Eur Arch Psychiatry Clin Neurosci (2004) 254 : 236–241 DOI 10.1007/s00406-004-0486-1

ORIGINAL PAPER

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Problem-solving ability in chronic schizophrenia

A comparison study of patients with traumatic brain injury

Received: 2 July 2003 / Accepted: 4 December 2003

Abstract We tested the hypothesis that patients with schizophrenia are more prone to impairment in planning and problem-solving as compared with normal controls and patients with traumatic brain injury (TBI) by administering the Tower of Hanoi (TOH) task. A total of one hundred and fifty-three participants (51 in each group) were recruited. The performance of the patient groups was markedly worse than normal controls in terms of profile score, number of rule-breaking behaviour, and mean execution time. Two-way 3 (group) x 6 (complexity) ANOVAs indicated that significant main effects of group and complexity were observed in the number of moves, planning time to initiate the first move and subsequent execution time. The general performance of TOH in the schizophrenia group was very similar to that of the TBI group. Subsequent comparison of sub-groups of frontal and posterior lobe damage indicated the pattern of performance in schizophrenia patients lie between them. Taken together, these findings suggest that neither focal frontal nor temporal lobe damage is a sufficient explanation for the problem-solving deficits in patients with schizophrenia.

Key words problem-solving · schizophrenia · brain injury

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Introduction

Consistent evidence of a major involvement of the frontal lobe in schizophrenia has been obtained from a wide range of studies – postmortem studies [1], structural and functional imaging studies [2, 3] as well as neuroanatomical and neurochemical studies [4, 5]. These all suggest that the prefrontal cortex is one of the key sites of abnormality in schizophrenia. Damage in this region has been shown to be associated with executive dysfunction characterized by poor planning, inability to maintain goal-directed behaviour, mental rigidity, impaired social judgment as well as impulsivity (e. g. [6, 7]).

The Tower of Hanoi task (TOH) [8] and its derivatives are one of the typical tasks to assess problem-solving ability. In this task, the participant is presented with disks arranged on a pegboard. He or she is asked to move the pegs from the starting state, in line with certain rules and to achieve a presented end state. These tasks have been used extensively with schizophrenia (e. g., [9–12]), traumatic brain injury (TBI) [12–15] and other clinical groups [12].

Patients with schizophrenia have consistently exhibited impairments in this task [9–11, 14]. Goldberg et al. [9] found that schizophrenia patients were impaired on a version of the test with three or four discs, taking significantly more moves to solve each problem. Bustini et al. [16] also found that their schizophrenia patients took more moves as well as made more illegal moves (number of rule-breaking behaviour) than controls. Using a computer version, Morris et al. [11, 14] showed that problem-solving impairment was not simply due to either motor or cognitive slowing. Marczewski et al. [10] further demonstrated there was significant interaction between group membership (schizophrenia patients and normal controls) and complexity of the task. That is, patients took more moves to solve the problems and this impairment worsened when the problem's complexity increased. Moreover, schizophrenia patients were significantly slower in completing the successfully solved problem than their normal counterparts.

Patients with TBI, particularly those with frontal lobe lesions, have also been shown to exhibit impairments in problem-solving tasks. Goel and Grafman [13] demonstrated that patients with frontal lesions had a greater difficulty with the goal-subgoal conflict that denoted a situation in which the correct solution was to move in a direction that was apparently away from the final goal. Morris and colleagues [12, 14] further showed that these impairments were particularly sensitive to left frontal lobe lesion. Chan and Manly [17] also found that patients with TBI took longer time to initiate the first move and took longer subsequent execution time to complete each problem as compared with normal controls. However, Rushe et al. [12] found that schizophrenia patients were impaired in overall types of problems, whereas patients with a left temporal lobe lesion were impaired specifically in problems with goal-subgoal conflicts. These authors therefore suggested that there might be different mechanisms contributing to the problem-solving deficit among these patient types.

