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Memory Storage and Encoding in Patients with Memory Deficits after Closed Head Injury

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Abstract

We studied the storage and processing of memory in 16 patients with closed head injury who complained of memory deficits. We compared the performance of patients on several measures with that of 16 age, education and sex matched normal controls. Patients had deficient short term storage and were slower to learn. The long term storage and retrieval were adequate. Depth of encoding and automaticity of encoding were poorer in quality though present in patients. Patients remembered better when the encoding was semantic and the retrieval cue was congruent. Storage and encoding deficits were not related. We postulate that the adequate retrieval in patients appears to involve a compensatory coping mechanism of greater mental effort.

Key words -

Closed head injuries,
Cognition disorders,
Head injuries,
Memory disorders,
Neuropsychological tests

Memory problems are the most commonly reported subjective symptoms after closed head injury [1], [2]. Impaired memory is one of the factors which decreases the work capacity and leisure pursuits [3], [4]. Short term and long term memory are impaired after head injury. Head injured patients have a deficit in the ability to place material in short term storage and deficit in the ability to retrieve material once it is stored [5]. Immediate memory (short term storage) as reflected by forward digit span is comparatively resistant to closed head injury. However backward digit span [6], visual short term memory [7], [9] are impaired. Recall under interference from long term memory is impaired [10]. Delayed recall is poor on a logical memory test [11].

Research on memory deficits as a sequelae of Closed Head Injury has concentrated on the stage (short term or long term) and the modality of the memory deficit. The process mediating failure in memory has not been studied. Research on memory deficits in other clinical conditions has given indications about what processes may lead to memory dysfunctions [12]. The two widely studied processes are the levels of processing [13] and automatic encoding [14]. Studies of depth of processing in amnesias [15] Korsakoff's syndrome [16], bilateral frontal lesions [17] and dementia [18] have shown impairment in deeper levels of processing. Immediate memory is intact, phonetic encoding (shallow levels) is preserved, whereas failure in semantic encoding (deeper levels) causes a deficiency in the transfer of information into permanent storage. Investigations using the automatic encoding approach in amnesias [19] and epilepsy [20] have shown that automatic encoding was effortful, whereas in depression automatic encoding was preserved but effortful encoding was affected [14], [21].

The approaches of depth of processing and automatic encoding have not been used to understand the memory deficits in head injury. The present study aimed to assess the nature of encoding process in closed head injury patients with subjective complaints of memory loss as compared with normal controls. We studied the nature of relationship between level of processing; automaticity of encoding; subjective ratings of memory loss; stages of memory i.e., short and long term storage, nature of retrieval and behavioural sequelae.

Method

Sample: We studied 16 patients with closed head injury and 16 normal controls. The mean age was 30.13 years (S.D = 3.77) for the patients and 29.94 years (S.D = 3.70) for normals. The 16 patients were drawn from the Neurosurgery outpatients clinic and post trauma clinic of NIMHANS, Bangalore and were tested between the period of 2 months and 1 year post head injury (Mean = 4.32 months, S.D = 1.92 months). The duration of unconsciousness after head injury ranged from few seconds to 10 minutes (mean = 4.0 minutes, S.D = 1.5 minutes). Patients were occupationally and socially well adjusted, but complained of memory deficits. Neurological deficits, dementia, psychosis, post traumatic epilepsy, history of neurological and psychiatric disorders were absent.

Visual anologue Scale: It consisted of a 10 cm line with markings from 0-9 representing minimum intensity to maximum intensity of memory impairment [22]. Each patient was asked to pinpoint on the scale a number which would best depict the extent of his/her memory loss, thereby representing the patient's subjective report of memory loss

Neurobehavioural rating scale: It consisted of 27 items to be rated on a 7 point scale ranging from "not present" to "extremely severe" [23]. These items had high loadings on 4 factors; Cognition/energy, meta cognition, somatic concern and language.

