Contribution of Working Memory Components to the Performance of the Tower of Hanoi in Schizophrenia

工作记忆对精神分裂症病人在河内塔任务中表现的影响

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Abstract

Objectives: To examine the underlying structure of neuropsychological tests involving working memory components and those not involving working memory components that contribute to the performance of the Tower of Hanoi task in schizophrenic patients.
Participants and Methods: A total of 90 patients with residual schizophrenia received a comprehensive cognitive assessment. Working memory was assessed with Letter-Number Span and Visual Patterns tests. Executive function was assessed by the Tower of Hanoi task. Stepwise multiple linear regressions were performed including age, education, duration of illness, and all cognitive functions.
Results: Principal component analysis was conducted and yielded a 4-factor solution: auditory working memory, visual working memory, verbal working memory, and verbal fluency. Subsequent stepwise regression indicated that only visual working memory components and auditory working memory components were retained in the final model accounting, which explained 23.5% of the variance.
Conclusions: These findings emphasise the importance of memory components, particularly those involving visual- and auditory-based working memory, when conceptualising the performance of the Tower of Hanoi task in residual schizophrenia.

Key words: *Memory, Short-Term; Neuropsychological tests; Schizophrenia*

摘要

目的：检查工作记忆影响精神分裂症患者在河内塔任务中表现的认知机制。
参与者与方法：90名慢性精神分裂症患者接受全面的认知评估。研究使用字母数位广度测试和视觉模式测试评估工作记忆，使用河内塔测试评估执行功能，并对年龄、教育水准、病程以及所有的认知功能进行逐步的多元线性回归分析。
结果：主成分分析结果显示4个因素：听觉记忆、视觉记忆、言语记忆以及流畅性。接下来的逐步回归分析显示最终模型中只包括视觉记忆和听觉工作记忆两个部分，能够解释23.5%的变异。
结论：结果强调了记忆，尤其是基于工作记忆的视觉和听觉部分，在考量慢性精神分裂症患者河内塔任务中表现时的重要性。

关键词：*短暂工作记忆、神经心理测试、精神分裂症*

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Introduction

The Tower of Hanoi task and related tower-based tasks play an important role in the assessment of frontal lobe function. A number of studies have demonstrated that with respect to this test, performance is impaired among patients with frontal lobe lesions.[1-4] On the other hand, patients with diffuse lesions, such as after traumatic brain injury,[5-7] other suspected pathologies in the frontal lobe region, as well as related connectivity disorders such as schizophrenia,[8,9] are also associated with general deficits in this task. In a recent review and meta-analysis, Sullivan et al[10] examined the validity of the tower tasks as a measure of executive function, and confirmed the theoretical hypothesis of the frontal involvement in tower task performances. Researchers have attempted to identify any differential performance profile among these clinical groups, using different versions of the Tower of Hanoi task.[2,11,12] For example, Morris et al[3,11] and Chan et al[12] used 2 different versions of tower tasks in patients with schizophrenia and found a similar deficit in goal-subgoal conflicts in these patients, i.e. trials with indirect moves engendered conflict between the overall goals (moving disks to their final positions) and the subgoals (moving disks away from the final positions). These authors also demonstrated that the pattern of deficits in patients with schizophrenia lay somewhere midway between patients with focal frontal and temporal lobe lesions. They therefore suggested that the poor performance of tower tasks in schizophrenia could not be solely explained by the focal frontal lobe impairment hypothesis.

Given the importance placed upon these tasks as assessment tools, it is better to identify the specific cognitive deficits that are being assessed. It is commonly assumed that problem-solving task such as the Tower of Hanoi relies heavily upon a working memory component that enables the simultaneous processing and storage of representation.[4] Unfortunately, data on this issue have been inconsistent. Some have argued that tasks of this kind draw on verbal planning processes and point to neuro-imaging and brain lesion studies that suggest left hemisphere rather than right hemisphere involvement as support for this claim.[11] However, Phillips et al[13] found that performance of the Tower of London task was disrupted by a spatial secondary task, but not articulatory suppression, thereby implicating spatial rather than verbal processes. Indeed articulatory suppression improved rather than disrupted Tower of London task performance, suggesting that verbal processing hindered performance rather than improved it.