The purpose of this study was to study the problem-solving ability among a group of patients with chronic schizophrenia using the TOH task. It also explored the relationships between the task features of TOH and types of symptoms in these patients. Finally, it attempted to compare the problem-solving ability among patients with schizophrenia and TBI, and normal controls in terms of TOH task. In particular, it attempted to examine the features of cognitive processing of this task to differentiate patients with schizophrenia, TBI and normal controls.

Methods and patients

Patients with schizophrenia: we recruited fifty-one (47 males, 4 females) chronic schizophrenia patients in a regional psychiatric hospital. All patients met the DSM-III-R [18] criteria for schizophrenia. Consensus diagnosis was made independently by two experienced psychiatrists by interview with the Structured Clinical Interview for DSM-III-R. Each patient was included in the study sample only if both psychiatrists agreed on the diagnosis of schizophrenia. Exclusion criteria were a history of perinatal trauma, organic illness involving the central nervous system, substance and/or alcohol abuse, and clinical evidence of mental retardation. As a result, 47 cases were diagnosed as paranoid schizophrenia, 2 cases as disorganized schizophrenia and the remaining 2 cases as residual schizophrenia. The mean age was 44 years (SD = 9.6) and the number of education year was 8.2 years (SD = 2.9). The mean duration of illness was 21.3 years (SD = 9.5). The mean daily dosage of medication was 1263.13 mg chlorpromazine equivalents (SD = 1577.74, range 700–7143 mg). All participants received conventional antipsychotic medication for their treatment.

Fifty-one patients with TBI were also involved in a study on attentional deficits and executive disorders that have been described previously (e.g., [19, 20]). These patients had satisfied the inclusion criteria of mild (45 cases) to moderate (6 cases) grade TBI. They were recruited from the neurosurgical out-patient clinics of Queen Mary Hospital and Tuen Mun Hospital. These patients were tested, on average, 25 months post-injury (median = 15 months, range 2–127 months). Thirty-four (66.7 %) of them had mild hypo-dense area or no abnormality in brain structure detected by CT scan, 10 (19.6 %) had frontal lobe involvement, 3 (5.9 %) had parietal lobe involvement, and 4 (7.8 %) had multiple lobes involvement. The median of Glasgow Coma Scale, loss of consciousness and posttraumatic amnesia was 14 (range from 7 to 15), 15 min (range from 0 to 24 hours), and 0 min (range from 0 to 24 hours), respectively.

Another group of fifty-one (43 men, 7 women) healthy participants were selected to match the two patient groups for age, education and gender proportion as far as possible. The mean age and education level was 41.7 years (SD = 5.7) and 8.8 years (SD = 1.9), respectively. The control group was selected from a pool of volunteers from an extensive local norm project on neuropsychological functions in Hong Kong. They were screened by medical officers with the use of a questionnaire to ensure they did not suffer from any psychiatric illness, brain injury, or any other neurological diseases, and were not reported to have any history of drug or alcohol problems.

One-way ANOVA indicated that there were no significant differences found among these groups in terms of age [$F(2, 150) = 1.256$, $p = 0.288$], education [$F(2, 150) = 1.502$, $p = 0.226$], and gender proportion [chi-square [2] = 2.318, $p = 0.314$].

