the Institutional Review Board (IRB) of Bugok National Hospital.

The diagnosis of schizophrenia in the patient group was established using the Structuredl Clinical Interview for the DSM-IV (SCID-IP) (First et al., 1995) and a comprehensive review of medical records. To assess the severity of positive and negative symptoms, the Positive and Negative Syndrome Scale (PANSS) (Kay et al., 1986) was applied to the patients. Forty-four patients were taking stable dosages of atypical antipsychotics such as aripiprazole, amisulpiride, clozapine, olanzapine, quetiapine, risperidone, and ziprasidone. Two patients were taking haloperidol, and another two were taking haloperidol in addition to an atypical medication. The chlorpromazine-equivalent dose (Woods, 2003; Genç et al., 2007) of the medication was 465.0 ± 268.0 mg daily (mean $\pm$ standard deviation).

2.2. Procedures

The behavioral experiment consisted of two parts: the one-person and two-person Rock–Paper–Scissors (RPS) game. In the one-person game, the subjects were asked to make their choices among rock, paper, and scissors as randomly as possible. The choices were made using a personal computer (PC) keyboard (i.e., key 1, 2, and 3 for scissors, rock, and paper, respectively) according to the order of the Korean version of the RPS game. In total, 100 choices were made and recorded for each subject without any time restrictions. This task was used to assess the ability to generate random sequences of RPS choices.

Subsequently, two subjects from the same group were matched for participation in the two-person RPS game. In total, 100 trials of the RPS game were conducted for a pair of players. In each trial of the RPS game, the choice of each subject was made using a PC as described above for the one-person game, and then the choice of both subjects, the outcome of the game (win, draw or loss), and the total number of wins for each player were displayed in the monitor. A total of 1000 KRW (approximately 1$ US) for each win exceeding the number of losses was paid for each player; the players were notified of the payment system at the start of experiment. Thus, each subject earned 1000 KRW per win and lost 1000 KRW per loss, but a total net loss (i.e., a balance of less than 0 KRW at the end of the experiment) was ignored.

Table 1
Demographic and clinical characteristics of schizophrenia patients and control subjects.

| Variables	Control (n=50)		Schizophrenia (n=48)		Significance level
	Mean	S.D.	Mean	S.D.	
Age (years)	37.2	7.9	38.3	7.9	$t(96)=0.69$, n.s.
Gender (male/female)	26/24		25/23		$\chi^2(1)=0.00$, n.s.
Education (years)	13.5	2.3	12.7	2.5	$t(96)=-1.77$, n.s.
Duration of illness (years)			14.1	7.6	
Age of onset			24.5	6.1	
Positive and Negative Syndrome Scale scores					
Positive score			20.5	3.2	
Negative score			21.4	2.8	
General psychopathology score			41.2	4.4	
Total score			83.1	7.2	
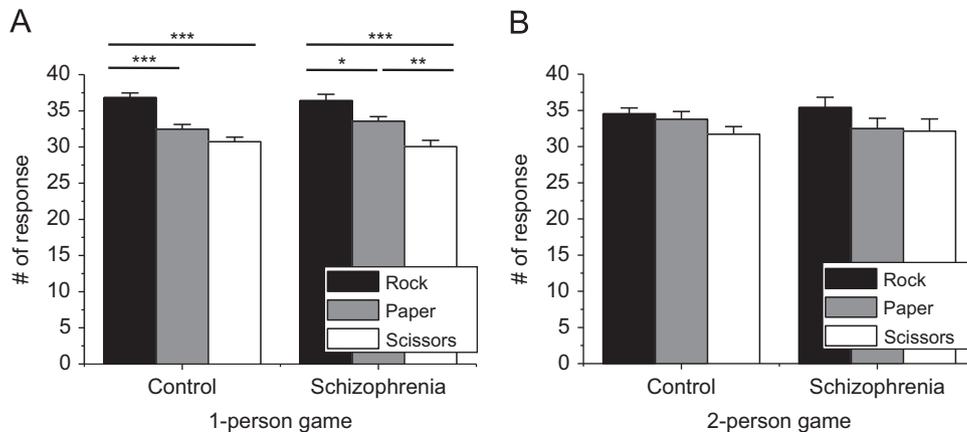
Fig. 1. The number of rock, paper, and scissors in the choices (mean ± SEM). R: rock (black), P: paper (gray), S: scissors (white). Both groups preferred rocks over other choices in the one-person game, but not in the two-person game. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, Tukey's test (post hoc).

