Frontal lobe involved in conceptual explicit and implicit memory process: evidence in favor of component process model

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[Abstract] Object There are many kinds of reference model of neural mechanisms to explain memory processing. According to the multiply memory of system, memory can be classified into explicit memory and implicit memory; According to the processing theory of memory: memory is divided into conceptual and perceptual processing. And component process framework indicated that different brain areas may process with specific memory components. In this study, patients with frontal lobe damage were enrolled to take a series of memory tasks, to certify the component process model of memory theory. **Method** To establish the conceptual and perceptual process explicit and implicit memory experimental paradigm, 25 patients with frontal lobe damage and 25 matched with the age, education of healthy control groups, two groups of patients were taken general cognitive function test, as well as explicit memory and implicit memory test. **Results** The frontal lobe injured group not only exists damage in background neuropsychology tasks, but the conceptual explicit memory and implicit memory are obvious damage, the performance of perceptual explicit memory and implicit memory in frontal lobe damage group has no obvious different with healthy controls. **Conclusion** Frontal lobe characteristic to participate in the conceptual memory processing, take a neuropsychological verification to the component process model of memory.

Keywords
Frontal lobe, implicit memory, explicit memory, component process modle.

Introduction

Memory is a complex process in human cognitive. For psychology and neuroscience researcher, several kinds of models used to explain the process of the memory. The memory systems framework, one of the most pressing theoretical issues was memory dissociated by explicit and implicit with different brain areas, According to the memory systems framework, explicit and implicit memory task are dissociable because they depend on different memory systems. The most popular theory within this framework is the declarative–nondeclarative theory, which postulates that explicit memory tasks are mediated by a declarative memory system, in which conscious awareness of having retrieved a memory is a prime component. By contrast, implicit memory tasks are mediated by several nondeclarative memory systems [1-2], such as procedural or perceptual systems, which do not depend on conscious awareness of the memory that is retrieved. Most common evidence for implicit memory arises in priming, a process whereby subject show improved performance on tasks for which they have been subconsciously prepared [3]. It has been argued that performance on explicit memory (like free recall and recognition) depends critically upon the integrity of the medial temporal lobe (MTL) and prefrontal cortex (PFC) regions, whereas performance on implicit memory (like free-association and category exemplar generation)

depends upon the integrity of other neural structures, like frontal and occipital lobe [1]. Although many functional neuroimaging and neuropsychology findings fit well with these ideas, but there was also found that explicit and implicit memory both involved in prefrontal lobe or MTL region.[4]
According to the processing modes framework, dissociations reflect differential engagement of different types of processing. The dominant theory within this framework is the conceptual–perceptual theory[5-6]. The processing modes framework believed that dissociations between explicit and implicit tasks occur because the former emphasize conceptual processing (or semantic processing) and the latter emphasize perceptual processing (or sensory processing). Although these predictions fit well with many functional neuroimaging studies, these broad differences cannot explain dissociations on memory tests between regions associated with the same processing mode. For example, the left anterior ventrolateral PFC and the middle temporal gyrus are both involved in semantic processing, but their contributions to memory task has been disassociated, the PFC contributed to both episodic memory encoding and semantic memory retrieval, but the middle temporal gyrus only associated with episodic memory encoding[7].

Finally, Moscovitch et al[8] raised the component process model which proposed that there are dozens of different processing components in memory. The model has four essential components: (1) a non-frontal neocortical component consists of perceptual modules, (2) a modular medial temporal/hippocampal component that mediates explicit, episodic tests with associative/cue dependent, (3) a central system, frontal-lobe component mediates performance on strategic explicit and procedural, and (4) a basal ganglia component mediates performance on sensorimotor, procedural memory. The component process model underlies region-specific theories that cut across memory systems and processing modes. The frontal lobe component was the most important factor in conceptual memory process. Badre et al[9] found that left ventrolateral prefrontal cortex mediates controls access to semantic representations can explain the involvement of this region not only during semantic and episodic memory tasks but also during conceptual priming tasks. Although there are dozens of these region-specific theories, only a few neuropsychology studies for PFC processing in memory component.

