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Effect of Frontal Lobe Traumatic Brain Injury on Sentence Comprehension and Working Memory

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Abstract

Background: This study was conducted to examine the sentence comprehension and working memory in individuals with mild and moderate frontal lobe traumatic brain injury (TBI) and determine the relationship between them.
Methods: Participants included 18 patients with mild TBI, 17 patients with moderate TBI and 18 non-TBI individuals. The digit span subtest of the Wechsler intelligence scale-IV (WISC-IV) and a N-back test were used to evaluate working memory. Moreover, the syntactic comprehension subtest of Bilingual Aphasia Test (BAT) was used for sentence comprehension assessment.
Results: The results showed that patients with mild and moderate TBI had a lower performance in comprehension of non-canonical sentences and working memory compared to the non-TBI group. There was also a significant correlation between sentence comprehension and working memory in the TBI groups.
Conclusions: Sentence comprehension and working memory in TBI patients with frontal lobe damage are significantly lower than that of the non-TBI group, which may lead to some daily communication problems in these individuals.

Keywords: Traumatic Brain Injury, Sentence Comprehension, Working Memory, Frontal Lobe

1. Background

The frontal lobe, especially the prefrontal region, is exposed to risks more than the other parts of the brain in the accidents that lead to brain injury, causing failures in cognitive levels and executive functions. The process of an executive function refers to cognitive functions at high levels that participate in the control and conduction of lower functional levels such as language, cognition, memory, and behavior (1-4). Moreover, inferior frontal gyrus (Broca's area) is a known area in speech production and syntactic comprehension (5). Language impairment, after TBI, is frequently reported in the recent studies. The occurrence of these disorders suggests that the problem of language in these individuals may be due to the problem of allocating attentive resources to the cognitive communication functions (6). More than experiencing specific language problems by the patients, they mainly suffer cognitive communication disorders, which seem to be due to the damages in language and meta-linguistic skills and the damages in non-linguistic cognitive functions such as the working memory, deductive reasoning, and perception discrimination (7). It seems that the problems of these people are mainly in language comprehension rather than expression. The comprehension problems of these people can extend from sentence comprehension to the discourse comprehension (8).

In addition, there are various reports indicating that the injury to the frontal lobe causes the failure of fluency, inhibitions, attention, set-shifting, and working memory (9, 10). Deficit in working memory performances is one of the most prominent cognitive problems in the patients with TBI (11). Working memory is a dynamic system used for temporary storage and manipulation of information and for the complex cognitive duties such as learning, reasoning, perception, and thinking. Moreover, working memory is associated with the information that should be transmitted to the long-term memory. In general, the working memory is involved in any process that requires reasoning (reading, writing, and mental calculations) (12).

According to Baddeley's model, the components of working memory include phonological loop, visual-spatial sketchpad, central executive mechanism, and episodic

memory. The phonological loop, also referred as phonological short-term memory (pSTM), is one of the slave sub-systems within the WM system that is responsible for short-term storage of verbal materials and preventing their decay. The central executive system is a commanding and controlling center that manages the interaction between the two storage components of the working memory. This part coordinates the activities related to attention and also supervises the responses of the individuals (13).

Considering the role of the frontal lobe in the language comprehension and working memory, any injury to this lobe will affect these two skills. To better understand the relationship between language comprehension and working memory, new research should be held more specifically and more precisely in patients with frontal lobe injury (14).

The aim of the current study is to evaluate the working memory skills as well as language comprehension performances at the sentence level in patients with mild and moderate frontal lobe injury. Although these patients return to their social activities, they have an experience of cognitive problems affecting their performances and have less consciousness on their cognitive skills (15). Neuropsychological deficits in these patients can cause the processing of information, attention, and executive performance to be defective. A study by Miotto et al. (2) showed that patients with mild to moderate TBI had deficits in data processing, attention, and memory. In addition, since patients with severe TBI showed severe problems in physical activity, concentration, attention, memory, and visual perception (barman), as well as a high prevalence of dysarthria (16), we chose mild to moderate TBI patients in this study. Furthermore, the correlation between language comprehension and working memory was investigated in this study. The relation between them can be used to establish new studies.

2. Methods

This article was extracted from a Master's thesis (registration code: 395793), which was reviewed and approved scientifically by the Research Council of Isfahan University of Medical Sciences. In addition, the whole procedure was approved by the Ethics Committee of Isfahan University of Medical Sciences (Ethics code: IR.MUI.REC.1395.B.3.793).