2.3. Behavioral measures and statistical analyses

The overall performance was assessed for the following variables: (1) The number of choices of rock, paper, and scissors in the one- and two-person games; and (2) The number of wins, draws, and losses in the two-person game. The frequencies of choice for rock, paper, and scissors were compared using a one-way analysis of variance (ANOVA) with Tukey's test for post hoc analysis. The difference between the schizophrenic patients and healthy subjects was examined using Student's t-test (two-tailed).

The serial dependence among choices was described using the terms of ascending, repeating, and descending order. Ascending choice was used to indicate sequential choices in the order of rock–paper, paper–scissors, and scissors–rock. Descending choice was used to indicate sequential choices in the opposite order. Repeating choice was used to indicate the same choice as the preceding choice. Each choice was classified as ascending, repeating, or descending with respect to the preceding choice. The frequencies of the ascending, repeating, and descending choices were examined using one-way ANOVA with Tukey's test used for post hoc analysis.

The dependence on the opponent's preceding choice was described using Cournot dynamics (Lee et al., 2005). In the RPS game, the Cournot best response (CBR) is the choice that wins against the opponent's previous choice, for example, rock for scissors. The Cournot second-best response (CSBR) in the RPS game is the choice that results in a draw with the opponent's previous choice. The Cournot worst response (CWR) is the choice that loses to the opponent's previous choice. The frequencies of the CBR, CSBR, and CWR were compared using a one-way ANOVA with Tukey's test for post hoc analysis.

To test the higher-order sequential dependency, we examined the distribution of successive two- and three-tuples. Successive m-tuples were collapsed into m-patterns (for $m = 2, 3$) that did not distinguish among rock, paper, and scissors. For example, the 3-pattern xyz represents (R,P,S), (R,S,P), (P,S,R), (P,R,S), (S,R,P), and (S,P,R). Each 3-tuple has an expected probability of 1/27; thus, the expected probability of the 3-pattern xyz is 6/27. The numbers of 2-patterns and 3-patterns observed for the choice sequences were examined across subjects and compared among tasks and groups using Student's t-test (two-tailed test).

The degree of randomness in the choice sequences was quantified using the entropy. If there are k possible outcomes and the probability of the ith outcome is P_i, the entropy H is defined by the following:

$$H = -\sum_{i=1}^{k} P_i log_2 P_i \ (bits).\tag{1}$$

In this study, the entropy was estimated using the player's choice sequence in two successive trials, so there were nine (i.e., 3^2) possible outcomes, and the maximum entropy was 3.17 bits. The entropy in the choice sequences from the two groups was compared using the Mann–Whitney U test.

To determine whether specific biases in the RPS game behavior are associated with psychiatric symptoms, Pearson's correlation coefficient was estimated between each subscale score of the PANSS and the following behavioral measures: the number of rock, paper, and scissors choices; the number of wins, draws, and losses; the frequency of ascending, repeating, descending choice; the frequency of CBR, CSBR, CWR; the frequency of 2- and 3-tuple patterns; and the entropy of the choice sequence. The correlation between the amount of medication (in chlorpromazine equivalents) and the behavioral measures was also tested in the same way.

We considered significance for $p < 0.05$ in all statistical tests. Bonferroni correction for multiple comparisons was applied in testing correlation between PANSS and behavioral task performances.

3. Results

The frequencies of the rock, paper, and scissors choices in both groups are shown in Fig. 1. Both groups preferred rock over paper and scissors in the one-person game (Tukey's test, $p < 0.05$), possibly because of the key location (key 2, which was used for rock, was between keys 1 and 3, which were used for scissors and paper, respectively). However, this preference disappeared in the two-person game. We found no significant differences between schizophrenic patients and healthy subjects in the frequencies of choice for rock, paper, and scissors in the one- and two-person games (t-test, $p > 0.19$). In addition, the number of wins, draws, and losses was not different between the two groups (data not shown).