In this study, we focused on the frontal lobe injured patients, and used structurally parallel perceptual (picture identification for perceptual IM and picture recognition for perceptual EM) and conceptual (category exemplar generation for conceptual IM and classification recall for conceptual EM) memory tests, as well as neuropsychology background tests. Based on component process mode, we predicted that patients with frontal lobe injury would exhibit specific deficits in conceptual or perceptual memory processing relative to healthy controls.

Materials and Methods

Participants

Brain injured group: 25 patients with injured frontal lobes, all of whom gave informed consent, were included in this study. The 25 patients with brain injuries were all hospitalized in the Department of Neurology of The People's Hospital of YuXi City. Inclusion criteria were: a) onset of frontal injury from 2 weeks to 2 months ago; b) no signs of aphasia, agnosia, diplopia, or neglect; c) no depression and psychiatric symptoms after injury, and no psychiatric history; d) general cognitive function rated normal, and a Mini-Mental State Examination (MMSE) ≥ 24 points. Exclusion criteria were as follows: a) clearly evident dementia or depression after stroke; b) clear history of stroke, cerebral infarction, or massive cerebral infarction; c) other brain injury that can lead to physical and mental dysfunction disorders. Lesions were on the right side in the prefrontal cortex of 12 patients, and 13 on the left side. Four patients who had injury extending outside the frontal cortex were excluded.

The healthy control group (HC): 25 people from the YuXi community, healthy normal adults or patient's relatives. The HC group included 13 male and 12 female subjects; aged 47 to 75 years (mean 65.50 ± 8.87). All were educated for over 5 years, with the average education level being 9.35 years (range of 6–15). Inclusion criteria were as follows: a) no psychiatric and neurological disorders; b) no complaints of memory decline; c) cooperative and with no serious physical illness; and d) MMSE ≥ 26 points.

Each subject underwent a uniform clinical evaluation that included a medical history, a neurological examination, and neuropsychological performance testing. The study was approved by the Research Ethics Committee of The People's Hospital of YuXi City (NO: 2012001), and written informed consent was obtained from all participants.

The neuropsychological tests detail introduced below were the same as our previous study (see [10]

Neuropsychological background tests

A comprehensive battery of tests was administered to assess general cognitive and memory functions, including the MMSE to measure global cognitive function, and the Verbal Fluency Test (VFT) to measure frontal lobe function. In the VFT, the subject was asked to generate as many words related to animals as possible in 1 minute. The total score the subject could receive on the VFT was the number of animals generated. Digit Span (DS) was used to measure working memory. The Digit Span Test included the Forwards and Backwards Digit Span Test. In the Digit Span Test, a series of lists of numbers is presented verbally to the subject. For each list, the subject is asked to recall the numbers in ascending (forward) or reverse (backward) numerical order. The total score is the number of lists that are correctly remembered in ascending and in reverse numerical order.

Memory test

Conceptual explicit memory task (CEM)

Conceptual explicit memory was evaluated by using the classification recall task. In the study phase, subjects were presented with 16 words include in four categories: furniture, animals, and body parts, career. Subjects were asked to classify words rendered judgment and memory word, record the correct rate of identification. After two minutes, take to the testing phase. During the testing phase, the subjects asked to recall the words of various types of memory, the recall number take as the classification recall score.

Perceptual explicit memory task (PEM)

A task named as picture recognition was taking as perceptual explicit memory test. Select 30 simple lines pictures including fruits, vegetables, animals and celebrities, tools, all pictures was showing to subjects in the test phase, ask subjects to name and try to remember these pictures, record the correct rate of naming. After two minutes, take to the testing phase. During the testing phase, the subjects were asked to identify the presented 60 randomly pictures (including the study had 30 pictures) whether studied or not. Correctly identified number minus error recognition number was picture recognition score.