Selective reminding test: This is designed to assess memory functions in terms of storage, in short term and long term memory and retrieval from long term memory [24]. The verbal subtest was used in this study which consisted of a list of 10 words that were serially presented to the subject with a 2 second gap between each word. The subjects recalled the list in any order. If the subject with a 2 second gap between each word the subjects recalled the list in any order. If the subject failed to recall any word(s), the experimenter selectively reminded him by reading out in serial order the words missed out. The subject then recalled the whole list again. This process continued until the whole list was recalled or until 10 trials were over, whichever was earlier. This modification resulted in four scores namely :

a) short term storage (STS), being the number of items recalled in the first trial;
b) Long term storage (LTS), being the number of items recalled twice consecutively (irrespective of non-recall of the same items in subsequent trials);
c) Consistent long term retrieval (CLTR), being the number of items recalled in the last four consecutive trials (or last three if total trials taken were 7 or less);
d) Total trials (TT) taken for the whole test (Rao, Mariadas, Personal communication)

Automatic Encoding tests

Frequency encoding test [14]**:** It consisted of 70 photographs divided into 2 sets, each containing 35 photographs [20]. Each set had 6 critical items and 17 distractor items. Each of these critical items were presented at different frequencies. Two photographs were presented 5 times each (10 photographs), 2 others were repeated 3 times each (6 photographs) and remaining 2 critical items were shown once (2 photographs). The critical items were interspersed with the distractor items such that no two critical items followed one another. The test was conducted under the incidental and intentional paradigms. In the incidental paradigm, the purpose of the test was not explained to the subjects. The photographs of one set were presented to each subject with a 5 seconds exposure rate. After the whole set was presented, the 6 critical items were individually shown and the subject was asked to report the number of times each critical item had occurred during the presentation. The intentional paradigm followed the incidental paradigm, in which the purpose of the test was explained to the subjects. The second set of photographs were used and the procedure was similar to the incidental paradigm. In each paradigm the score was the sum of the deviation score (i.e., sum of the difference between actual frequency and reported frequency for each critical item).

Spatial encoding test [20]**:** It consisted of 2 sets of 16 common objects. Each set was arranged in a 4 × 4 matrix array in a dimension of 2 × 2 feet. In both the incidental and intentional paradigms, the set of 6 objects were exposed for 2 minutes and the subject named each object. Then the objects were covered and a paper with a 4 × 4 matrix block was presented. The subject spatially located on the matrix block all the objects named by the examiner. As in the frequency encoding test, in the incidental paradigm the subjects were blind to the purpose of the test, whereas in the intentional paradigm the nature of the test was known to the subjects. The total number of correct responses constituted the score in each paradigm.

Depth of processing test [25]**:** It consisted of 48 common concrete nouns with a length of 4-6 letters. Each word had an encoding cue and a retrieval cue belonging to the context of a rhyme (denoting shallow level of processing) or category (denoting deeper level of processing). In the encoding condition, each word was preceded by a question pertaining to a context, eg. (a) Does the word rhyme with the following word? (Category encoding). The subjects were asked to respond positively or negatively, since half the words did not have a relevant cue (i.e., half the test words either did not rhyme with the given word or fit the given category). This was done to ascertain which of the two encoded traces (in the light of the encoding-specificity view) would yield higher recall. Hence combination of the two encoding context types (rhyme and category) and two response types (positive and negative) yielded four different encoding retrieval conditions. Forty eight cue cards were used for retrieval, each of which was a valid cue of one of the 48 words shown in the encoding phase. Of the 48 words, 24 had rhyme cues and 24 had category cues. Except for the two conditions of rhyme-positive followed by rhyme cue (retrieval cue was identical to the encoding question), retrieval cues were not identical to the encoding question. Typically, a word encoded under one question (e.g. rhymes with brain?-TRAIN) would be given a different but valid retrieval cue (i.e. form of transport). Similarly, words whose encoding questions yielded negative responses in the encoding phase were given valid cues at retrieval. The subjects were told that they would be participating in a reaction time experiment. In each trial the subject saw a card, on which an encoding question was printed. After reading the question, the subject looked into a tachistoscope, wherein a word eg. (HAT) was exposed for 200 ms. On reading the word the subject had to answer immediately with either a 'Yes' or 'No' in response to the encoding question. After the completion of 48 such trials the subject recalled these words with the help of another 48 words which were retrieval cues presented individually on cards. The subjects knew that the retrieval cues were either a rhyme or denoted the category of the words previously seen through the tachistoscope. The score was the sum of the correct recall under each encoding-retrieval condition.