The present study aimed to further investigate executive function testing, emphasising the Tower of Hanoi to understand relationships among working memory (visual- and auditory-based) and non–working memory components, which contributed to the final task performance in a group of patients with residual schizophrenia.

Methods

A total of 90 (74 males, 16 females) residual schizophrenic patients were recruited from a regional psychiatric hospital in Hong Kong. All of them were inpatients meeting the criteria for schizophrenia in the 4th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV).[14] A consensus diagnosis was made independently by 2 experienced psychiatrists based an interview using the Structured Clinical Interview for DSM-IV. Each patient was included in the study sample only if both psychiatrists agreed on the diagnosis of schizophrenia. Exclusion criteria included a history of organic illness involving the central nervous system, substance and / or alcohol abuse, and clinical evidence of mental retardation.

Background Cognition and Non–working Memory Tests

In order to give intelligence estimates of the group, background cognition was assessed with the information obtained using the Digit Span Forward, Digit Span Backward, and Arithmetic subscales of the Wechsler Adult Intelligence Scale-III.[15]

Verbal and visual working memory were assessed by the Logical Memory Test (immediate and delayed recalls) and the Visual Reproduction Test (immediate and delayed recalls) from the Wechsler Memory Scale-III.[16] Moreover, the Monotone Counting Test[17] and verbal fluency task were used to assess the sustained attention and executive function. These tests have been found to be valid and sensitive for detecting the cognitive deficits in patients with schizophrenia.[18]

Working Memory Tests

The Visual Patterns Test[19] was used as a test of visual working memory. The stimuli consisted of a number of boxes, which could be filled or unfilled. Participants were asked to attend to the location of the filled boxes and to indicate this after the stimulus had been removed from sight. The stimulus entailed increasing numbers of boxes presented to participants in successive order. The numbers of boxes correctly processed were recorded.

The Letter-Number Span test[20] involved the auditory presentation by an examiner of a mixed series of alternating numbers and letters. The participant was requested to respond by first saying the numbers in order from smallest to the largest, followed by stating the letters in alphabetical order. Therefore, it was mainly used to assess verbal working memory and attentional switching for separating and sequencing the presented stimuli. The longest correct sequence recalled was recorded.

Executive Function Task

The executive function task was assessed by the Tower of Hanoi.[21] The detailed scoring method has been described elsewhere.[12,21] Simply speaking, this task requests participants to solve a series of problems by moving the disks from a given starting position to a given final position using the smallest possible number of moves. This test comprises 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). A total profile performance was computed to reflect the ability to solve the whole series of 12 problems.

Clinical Symptoms

The Positive and Negative Syndrome Scale was used for the assessment of schizophrenic symptoms.[22]

Procedure

The university and the corresponding hospital's ethics committees approved the research plan and the recruitment procedure of the subjects with schizophrenia. Informed consent was obtained from all the subjects prior to the testing session in accordance with the Declaration of Helsinki. A trained research assistant administered the tests in a quiet cubicle in 2 sessions during a 2-day period. Background cognition tests were implemented before the neuropsychological session. All patients completed all the tests, which were administered in a fixed order.

Statistical Analyses

The Statistical Package for the Social Sciences Windows version 11.0 was used for analysis of the results. Pearson product-moment correlations, controlling for age, education and medication, were conducted to determine associations between measures of non-executive function and executive function test findings. Given the number of correlations performed, the Bonferroni's correction was used for multiple comparisons, i.e. considered significant at $p < 0.001$, corresponding to a p value of 0.05.