Conceptual implicit memory task (CIM)

Conceptual priming was evaluated by using the category exemplar generation task [11]. During the study phase, the participants were visually presented with 20 words belonging to 1 of 2 categories (e.g., vegetables, household appliances), 1 at a time, individually printed on cards. The categories were matched with respect to category potency [12]. The subjects were asked to indicate whether the words represented living or nonliving entities. During the test phase, which was administered 15 minutes after the study phase, the subjects were asked to generate 8 examples for each of 4 specified categories (2 old and 2 new) as quickly as they could. The instructions were given without reference to the previously studied list of words. A different category was presented when the individual had generated 8 examples or if the subject failed to produce a new response in a 1-minute period. The examiner recorded the words they said by using a tape recorder. The examples for the unstudied categories were used as a baseline measurement of performance for this task. Priming was measured as the increase in the probability of producing a studied versus an unstudied category example.

Perceptual implicit memory task (PIM)

Perceptual priming was investigated by a picture identification test [13]. The stimuli consisted of 80 grayscale images comprising 40 “entity” images of common objects, and 40 corresponding mosaic images of each picture. The entity images contained animals, fruit, tools, and other common objects, and the mosaic images were manufactured using Adobe Photoshop software. The identification rate of each entity image and each mosaic image was over 98% and 20%–30%, respectively, by 40 adults. During the study phase, the participants were presented with a list of 20 entity images, and were required to rate each image on a 5-point liking scale. The study list assignment was counterbalanced across the participants. The study was self-paced, but the participants were told to respond as quickly as possible. During the test phase, which was administered 15 minutes after the study phase, participants were presented with the 40 mosaic images (half with studied items and half with new items). The participants were asked to name each image within 10 seconds. Guessing was allowed. Priming was measured as the increase in the probability of naming a studied versus an unstudied mosaic image.

Statistical analysis

The SPSS (version 15) statistical package was used for the data analysis. Differences in age, education, MMSE, VFT, and DS score between patients with brain injury and healthy controls were assessed using t-tests. Comparisons among patients with brain injury and healthy controls on the performance of explicit memory and implicit memory were performed via an independent samples t-test. Comparisons among left and right frontal patient and healthy controls on memory task were assessed by One Way ANOVA, and comparison among groups used the S.N.K test. We used Pearson's correlation to examine the association between implicit and explicit memory tests and neuropsychological background tasks. The probability level of significance was 0.05.

Results

Background and basic neuropsychological evaluation task

In Table1, there was no significant difference between the frontal lobe injured patients and the healthy controls in terms of age, education ($t = 1.821$, $P > 0.05$). The performance of the patients in frontal lobe injured groups was significantly poorer than HC group on the MMSE, VFT, DSF, and DSB (MMSE: $t = 6.958$; VFT: $t = 7.045$; DSF: $t = 4.896$; DSB: $t = 4.000$; $P < 0.05$) (see Table 1, Figure 1).

Insert Table 1 Figure 1

Performance of the explicit memory task

There was no significant difference between the frontal lobe injured group and healthy control on perceptual explicit memory task ($t= - 1.439$, $P > 0.05$), but the conceptual explicit memory in frontal lobe injured group was poorer than healthy controls ($t= 5.719$, $P<0.01$), and there was no different in correct rate on study phase in classification recall task ($t = -0.439$, $P<0.05$). (See Table 2, Figure 2)

Insert Table 2 Figure 2

Performance of the implicit memory task

There was no significant difference between the patients with frontal lobe injured group and the healthy control group in terms of the identification task ($t = 0.858$, $P > 0.05$), but the performance of the image category exemplar generation task in the patients with frontal injured group was poorer than that in the healthy control group ($t = 6.945$, $P < 0.01$), and the accuracy of image identification in frontal lobe injured group was no poor than that in the healthy controls group ($t =2.015$, $P < 0.05$). (See Table 2, Figure 2)