The serial dependence between the successive choices of the subjects is depicted in terms of the ascending, repeating, and descending choice in Fig. 2. In the one-person game, the healthy subjects tended to avoid repeating choice when compared with ascending and descending choice (Tukey's test, $p < 0.001$). In contrast, the schizophrenic patients showed biases toward ascending choice (Tukey's test, $p < 0.001$). Thus, the schizophrenic patients preferred to shift their choice in successive trials in one direction, i.e., to the order of rock–paper–scissors–rock. However, this bias in the successive choices disappeared in the two-person game.

The serial dependence in the choice sequences was also assessed according to the frequency of patterns in successive 2- and 3-tuples, as depicted in Table 2. The overall frequencies of each pattern were not different between the schizophrenic patients and healthy subjects (t-test, $p > 0.1$). The healthy subjects showed more xy patterns, i.e., a shift between successive trials, in the one-person game than in the two-person game, but this trend was only marginally significant for the schizophrenic patients because of high individual variance (t-test, $p < 0.001$ for the healthy subjects and $p = 0.059$ for the schizophrenic patients). For 3-tuples, the xyz pattern was more frequent in the one-person game than in the two-person game (t-test, $p < 0.001$ for the healthy subjects and $p < 0.01$ for the schizophrenic patients), but the xxy and xyy patterns were less frequent in the one-person game than in the two-person game (t-test, $p < 0.01$ for both groups). In the healthy subjects, the xxx pattern was significantly less frequent in the one-person game than the two-person game ($p < 0.01$), but no significant difference for the xxx pattern was observed between the one- and two-person games for the schizophrenic patients.

The conditional probability of choices depending on the opponent's previous choice in the two-person game was estimated
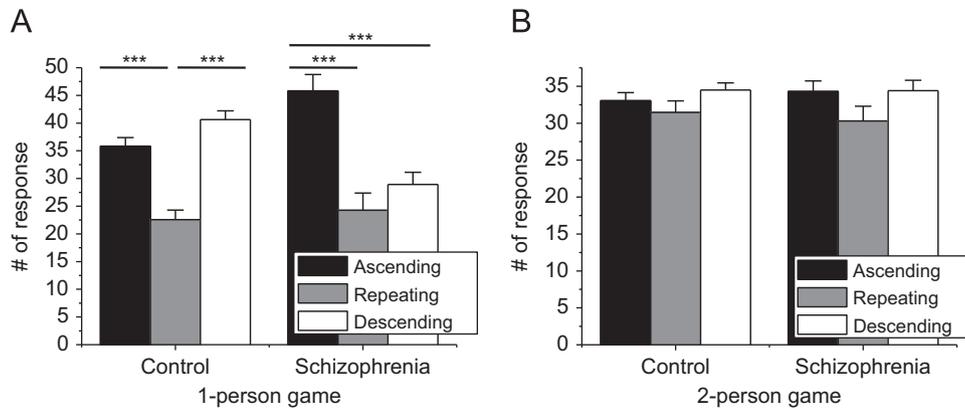
Fig. 2. The number of responses in ascending (black), repeating (gray), and descending (white) order with the subjects' own previous choice (mean ± SEM). The healthy subjects avoided repeating response, and the schizophrenic patients preferred response in ascending order in the one-person game. These biases were eliminated in the two-person game. ***$p < 0.001$, Tukey's test (post hoc).

Table 2
Occurrence of all 2- and 3-tuple patterns across subjects (mean ± S.D.).