Problem-solving task

The present study adopted the modified version of Humes and colleagues' [21] version of TOH. In this task participants were presented with a 3-peg pegboard and four wooden disks of differing sizes. The task was to transfer the disks from a given starting position to a given final position using the smallest possible number of moves. This test comprised 12 problems with different complexity levels – 5-move 3-disk task (problems 1 and 2), 6-move 3-disk task (problems 3 and 4), 7-move 3-disk task (problems 5 and 6), 7-move 4-disk task (problems 7 and 8), 11-move 4-disk task (problems 9 and 10), and 15-move 4-disk task (problems 11 and 12). Examples of the problems are shown in Fig. 1. Performance measures were based on 4 main parameters: the number of moves required for each problem, the planning time for the initiation move of each problem, the execution time, and a profile performance score. Planning time was referred to the time taken by the participant from being presented with the problem to initiate the first move. The execution time was defined as the total time for the participant to complete the problem. The profile performance score reflected the ability to solve the whole series of 12 problems (c. f. 21 for detailed description of calculation method). In brief, patients were required to perform the same problem for at least 2 trials in order to proceed to the next problem. Points would be assigned based on the number of trials required for two successive consecutive solutions. For example, 6 points would be given if the patient was able to solve the problem in the first 2 successive consecutive trials 1 and 2; and 5 points would be given if the patient could solve the problem only at the second and third successive trials, and so on so forth, i. e. 4 points for trials 3 and 4; 3 points for trials 4 and 5; 2 points for trials 5 and 6. On the other hand, if the patient could only solve the problem in only 1 trial or if s/he could or if no consecutive correct trials were achieved, the patient would receive no mark for this problem.

Clinical symptoms

The Positive and Negative Syndrome Scale (PANSS) was used for the assessment of symptoms [22]. It contains items for rating positive symptoms, negative symptoms as well as global symptoms. All items were rated from 1 (absent) to 7 (extreme) according to the standardized instructions. Inter-rater reliability for the PANSS was evaluated with the intra-class correlation coefficient (ICC). ICC was 0.83 for the global PANSS score, 0.84 for the positive symptoms subscale and 0.73 for the negative symptoms subscale.

The university and the corresponding hospital ethics committees had approved the research plan and the recruitment procedure. Informed consent was obtained from all the participants prior to the testing session in accordance with the Declaration of Helsinki. Men-