Results

1. Comparison of memory storage and retrieval

We compared the mean scores of short term storage (STS), long term storage (LTS) and consistent long term retrieval (CLTR) assessed by the selective reminding test (Table I).

Table I - Mean and standard deviation of storage and retrieval scores

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Two way ANOVA repeated measures showed on STS, LTS and CLTR scores and subsequent Duncan multiple range test found the short term storage of patients to be significantly lesser than that of the normal controls. Patients took significantly longer to learn as seen by the larger total trails score (t test for uncorrelated means).

2. Comparison of automaticity of processing

We compared the incidental and intentional paradigms in the frequency encoding condition and in the spatial encoding conditions (Table II).

Table II - Mean and Standard Deviation of automatic encoding

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Two way ANOVA (repeated measures) showed the patients were significantly poorer than normals in both frequency encoding $F = 97.7$, $P < .01$ ($F = 11.5$, $P < .01$) and spatial encoding ($F = 97.7$, $p < .01$). The significant interaction ($F = .05$ and $F = .41$) respectively indicated that it was true in incidental and intentional paradigms. Duncan's multiple range test did not find a significant difference between the incidental and intentional paradigms in either encoding condition in patients or in normals. Therefore automaticity of frequency and spatial encoding is present in patients and in normals.

3. Comparison of depth of processing

The mean scores of the depth of processing test are shown in Table III.

Table III - Means and Standard Deviations of depth of processing

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rr = Phonetic encoding, Phonetic retrieval cue
cc = Semantic encoding, Semantic retrieval cue
rc = Phonetic encoding, Semantic retrieval cue
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Three way ANOVA (repeated measures) and subsequent Duncan's multiple range test gave the following significant findings. In patients depth of processing was present. Recall was better under the semantic encoding condition (cc) when compared with the phonetic encoding condition (rr). The principle of encoding specificity operated only in the semantic encoding condition (cc+). Patients remembered better when the encoding was semantic and the retrieval cue was congruent. However in this semantic encoding-cue congruent condition, the patients remembered less compared with normals. Even when the nature of encoding and retrieval were phonetic patients remembered less than normals. These findings indicate that patients are deficient in the depth of processing. In normals also the depth of processing was present, as the recall under semantic encoding (cc) was better than under phonetic encoding (cc). Encoding specificity operated. Congruence between the nature of the encoding condition and the nature of the retrieval cue improved recall. Recall was better on semantic encoding congruent cue condition (cc) and phonetic encoding congruent cue condition (rr) in comparison with the non congruent conditions (r and c). The relationships are set out in Figure I. In both groups performance was better under the positive encoding question type in the semantic and phonetic encoding conditions.

4. **Relation of patient variables with storage and encodings**

We assessed the relationship of subjective complaint of memory loss (visual analog scale score) and neurobehavioural sequelae (Neuro behavioural rating scale score) with the measures of storage and encoding in the patient group. The depth of processing score was computed as $rr^{+} - cc^{+} + 10$. Only the score arising from the positive encoding questions were used since the level of processing was deep in this condition in both groups. To eliminate the signs, a standard score of 10 was added to the difference between the phonetic and semantic congruent score in the positive encoding question type. Thus a score of below 10 would indicate deeper levels of processing.