Pattern	Control		Schizophrenia		Expected
	One-person	Two-person	One-person	Two-person	
xx	22.6 ± 12.3	31.5 ± 10.9**	23.8 ± 20.0	30.5 ± 12.9	33.0
xy	76.4 ± 12.3	67.5 ± 10.9**	75.2 ± 20.0	68.5 ± 12.9	66.0
xyz	40.7 ± 15.1	26.1 ± 10.2**	41.2 ± 22.9	27.4 ± 13.4*	21.8
xyx	18.4 ± 6.9	20.4 ± 7.7	18.8 ± 11.9	21.7 ± 9.5	21.8
xxy	16.5 ± 6.8	20.2 ± 5.5*	14.4 ± 7.7	18.7 ± 5.8*	21.8
xyy	16.5 ± 6.8	20.2 ± 5.6*	14.5 ± 7.7	18.7 ± 5.7*	21.8
xxx	5.9 ± 8.4	11.1 ± 7.9*	9.1 ± 16.5	11.5 ± 11.3	10.9

All $p < 0.1$ between schizophrenic patients vs. healthy controls.

* $p < 0.01$.

** $p < 0.001$, t-test between one-person vs. two-person games for each group.

with regard to CBR, CSBR, and CWR as shown in Fig. 3. There was no significant bias toward CBR, CSBR, or CWR in the healthy subjects, but schizophrenic patients preferentially chose CBR, i.e., the winning choice against the opponent's previous choice (Tukey's test, $p < 0.001$).

The entropy distribution in the choice sequences of both groups is depicted in Fig. 4. The entropy of the choice sequences in the schizophrenic patients was significantly lower than that of the healthy subjects in the one- and two-person games (Mann–Whitney test, $p < 0.01$ for the one-person game and $p < 0.05$ for the two-person game). This finding indicates that the choice sequences of the schizophrenic patients are less random than those of healthy subjects.

No significant correlation between the subscales of the PANSS and the behavioral measures remained after Bonferroni correction for multiple comparisons. Additionally, there was no significant correlation between the amount of medication and the behavioral measures (all $p < 0.05$, after Bonferroni correction).

4. Discussion

The response randomization behavior was clearly different between the one- and the two-person RPS game in both schizophrenic patients and healthy subjects. The deviation from the ideal randomization was larger in the one-person game than in the two-person game for both groups. Bias in the choices among rock, paper, and scissors was observed only in the one-person game. More shifts and fewer repeats between successive choices were also more profound in the one-person game than in the
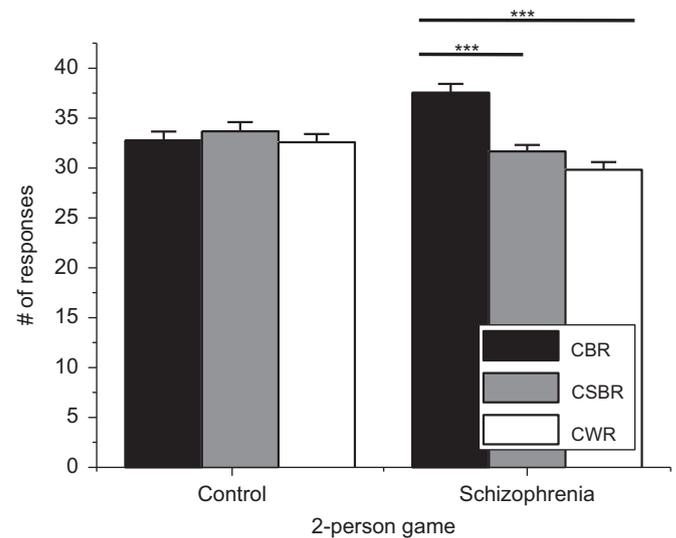

Fig. 3. The number of Cournot best (CBR, black), second best (CSBR, gray), and worst (CWR, white) responses against the opponents' previous choice (mean ± SEM). CBR, CSBR, and CWR are the choices resulting in win, draw, and loss against the opponent's previous choice, respectively. The schizophrenic patients preferred CBR over others, but the healthy subjects did not. ***$p < 0.001$, Tukey's test (post hoc).

two-person game, which agrees with previous reports (Rapoport and Budescu, 1992; Budescu and Rapoport, 1994; Rapoport and Budescu, 1997). These differences in randomization behavior imply that the subjects utilized different cognitive modes in the one-person game compared with the two-person game.