These analyses were followed by a principal component analysis (PCA) with varimax rotation of all the neuropsychological test variables, as well as working and non–working memory tests. Whereas the pairwise correlational analyses focused on associations between various working memory measures, we performed the PCA to identify unique underlying processes across a number of working and non–working memory measures, specifically to establish whether a component corresponding to executive processes would emerge. The PCA also served to determine summary measures for examination of predictors of the Tower of Hanoi task performance variance in our sample. Components with eigenvalues of 1 or greater were included in the PCA. For analysis of the impact of each component on the Tower of Hanoi task performance, component scores were derived from the rotated PCA. Stepwise multiple linear regressions were then performed based on age, education, duration of illness, and all these component scores to determine the role of these variables in explaining performance of the Tower of Hanoi task.

Results

Table 1 summarises the sample characteristics and their corresponding neurocognitive functional performances. All participants received conventional antipsychotic medication as treatment.

Partial Pearson Product-moment Correlations

Partial correlation analyses, controlling for age, education and medication effects, indicated a series of significant correlations between several neurocognitive function variables (Table 2). Most of the neurocognitive functional tests correlated significantly with the Tower of Hanoi task performance; only Digit Span Forward did not correlate significantly. On the other hand, the set of neurocognitive functional tests also correlated significantly with one another.

Table 1. Description summary of the demographics and neurocognitive function performance scores.

Item	Mean (standard deviation)
Demographics (years)	
Age	46 (10)
Education	8 (3)
Duration of illness	22 (10)
Clinical symptoms (PANSS)	
Positive symptoms	15 (6)
Negative symptoms	18 (7)
General psychopathology	37 (10)
Social impulsivity	5 (3)
Background cognition	
Information	7 (3)
Arithmetic	10 (5)
Digit Span Forward	8 (2)
Digit Span Backward	4 (1)
Memory tests	
Logical Memory (immediate recall)	4 (3)
Logical Memory (delayed recall)	2 (3)
Visual Reproduction (immediate recall)	12 (6)
Visual Reproduction (delayed recall)	9 (6)
Monotone Counting	10 (3)
Verbal fluency	11 (5)
Working memory tests	
Visual Patterns Test	5 (2)
Letter-Number Span test	3 (1)
Executive function test	
TOH mean planning time (seconds)	5 (4)
TOH mean execution time (seconds)	37 (3)
TOH profile score	30 (24)

Abbreviations: *PANSS = Positive and Negative Syndrome Scale; TOH = Tower of Hanoi.*

Principal Component Analysis

A PCA using varimax rotation was conducted on all the neurocognitive test variables. This analysis yielded a 4-component solution accounting for 65% of the variance (Table 3). The first component, accounting for 23% of the variance, was weighted by scores from auditory working memory components, which included: Arithmetic, Letter-Number Span, Information, Digit Forward, Monotone Counting, and Digit Backward. The second component accounted for another 17% of the variance, and obtained highest loadings from most of the tests involving visual working memory components, such as the Visual Patterns Test, as well as tests involving visual working memory components (e.g. Visual Reproduction). The third factor, added a further 15% to the variance, comprised items

Table 2. Partial Pearson product-moment correlation matrix for neurocognitive function tests.*

Test variable	Tower of Hanoi	Information	Arithmetic	Digit Forward	Digit Backward
Information	0.33	-	-	-	-
Arithmetic	0.32	0.36	-	-	-
Digit Forward	0.06	0.16	0.27	-	-
Digit Backward	0.35	0.29	0.32	0.31	-
LM (immediate)	0.33	0.38	0.2	0.08	0.09
LM (delayed)	0.33	0.29	0.18	0.17	0.11
VR (immediate)	**0.42**	0.17	0.16	0.15	0.18
VR (delayed)	**0.44**	0.14	0.13	0.01	0.03
Monotone	0.22	0.33	0.37	0.25	0.35
Verbal fluency	0.24	0.38	0.23	0.27	0.19
Visual Patterns	0.16	0.22	0.31	0.28	0.34
Letter-Number	0.36	0.48	0.41	0.2	**0.45**

Abbreviations: *LM = Logical Memory; VR = Visual Reproduction.*

* *Figures in bold indicate significance after Bonferroni's correction corresponding to p < 0.05.*