Table IV - Mean and standard deviation of subjective memory loss, neurobehavioural sequelae and depth of processing

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The rank difference correlation coefficient method was used to determine the relationship between the patient variables on the one hand and the measures of storage and encoding on the other. There were no significant relationships between the subjective complaints of memory loss and storage retrieval functions of memory and the encoding process. (b) no significant relation between the neurobehavioural sequelae and storage/retrieval functions of memory and the encoding process. (Table V).

Table V - Correlations between clinical variables with storage and encoding in patients

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5. **Relation between storage and encoding in patients & normals**

The relationship between storage and encoding in patients and normals were computed using the Rank difference correlation coefficient method. (Table VI). The results showed that in patients, there was no significant relation between the encoding processes (frequency encoding, spatial encoding and depth of processing) and storage and retrieval functions of memory. In normals,
(a) there was a positive, significant relation between frequency encoding and retrieval indicating that

greater the frequency encoding, greater would be the retrieval.

(b) there was a positive, significant relation between spatial encoding and short term storage; as well as between spatial encoding and retrieval. This implied that greater the spatial encoding, greater would be the short term memory and retrieval.

(c) there was a significant, positive relation between depth of processing and long term storage and depth of processing and retrieval, thereby indicating that greater the depth of processing, greater would be the long term memory and retrieval.

Table VI - Relationship between storage and encoding in patients and normals

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Note: * $p < 0.01$ **$p < 0.05$

Discussion

Depth of processing and automaticity of processing are present in head injured patients, but are poor in quality. Despite the poor quality of processing (poor spatial encoding, poor frequency encoding and poor depth of processing) it was found that the quantum of information recorded in long term storage was similar to the normals, even though LTS was attained at a slower pace. This would indicate that besides the processes of automaticity and depth, some other process could be operating which compensates for the differences in encoding between the two groups. Two hypotheses may explain these results. First, at the stage of encoding another mechanisms of encoding may be operating which was not recorded by the tests of encoding used in this study. The depth of processing test could also be making use of figural encoding besides verbal encoding resulting in double encoding [26]. Therefore, in patients the capacity for evoking a final code upon the presentation of a verbal stimulus could be more relied upon than in normals for storage and retrieval, thereby compensating for the deficits in the semantic and phonetic encoding. Second, due to the deficits in encoding, the patients could be making a greater mental effort to compensate for these deficits, thereby achieving long term storage similar to normals, though at a slower pace. A similar coping hypothesis was put forth explaining that the decreased rate of information processing in head injury patients resulted in a compensatory effort to deal efficiently with the demands on daily life [27]. This mental effort could be reflected in the behavioural repertoire of the patients. An analysis of the neurobehavioural sequelae of the patients revealed that majority of the patients reported somatic symptoms of headache and dizziness (N = 16), rapid fatiguability on cognitive tasks (N = 15), anxiety (N = 13) and tension (N = 12). It has also been stated that when the compensatory effort became chronic, it could result in secondary symptoms called the post concussional syndrome (i.e. complaints of headache, dizziness, anxiety, fatigue and irritability) [27]. Further, it was found that the subjective complaint of memory loss had no significant relation to memory processes. Head injury patients who complained of poor memory in activities of daily living performed within normal limits on formal memory testing [28]. The compensatory mechanism discussed above could also be influencing this phenomenon.

Moreover, it was found in the study that patients were unable to profit from the provision of cues in frequency and spatial encoding (intentional paradigms). This could indicate that the greater mental effort utilized may be interfering in the encoding process. The deficit in short term storage could be indicative of a slowing down in the registration of information, in terms of slowing in feature extraction and iconic trace. A slowing down in information processing has also been reported after head injury [8], [29], [30], [31]. A significant relation between retrieval and frequency encoding spatial encoding and depth of processing was found in normals and not in patients. This would indicate that multiplicity of encoding cues ensure retrieval in normals, and because of the paucity of these cues (possibly because of the poor quality) patients require a compensatory coping mechanism of greater mental effort, for adequate retrieval.

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