Insert Table 3 Figure 3

Different between left and right frontal lobe injured patients in conceptual and perceptual memory

In the frontal injured group, 13 patients injured at left frontal lobe and 12 patients at right. To compare whether there was different performance of memory in the left and right, we adopt a one way ANOVA. The statistical results displayed that the three groups had significant different in performance of MMSE, VFT, DSF, DSB, CIM, CEM tasks ($P > 0.05$). The comparisons results between left and right frontal patients groups displayed no significant different in all conceptual explicit and perceptual memory tasks, but in conceptual implicit memory task, the scores of left frontal patients were poorer than right frontal patients ($P < 0.01$). (See Table 3, Figure 3)

Relationship between implicit and explicit memory tests and neuropsychological background tasks

The relationship between priming performance on the implicit tasks performance and the related explicit tasks was analyzed. No correlations were significant (r's = 0.04 to 0.3, $P > 0.05$). The conceptual implicit task (category exemplar generation) was positively correlated with verbal fluency test ($r = 0.642$, $P < 0.01$), No signification correlations were found in other memory tests and neuropsychological background tests (r's = 0.02 to 0.25, $P > 0.05$).

Discuss

In this study, we first established a series of conceptual and perceptual process tasks, including explicit and implicit memory. The frontal lobe injured patients and controlled healthy adults were involved to take the four memory tasks, as well as a neuropsychology background test like MMSE, VFT, and digital span. Our results showed that frontal lobe injured presented poorer in the general cognation (MMSE), verbal fluency (VFT) and work memory (DS). The mainly found in the study was that frontal lobe injured patients showed not only explicit memory but also implicit memory impairment, impaired in conceptual memory but not in perceptual memory disregard the process was explicit or implicit.

These findings match those of a considerable number of studies that have found a dissociation between conceptual priming and perceptual priming in frontal damaged patients (in Korsakoff patients[14], in schizophrenia[15], and right frontal lobe lesions[16]). In the aspect of explicit memory, frontal lobe lesion patients also found impaired in episodic memory, working memory, and source memory[17], and for explicit conceptual process task, like semantic memory, the prior studies proved much more that frontal lobe involved in semantic memory processing[18]. In addition, specific task demands of the experimental protocols may vary in the need for frontal lobe involvement among studies, if the tasks vary in the requirement for semantic process encoding or strategic search and retrieval strategies as previously proposed [19-20].

The finding that frontal patients exhibited impaired performance on explicit and implicit a conceptual test of cued recall suggests that the memory deficits of these patients may not be limited to conscious processes. Some past studies have suggested that frontal patients exhibit only explicit conceptual memory. Gershberg, et al[21] found that frontal patients exhibited impaired explicit category-cued recall and associate-cued recall compared to their controls, but in the implicit category production test and free association test, the frontal patients priming effect was not signification different to controls. But in their implicit task, there was little semantic process in the study phase (only read the words), and their sample size was small (only 7patients). Bergerbest's, et al[22] fMRI study exhibited that reduced asymmetry of prefrontal activation reductions in healthy aging was related to conceptual repetition priming, promoted aging spare in semantic priming, but need collaboration of both cerebral hemisphere, mainly prefrontal lobe. Eskes, et al[23] found word fragment completion priming and category exemplar cued recall was impaired by left dorsolateral and medial lesions patients,

Damage to the frontal lobes results in memory impairment across a variety of tasks, including tests of immediate memory span, memory for temporal and source information, and metamemory[24]. The cortical regions involved in semantic processing was considered in the prefrontal cortex[25], especially reliant on left inferior frontal gyrus[26]. In this study, four memory tasks were designed to test conceptual and perceptual explicit or implicit memory. Classification recall and category exemplar generation task which was taken for conceptual memory evaluate both involved with a semantic process in study phase, in test phase both task used free recall to evaluate the memory, there was a common three stage processing: semantic encode, store and retrieve. Picture recognition and picture identification task which was taken to evaluate the perceptual both involved a visual perception encode in study phase, and in the test phase both conclude a perceptual recognition, there was also a common three stage processing: visual perception encode, store and retrieve. The results of present study displayed that frontal patients impaired in both conceptual task but preserved in both perceptual task no matter explicit or implicit. Thus, these findings suggest that frontal patients have a basic deficit in semantic processing of individual items. Rather, their conceptual deficit may be related to their deficits in the use of semantic encoding and strategic retrieval processes on matter the encoding was conscious or non-conscious[27].