Table 3. Component loadings of the neurocognitive test variables.*

Test variable	Auditory working memory	Visual working memory	Verbal working memory	Verbal fluency
Arithmetic	**0.767**	0.006	0.140	0.001
Letter-Number Span	**0.713**	0.008	0.128	-0.137
Information	**0.635**	0.228	0.309	0.008
Digit Span Backward	**0.626**	0.257	0.009	0.228
Monotone	**0.519**	0.295	0.007	0.357
Digit Span Forward	**0.5**	0.17	0.007	0.29
Visual Reproduction (immediate recall)	0.209	**0.897**	0.148	0.007
Visual Reproduction (delayed recall)	0.123	**0.859**	0.143	0.147
Visual Patterns	0.492	**0.525**	0.02	-0.105
Logical Memory (immediate recall)	0.196	0.128	**0.909**	0.004
Logical Memory (delayed recall)	0.170	0.120	**0.895**	0.003
Verbal fluency	-0.108	0.001	0.001	**0.839**
Eigenvalues	4.29	1.34	1.16	1.02
Variance	22.63%	17.44%	15.16%	9.9%

* *Figures in bold indicate significance after Bonferroni's correction corresponding to p < 0.05.*

involving verbal memory components, such as Logical Memory (immediate and delayed recalls). The final factor accounted for 10% of the variance and comprised verbal fluency as the sole item. The latter could be considered to be a fluency factor.

In the present sample, significant correlations were found between these composite scores and clinical symptoms. The visual working memory component was inversely correlated with negative symptoms (r = –0.39, p < 0.001) and social impulsivity symptoms (r = –0.28, p = 0.01). The verbal working memory component was also associated with negative symptoms (r = –0.34, p = 0.002) and social impulsivity (r = –0.35, p = 0.001).

Stepwise Regression

Composite scores were computed for each of the listed components. These scores together with age and education were included as predictors in a stepwise regression analysis with the Tower of Hanoi task performance as the dependent variable. As detailed in Table 4, the final regression model accounted for 24% of the total Tower of Hanoi performance variance. Step 1 involved the visual working memory component weighted by results from the Visual Patterns and Visual Reproduction tests, and accounted for 19% of the variance (p < 0.001). Step 2 with the auditory working memory component weighted by the Arithmetic, Letter-Number Span, Information, Digit Span Forward,

LM (immediate)	LM (delayed)	VR (immediate)	VR (delayed)	Monotone	Verbal fluency	Letter-Number
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
0.7	-	-	-	-	-	-
0.3	0.28	-	-	-	-	-
0.28	0.08	**0.67**	-	-	-	-
0.2	0.13	0.31	0.28	-	-	-
0.26	0.27	0.39	0.34	0.21	-	-
0.18	0.23	0.3	0.27	0.2	0.37	-
0.26	0.16	0.13	0.18	0.26	0.32	**0.52**

Table 4. Stepwise regression model.

Step	Variable	R^2	Increment in R^2	R^*R change		
				F	Degrees of freedom	p Value
1	Visual working memory component	0.187	0.187	20.27	1,88	< 0.001
2	Auditory working memory component	0.247	0.048	5.46	1,87	0.02

Monotone Counting, and Digit Span Backward accounted for the remaining 5% of the variance. The final model is summarised in the following equation:

> Tower of Hanoi task performance = 0.37 Visual Working Memory Component + 0.23 Auditory Working Memory Component - 17.73