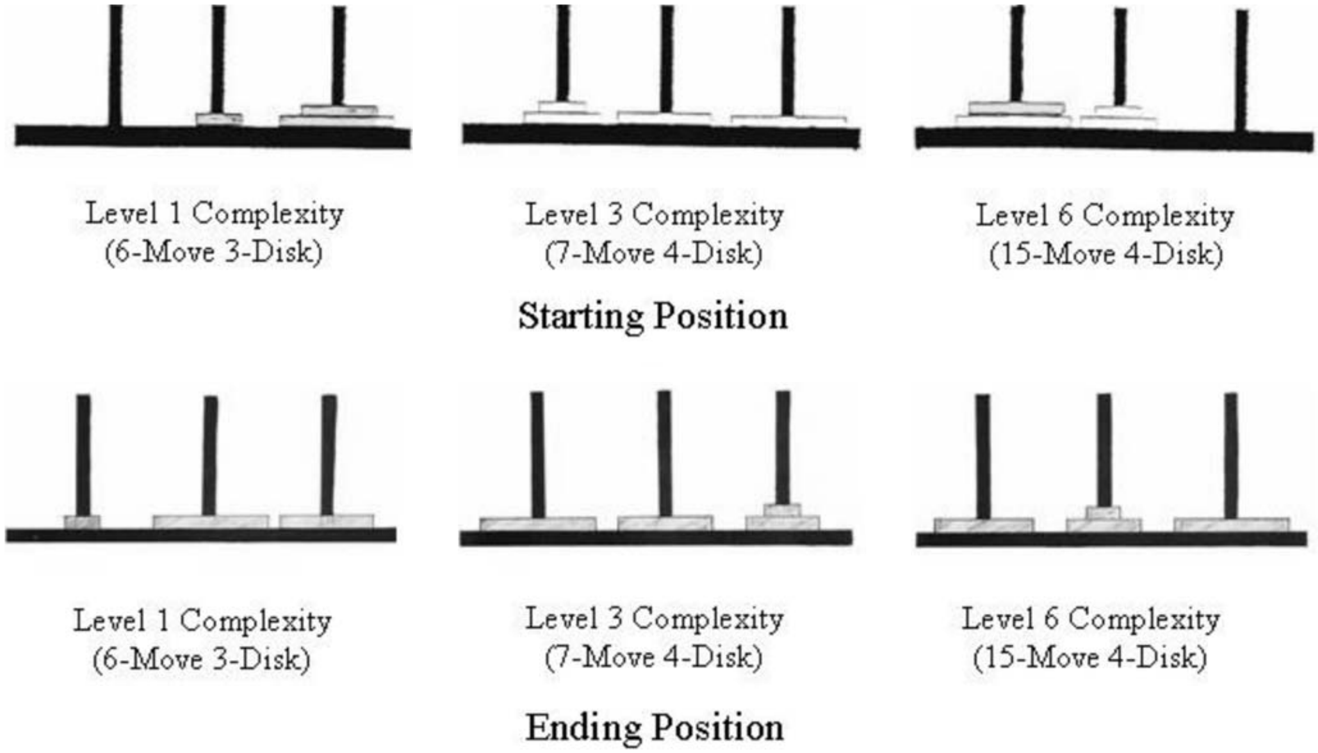

Fig. 1 Examples of different complexity levels of Tower of Hanoi task

tal state was evaluated with a clinical interview administered by a trained research assistant (who also received medical training) just before the neuropsychological session. All the tests were implemented in a quiet cubicle.

Data analysis

Analyses of group differences in the TOH performance were undertaken by a series of ANOVAs, with Tukey Honest Statistical Difference (HSD) test as post-hoc analysis. These analyses were performed in two ways: 1) The standard scores described by Humes et al. [21] including the total profile score of the series of problems solved, the mean planning and execution time, and the total number of rule-breaking behaviour; 2) The detailed analyses of the number of move, planning time and execution time were conducted with a series of two-way 3 (group) x 6 (complexity) ANOVAs in order to examine the main effect of group and complexity level as well as the interaction effect.

Specific to the schizophrenia patients, correlation analysis was conducted to explore the association between the psychotic symptoms and the task performance score. Scores on the PANSS were computed to give composite scores for positive, negative, and general psychopathology in addition to the total score.

Results

Comparison of patients with schizophrenia, TBI and normal controls

Regarding the complete set of 12 problems, significant differences were found among the groups in terms of total profile score of TOH [$F(2, 152) = 72.67$, $p = 0.0005$], number of rule-breaking behaviour [$F(2, 150) = 15.40$, $p = 0.0005$], and mean execution time [$F(2, 150) = 22.44$, $p = 0.0005$]. However, the mean planning time for the three groups did not differ significantly [$F(2, 150) = 1.845$, $p = 0.161$]. Post-hoc analyses indicated that patients with schizophrenia performed significantly worse in the profile score as compared with patients with TBI ($p < 0.0005$) as well as normal controls ($p < 0.0005$). These patients also committed significantly more rule-breaking behaviour as compared with both patients with TBI ($p < 0.0005$) and normal controls ($p < 0.0005$). On the other hand, these patients had a significantly longer mean execution time than TBI patients ($p < 0.0005$) and normal controls ($p < 0.0005$).

In order to further investigate whether schizophrenia patients were particularly impaired when the problems were more difficult, a series of two-way 3 (group) x 6 (complexity) ANOVAs was computed on the number of move, planning time and execution time taken by these participants. For the number of move, there were significant main effects of group [$F(2, 608) = 5.414$, $p < 0.005$] and complexity [$F(5, 608) = 51.634$, $p < 0.0005$]. Post-hoc analyses indicated that patients with schizophrenia took significantly more moves to solve the problems than normal controls ($p < 0.0005$). They did not take significantly more moves than patients with TBI ($p = 0.226$). On the other hand, TBI patients also took significantly more moves to solve the problem as compared with the normal controls ($p = 0.011$). No significant interaction was found between group and complexity level in terms of number of moves [$F(10, 608) = 1.17$, $p = 0.308$].