The processing components themselves are associated with different neural regions and recruited in a flexible and often task specific manner to achieve some particular processing goal[27]. In this case, a frontal executive component requiring strategy selection and maybe response inhibition could be seen as being activated for both the conceptual tasks. The present study result display a single disassociation in perceptual and conceptual processing in whether implicit or explicit memory, and our result also manifested conceptual implicit memory and conceptual explicit memory may have a same process brain area, maybe the frontal lobe. Our study was well certified the component process model of memory in the frontal areas, and it is considered that frontal lobe may mainly involved in semantic process encoding and retrieving.

In summary, our results suggest that the two types of memory in explicit and implicit memory are dissociated in frontal lobe injured patients. Compared with healthy controls, patients with occipital stoke seem to demonstrate impaired performance on conceptual, but not perceptual memory tasks.

The current study also implies that conceptual memory is a processing component in frontal lobe.

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Table 1 Demographic and neuropsychological background tests of PF and HC. ** $P < 0.01$.

Characteristic	Patients with frontal lobe injured (PF)	Healthy controls (HC)
Number of participants	25	25
Sex (F/M)	12/13	13/12
Age, years (mean (SD))	63.76 ±11.63	65.04 ± 8.86
Educational level	8.28 ± 2.34	9.64 ± 2.91
MMSE, mean (SD)	$25.64 \pm 2.59^{**}$	29.36 ± 0.64
DS-F, mean (SD)	$6.52 \pm 1.08^{**}$	7.68 ± 0.48
DS-B, mean (SD)	$3.40 \pm 0.82^{**}$	4.20 ± 0.58
VFT, mean (SD)	$9.48 \pm 3.18^{**}$	15.76 ± 3.13

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Measurement	Patients with frontal lobe injured (PF)	Healthy controls (HC)
Explicit memory		
Classification recall	3.88 ± 1.51**	6.04 ± 1.13
Classify correct rate (%)	97.75 ± 3.98	97.25 ± 4.07
Picture recognition	25.40 ± 2.86	25.28 ± 3.26
Picture naming correct rate (%)	96.93 ± 3.96	98.40 ± 3.21
Implicit memory		
Category exemplar generation	1.98 ± 0.96**	3.50 ± 0.52
Picture identification	20.55 ± 7.02	21.99 ± 4.74
Picture naming rate in study phase (%)	91.55 ± 9.06	95.55 ± 4.08

Table 2 Explicit and implicit memory scores of healthy controls and PF patients. ** $P < 0.01$.

Measurement	Patients with left frontal lobe injured (lPF)	Patients with right frontal lobe injured (rPF)
Explicit memory		
Classification recall	3.25 ± 1.42	4.46 ± 1.39
Picture recognition	24.33 ± 2.54	26.38 ± 2.87
Implicit memory		
Category exemplar generation	1.41 ± 0.87**	2.50 ± 0.74

Picture identification	19.43 ± 7.18	21.58 ± 7.01

Table 2 Explicit and implicit memory scores of left and right frontal patient. ** $P < 0.01$.

Figure 1 the background neuropsychology test of frontal patients and healthy controls. MMSE: Mini-Mental State Examination; VFT: Verbal Fluency Test; DSF: Digit Span Forward; DSB: Digit Span Backward; PF: patients with frontal lobe injured; HC: healthy controls. ** $P < 0.01$.