Both group of subjects avoided the repeating choice, but the serial dependency pattern of schizophrenic patients was distinct from that of the healthy controls. Schizophrenic patients preferred ascending choice, which resulted in a one-directional shift in the successive choices rather than only avoiding repetition, which was found in healthy subjects. Thus, schizophrenic patients were likely to generate serial patterns in the rock–paper–scissors–rock order in the one-person randomization task. This stereotypic and consistent switching was profound in the one-person game but disappeared in the two-person game.

The serial bias in response randomization was frequently observed in previous random number generation experiments in schizophrenic patients (Spatt and Goldenberg, 1993; Salamé et al., 1998; Morrens et al., 2006; Peters et al., 2007; Salamé and Danion, 2007). The failure of the on-line inhibition of prepotent responses has been attributed to the serial counting and stereotyped responses.
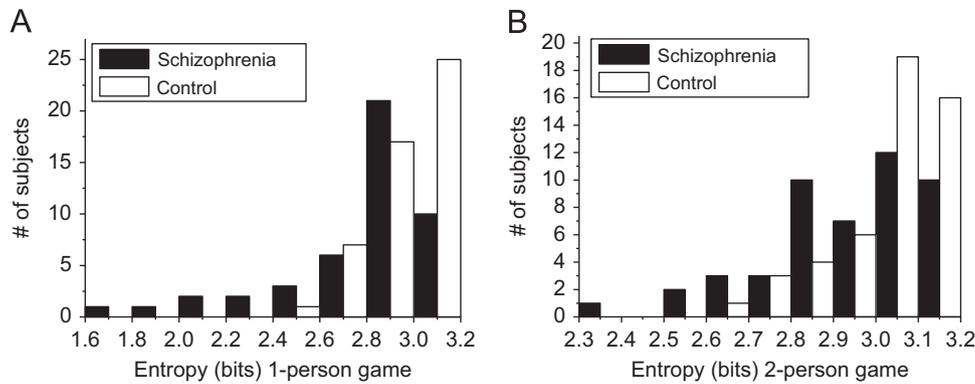
Fig. 4. The entropy of choice sequences across subjects. The schizophrenic patients exhibited significantly lower entropy in the choice sequences than did the healthy subjects ($p < 0.01$ for the one-person game, $p < 0.05$ for the two-person game. Mann–Whitney test).

In healthy subjects, the random number generation task activates the cortical network of executive control including the dorsolateral prefrontal cortex (DLPFC), the anterior cingulate cortex (ACC), and the superior parietal cortex in functional neuroimaging studies (Jahanshahi et al., 2000; Daniels et al., 2003). The disruption of the left DLPFC by transcranial magnetic stimulation also increased habitual counting in ones, i.e. serial responses, in healthy subjects (Jahanshahi et al., 1998). Finally, the superior part of the ACC was associated with the non-randomness of response randomization in healthy subjects but not in schizophrenic patients (Artiges et al., 2000). Thus, the sequential response pattern of schizophrenic patients in the one-person game might reflect the failure of executive control implemented by the fronto-cingulate-parietal network in the brain.

In the two-person game, there was no significant non-random bias in healthy subjects, but schizophrenic patients showed a marked serial dependence upon the opponent's previous choice. Schizophrenic patients tended to choose CBR (i.e., the choice winning against the opponent's choice in the preceding trial). This bias in the schizophrenic patients likely represents a tendency to rely too much on the opponent's most recent choice and is in accordance with the Win-Stay-Lose-Switch (WSLS) strategy observed in the matching penny game (Kim et al., 2007), in which schizophrenic patients were more influenced by the most recent choice of the opponent (computer). Such a bias towards the most recent choice of the opponent can arise from an impaired inhibition of prepotent default strategy (i.e., CBR). Kim et al. (2007) showed that this impairment was prominent in dynamical settings where the strategy should be adapted on-line.