Discussion

The purpose of the current study was to examine the relationship among neurocognitive function tests, particularly the working memory–based tests, and how they relate to an executive function task that presumably involved on-line working memory components. Results of correlation analyses suggest that some, but not all, neurocognitive function tests have common underlying processes. Data from the PCA indicated that there were 3 types of memory factors. The first factor loaded largely on tests involving auditory modalities. For example, Monotone Counting and Digit Span tests and even Information subscales that demanded the subject withhold information on-line by hearing the stimuli and manipulating it bit by bit. This factor was thus best depicted as related to auditory working memory. On the other hand, the underlying associations of this factor having a bearing in specific working memory tests (e.g. Letter-Number Span test) remained stable with the introduction of presumed working memory tests such as the Visual Patterns Test. Thus, the isolated loadings of this test and other visually involved memory tests such as the Visual Reproduction subscale on factor 2 may reflect their unique working memory abilities. These included: brief storage and mental manipulation using visual modalities rather than auditory ones. Similarly, factor 3 comprised items involving another type of memory, i.e. auditory modalities and with greater emphasis on the verbal context of the stimuli. Factor 4 was the only factor comprised solely 1 item, namely verbal fluency, which demanded that within 1 minute the subject generates animal exemplars as much as possible. The PCA therefore provided complementary information on associations among working and non–working memory tests, emphasising unique dimensions assessed by these tests.

The Tower of Hanoi task was consistently studied in patients with schizophrenia. Regression analysis, after accounting for age, education and medication, showed that measures of visual modalities of memory (e.g. the Visual Patterns Test and Visual Reproduction immediate recall) explained the greatest component of the variance. However, it is also important to note that auditory-based memory contributed an almost equal amount of predictive power to Tower of Hanoi task performance, demonstrating the strong influence of overall memory ability, particularly working memory components. These findings were very similar to those reported by Phillips et al,[13] namely that secondary verbal memory can improve performance on a spatial planning task such as for the Tower of Hanoi. In an anecdotal study of 10 patients with traumatic brain injury, Chan et al[23] also found a similar improvement in performing the Tower of Hanoi task. This study entailed asking the patients and healthy subjects to verbalise their actions and plan, while performing the task. They found that these "on-line verbal cues" can improve not only Tower of Hanoi task performance but also other tasks involving more complex visual-based problem-solving, such as jigsaw puzzles. The gain in task performance was significantly greater in patients with traumatic brain injury than the healthy controls.

However, our findings indicated that both visual- or auditory-based memory contribute equally in the performance of Tower of Hanoi task by patients with residual schizophrenia. Although visual-based memory accounted for a slightly higher variance than the auditory-based working memory, their standardised regression coefficients were roughly the same in terms of explaining the final task performance.

Our study did not recruit a matched normal control group to test the variability of Tower of Hanoi task predicted by these supposedly different types of working memory components. Since patients with schizophrenia are consistently associated with different degrees of working memory impairments, we do not know whether the contribution of working memory would be the same as in subjects with intact working memory. Therefore, our results are very preliminary and in the future studies these should be validated in a healthy population as well as other clinical groups. However, our findings did provide partial support for the assertion that an understanding of a problem-solving task or an executive processing requires knowledge of the coordination of multiple cognitive abilities,[24] and in the present sample most probably this executive processing could be fractionated into different specific components (e.g. visual and auditory working memory components, verbal memory, and verbal fluency). Moreover, most recent studies also demonstrated that executive processing could be fractionated into different specific components in both health subjects and in clinical groups.[12,18,25-28] The consideration of the multi-component nature of executive functioning may lead to a clearer interpretation of a neuropsychological evaluation.

The present findings appear to add further knowledge to potential rehabilitation strategies for patients with poor executive function or problem-solving task performance. We may adopt various sensory modalities to improve problem-solving tasks, by training subjects to learn techniques that improve both the visual and auditory working memory. This is particularly useful for schizophrenic patients who have consistently demonstrated differential deficits in working memory capacity. Future research should be systematically conducted with a series of pre- and post-training measures of different modalities of working memory components, using a stringent experiment, multiple-baseline-by-subjects design, in order to permit cause-effect inferences concerning the training programme.

In conclusion, the present findings can be summarised as follows:

1. Some, but not all, neurocognitive function tests have common underlying processes.
2. Analyses of working memory and non–working memory cognitive function tests suggest that examining executive function in isolation does not always capture the full spectrum of cognitive processes involved in such tasks.
3. Data from the regression analysis indicate that Tower of Hanoi task could be better explained by both visual- and auditory-based memory components, particularly those involving working memory component, in a group of residual schizophrenic patients.

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