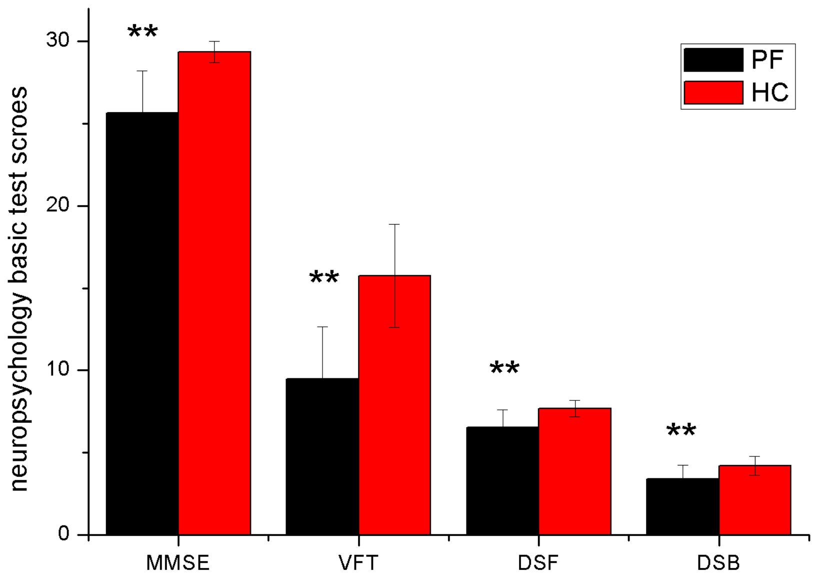

Figure 2 the scores of memory task in frontal patients and healthy controls. CEM: conceptual explicit memory; CIM: conceptual implicit memory; PEM: perceptual explicit memory; PIM: perceptual implicit memory; PF: patients with frontal lobe injured; HC: healthy controls. ** $P < 0.01$.

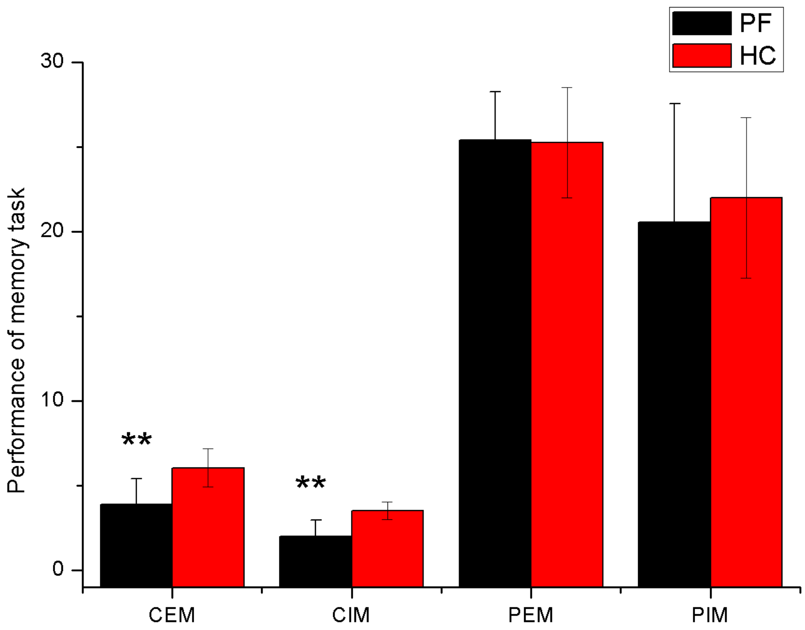

Figure 3 the scores of memory task in left and frontal patients. CEM: conceptual explicit memory; CIM: conceptual implicit memory; PEM: perceptual explicit memory; PIM: perceptual implicit memory; lPF: patients with left frontal lobe injured; rPF: patients with right frontal lobe injured; $^{**}P < 0.01$.