For the planning time of the first initiation, significant main effects of group [F(2, 604) = 12.063, p < 0.0005] and complexity [F(5, 604) = 4.929, p < 0.0005] were observed among the three groups. Patients with schizophrenia and TBI demonstrated significantly longer planning time for the initiation move than the normal controls (p < 0.0005). By contrast, there was no significant difference found between patients with schizophrenia and patients with TBI. There was also a trend for the interaction effect between group and complexity level [F(10, 604) = 1.77, p = 0.063], suggesting that patients with schizophrenia were more sensitive to the complex problems in terms of planning time for the first initiation.

Finally, there were significant main effects of group [F(2, 593) = 19.15, p < 0.0005] and complexity [F(5, 593) = 9.284, p = 0.0005] found among the participants in the mean execution time. Post-hoc analyses showed that patients with schizophrenia took significantly longer execution time to complete the solved problem as compared with normal controls (p = 0.03) but not with patients with TBI. Patients with TBI also took significantly longer execution time to complete the solved problem than normal controls (p < 0.0005). There was no interaction found between group and complexity level among the participants [F(10, 593) = 0.944, p = 0.492].

Figs. 2, 3 and 4 show the general pattern of TOH performance across groups and complexity level in terms of number of moves, planning time and execution time respectively. Patients with schizophrenia and TBI demonstrate a similar pattern but impaired performance in number of moves and execution time. However, there was a reverse pattern found in schizophrenia patients in planning time as compared with the other groups. In order to further explore whether the cause of the problem-solving deficit in schizophrenia would resemble that in patients with specific focal lesions, the patterns of TOH performance in frontal lobe lesion (N = 10) and posterior lobe lesion (N = 3) were examined (Figs. 5–7). The number of moves and execution time taken by schizophrenia patients was similar to that of the frontal group, whereas the planning time to initiate the first move was resembled to that of the posterior group. However, it should be noted that there was a trend of interaction at the most difficult problems in the number of moves and execution time as well as at the mid-range complex problems in the planning time.

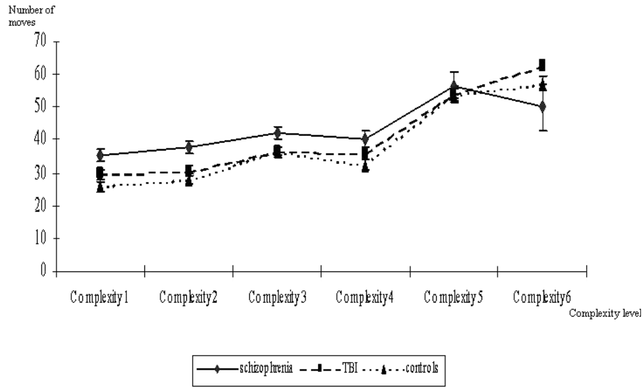

Fig. 2 Number of moves of Tower of Hanoi task among patients with schizophrenia, TBI and controls

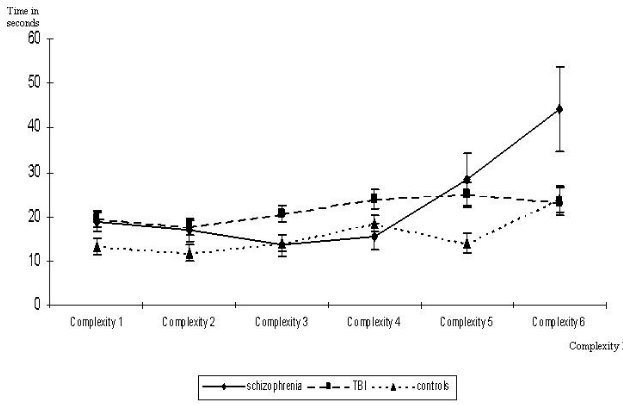

Fig. 3 Planning time of Tower of Hanoi task among patients with schizophrenia, TBI and controls