In the framework of game theory, schizophrenic patients deviated from the optimal strategy (i.e., the mixed Nash equilibrium or the minimax solution) in which the players randomize their choice to prevent it from being predicted by the opponent. A high level of mentalizing with regard to the "influence" of one's own choice on the opponent was implicated in choice behavior in competitive games in a functional magnetic resonance imaging study (Hampton et al., 2008). The medial prefrontal cortex and the superior temporal sulcus were found to be associated with the mentalizing-related computation in competitive games. The bias toward CBR in the schizophrenic patients reflects a deficit in this type of mentalizing and agrees with previous reports showing similar deficits in schizophrenic patients (Pickup and Frith, 2001; Bora et al., 2009).

Finally, the randomness measured by entropy was significantly lower in schizophrenic patients than in healthy subjects for the one- and two-person games. Thus, the complexity in the response sequence was decreased in the schizophrenic patients, and the patients were likely to develop biases to the specific sets of successive choices. The entropy measure can be used to quantify any stereotypic pattern in successive choices that might vary across

individuals. The serial dependence measured by counting order (ascending or descending) was not significantly biased in either group in the two-person game; however, the entropy indicated more sequential biases in schizophrenic patients than in healthy subjects. Impaired executive control in schizophrenic patients might result in such sequential biases that would be detrimental in competitive games.

Taken together our findings indicate that disrupted inhibition of the prepotent response is the most prominent feature of the choice behavior of schizophrenic patients in the one- and the two-person game. The lack of inhibition might result in stereotypic patterns in the one-person game and the tendency to make the CBR in response to the opponent's previous choice in the two-person game. However, the deviation from randomness was relatively limited and qualitatively different in the two-person game, which implies that adaptive decision-making in interpersonal interactions also involves distinct cognitive processes that include mentalizing about the opponent; therefore, the deficits in cognitive function can manifest differently.

The relationship between behavioral task performance, clinical variables, and real-world behaviors of schizophrenic patients might be rather complicated, as no significant correlation was found between the behavioral measures and clinical variables such as scores on the PANSS subscales in the present study. Neuropsychological performances and clinical symptoms were found to be associated with specific domains of patients' everyday functioning directly and indirectly through functional capacity (Bowie et al., 2006; McClure et al., 2007; Bowie et al., 2008). For example, executive function directly affected interpersonal behaviors, and indirectly modulated community activities and work skills by contributing to the level of functional competence (Bowie et al., 2008). An extensive neuropsychological test battery and factor analysis can be helpful to specify functional deficits in response randomization and their relationship with daily life activities.

There are several limitations and possible confounding factors in the present study. First, all patients in this study were stabilized on atypical or typical antipsychotic medication; the medication may affect the behavioral performance in the decision-making tasks. Atypical antipsychotics such as clozapine, risperidone, and olanzapine have been reported to improve cognitive functions including attention, working memory, and executive function (Meltzer and McGurk, 1999; Harvey et al., 2003; O'Grada and Dinan, 2007). The type and amount of medication also varied among patients in the present study, which may have introduced further heterogeneity in the patient group. Second, the general cognitive ability of the healthy subjects and the schizophrenic patients was not controlled in the present study. Age, gender and years of education were matched between the two groups, but the general intelligence was not examined in both groups. However, the decision biases in the

present study seemed to be caused by deficits in specific functions such as executive function or mentalization rather than general impairment in view of the distinct behavioral patterns between the one- and the two-person game. Finally, the responses in both tasks were made at the subject's own pace; thus, the response time varied across subjects. The response time affects the difficulty of the task and resulting nonrandom biases, so comparisons of the present study with previous random generation experiments should be performed with caution.

In conclusion, the impaired decision-making of schizophrenic patients in social interactions can be captured by their response randomization in the RPS game. The schizophrenic patients showed distinct patterns of deviation from healthy subjects in the one- and two-person games, which suggests that the failure in response randomization arises not only from deficits in executive function but also from impaired social cognition, e.g. mentalization ability. The behavioral assessment in the framework of game theory can be used as a potent tool to study the social and cognitive impairment of psychiatric populations, and the growing application of the game-theoretical approach has been shown in other recent studies (Kim et al., 2007; Agay et al., 2008; Chung et al., 2011).

Acknowledgement

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