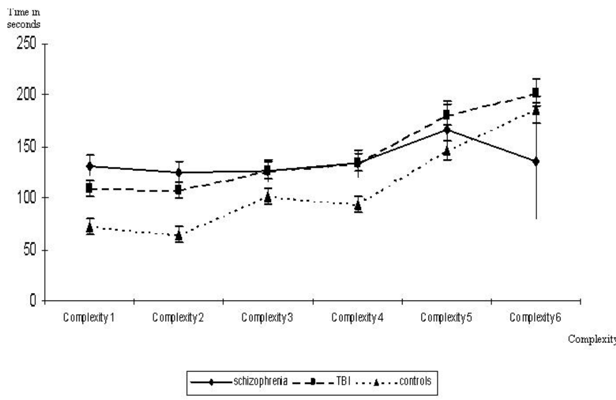

Fig. 4 Execution time of Tower of Hanoi task among patients with schizophrenia, TBI and controls

Correlation analysis

Significant inverse correlation was found between age and total profile score of TOH in patients with schizophrenia (r = –0.316, p = 0.04). No other significant associations were found between TOH performance parameters, education level, and duration of illness. On the other hand, the PANSS total score was significantly correlated with the profile score of TOH (r = –0.31, p = 0.027). Since previous studies had identified correlation between age, duration of illness and psychotic symptoms in schizophrenia, a partial correlation coefficient was carried out to control for these confounding effects (Table 1). The results indicated that there was still a significant inverse correlation between general psychopathology and TOH profile score (r = –0.339, p = 0.028). There was also a trend of inverse correlation between the total symptom score of PANSS and TOH profile score (r = –0.293, p = 0.06). Moreover, the correla-

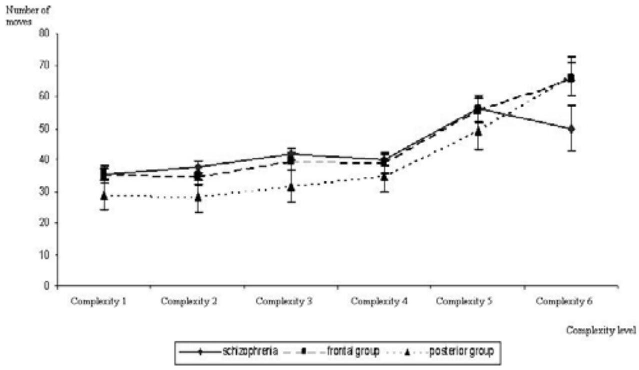

Fig. 5 Number of moves of Tower of Hanoi task among patients with schizophrenia, frontal lobe and posterior lobe lesions

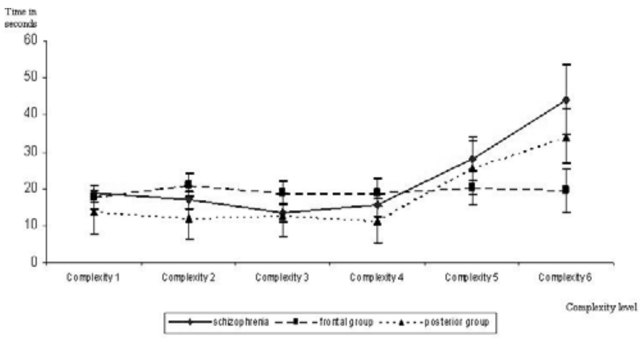

Fig. 6 Planning time of Tower of Hanoi task among patients with schizophrenia, frontal lobe and posterior lobe lesions

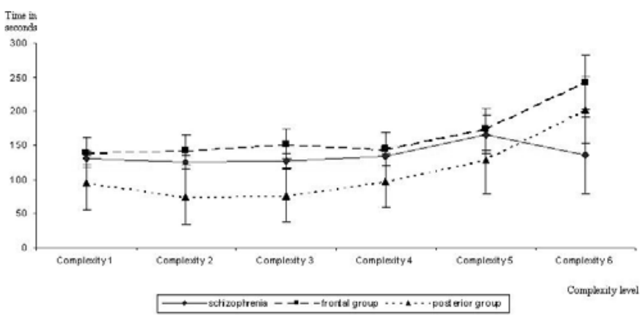

Fig. 7 Execution time of Tower of Hanoi task among patients with schizophrenia, frontal lobe and posterior lobe lesions

Table 1 Partial correlation coefficients between psychotic symptoms and Tower of Hanoi task performance controlling for age and duration of illness

	PANSS Positive symptom	PANSS Negative symptom	PANSS General psychopathology	PANSS Total symptom
Profile score	0.021	−0.164	−0.339*	−0.293
Planning time	0.401**	−0.036	0.192	0.251
Execution time	0.099	−0.04	−0.026	0.02
Number of rule-breaking	−0.087	0.182	0.183	0.193

* $p < 0.05$; ** $p < 0.005$

tion coefficient between positive symptom and TOH planning time was strengthened to 0.401 ($p = 0.008$). In contrast, none of the other symptoms were found to be correlated with TOH performance parameters.

Discussion

The present findings showed that there was a general deficit in problem-solving ability in both patients with schizophrenia and TBI as compared with normal controls in terms of number of moves as well as longer subsequent execution time. These findings were broadly consistent with previous studies [9–11, 15, 23, 24].

It is also noteworthy to see the reverse pattern of planning time across all levels of complexity demonstrated by schizophrenia patients as compared with TBI patients and normal controls. schizophrenia patients tended to plan more carefully in initiating the first move for simple and complex problems. In other words, they required less time to initiate the first move in mid-range complex problems – problems 5, 6, 7 and 8. A check on the starting and ending positions of the disks in these problems indicates that three (problems 5, 6 and 8) out of four are exactly the mirror positions to each other. Schizophrenia patients might therefore wrongly perceive these mirror-positions to be simple problems and might take a quick initiation for the first move. These findings were in concordance with previous studies on "goal-subgoal conflict" [13] and "congruent-conflict" [12] problems of Tower of Hanoi. In certain situations, the appropriate subgoal of moving the disk was in a direction away from the final goal. The schizophrenia patients in the present study might be unable to solve this conflict in starting-ending mirror-position problems.

Another reason for this inconsistent pattern in planning time might be due to the heterogeneity of the TBI groups. Since the major composition of this group was mild grade TBI without abnormality detected finding by CT scan, the non-specificity of the cortical regions involved might confound the actual patterns found between schizophrenia patients and patients with observable focal lesions. A post-hoc check on the differential patterns of TOH performance in the frontal group and posterior group revealed that the performance of schizophrenia patients was at the mid-range between patients with frontal and posterior lobe lesions. There was also a trend for schizophrenia patients to interact with the frontal and posterior sub-groups. In other words, focal frontal or temporal cortical involvement might not be attributable to the problem-solving deficit observed in schizophrenia patients. Although limited by the crude classification of frontal/posterior sub-groups and the small number of patients in each sub-group, the present findings supported the speculation of "functional connectivity" of the system involving frontal and temporal circuits [25, 26] as the cause of the significant deficits in schizophrenia patients.

The problem-solving ability was not significantly correlated with positive or negative symptoms in schizophrenia. This was in contrast to the previous studies on problem-solving ability and symptomatology, negative symptoms in particular [11]. This might be due to the sample bias in the present study. Alternatively, this might also argue against a simple relationship between problem-solving ability and symptomatology in schizophrenia.

Future research should involve comparisons between schizophrenia patients and those with specific brain lesions using experimental paradigms and functional imaging to clarify the underlying mechanism of problem-solving in these patients.

Acknowledgement The authors would also like to thank patients and staff at the Castle Peak Hospital for their participation and assistance in the study. This project was supported in part by the Research Grants No. 10203 555 from the University of Hong Kong and the 100-Scholar Plan of the Sun Yat-Sen University to the first author.

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