2.1. Participants

The patients were recruited from the neurology department of Kashani Hospital in Isfahan. A total of 34 patients were selected based on the inclusion and exclusion criteria of the study. The inclusion criteria of this study were: having a focal frontal lesion (such as frontal contusion, subarachnoid hemorrhage, subdural hematoma (17) according to computed tomography (CT) scan and magnetic resonance imaging (MRI) results recorded in participants' medical history file), age range of 18 - 65 years, right-handed (according to the Edinburgh inventory), glasgow coma scale (GCS) score of 9 - 14 on admission, post traumatic amnesia (PTA) duration of more than one hour and less than seven days, at least a four month post-injury, no history of hearing or visual impairment (based on patient and caregiver interview), no co-existing aphasia (as established through performance of the Western aphasia battery (WAB) adapted) (18), and no evidence of pre-existing neurological or psychiatric disorder (based on patient and caregiver interview).

Moderate TBI was determined by GCS 9 - 12 on admission and duration of PTA more than 24 hours but less than seven days and mild TBI was defined by GCS 13 - 15 on admission and duration of PTA 24 hours at most (19). Neurological details of TBI individuals are presented in Table 1.

The non-TBI group consisted of 18 non-TBI subjects recruited from the local community who were matched with the TBI group on age and education level. Exclusion criteria for the non-TBI group were the self-reporting of previous brain injuries (such as stroke, tumor, and traumatic injury) or psychiatric disorders, drug abuse history, or non-corrected auditory or vision problems.

2.2. Instruments and Procedures for Data Collection

Participants were tested individually in a quiet room of speech therapy clinic. Three tasks including the forward and backward digit span subtests of the WISC-IV (20) and N-back test (21) were used for measuring the working memory skills of participants. Moreover, Bilingual Aphasia Test (BAT) (22) was used for evaluating the sentences comprehension. Working memory and sentences comprehension tests were executed by two separate examiner who were blind to the aim of the study. The total time for executing the tests was about 40 min.

2.3. Sentences Comprehension Task

The syntactic comprehension task contains 87 sentences including affirmative and negative sentences with the subject, object, and verb orders, the sentences that their processing depends on pronouns, cleft sentences (It-Cleft), and affirmative and negative sentences with object + subject + verb (23). Before the research, the sentences of the test were given to 25 normal people who had no information regarding the aims of the study. They were asked to assign the scores "0" or "1" to each sentence regarding the frequency in the sentence applications in the official

Table 1. Neurological Details of TBI Individuals

Patient	Side of Injury	Kind of Injury	Brain CT Scan Finding in Admission	Age, y	GCS in Admission	Posttraumatic Amnesia (Hour-Day)
P1	Left frontal	MVA[a]	Frontal contusion	40	9	5 d
P2	Left & right frontal	MVA	Frontal contusion	18	14	1 d
P3	Left frontal	MVA	Subarachnoid hemorrhage (SAH)	21	13	5 h
P4	Right frontal	MVA	Frontal contusion and SAH	32	14	2 h
P5	Left frontal	MVA	Frontal contusion and Subdural hematoma (SDH)	26	10	2 d
P6	Left frontal	MVA	Frontal contusion and intracerebral hematoma (ICH)	25	12	2 d
P7	Left frontal	MVA	Frontal contusion and SAH	18	14	2 h
P8	Right frontal	MVA	Frontal contusion and SDH	45	9	4 d
P9	Right frontal	MVA	Frontal contusion	22	10	2 d
P10	Left frontal	Falling	Frontal contusion	27	14	1 h
P11	Left & right frontal	Falling	Epidural hematoma (EDH)	20	13	2 h
P12	Left frontal	MVA	Frontal contusion and ICH	30	11	2 d
P13	Right frontal	MVA	Frontal contusion	30	13	1 d
P14	Left frontal	MVA	Frontal contusion and ICH	38	11	2 d
P15	Right frontal	Assault	Frontal contusion	29	12	2 d
P16	Left frontal	MVA	Frontal contusion	24	15	1 h
P17	Right frontal	Falling	SAH	24	14	1 h
P18	Left frontal	MVA	SAH	26	13	1 d
P19	Left & right frontal	MVA	Frontal contusion and SDH	19	13	1 d
P20	right frontal	MVA	Frontal contusion and ICH	21	9	3 d
P21	Left frontal	MVA	Frontal contusion and ICH	23	10	2 d
P22	Left frontal	Sport injury	Frontal contusion and SAH	25	11	2 d
P23	Left frontal	MVA	Frontal contusion and SAH	31	12	1 d
P24	Right frontal	MVA	Frontal contusion	28	14	2 h
P25	Left frontal	Falling	Frontal contusion	22	12	2 d
P26	Right frontal	MVA	SAH	18	13	1 d
P27	Right frontal	MVA	Frontal contusion and ICH	40	13	1 d
P28	Left frontal	MVA	Frontal contusion and SDH	36	10	2 d
P29	Left & right frontal	MVA	SAH	28	9	4 d
P30	Left frontal	MVA	EDH	19	14	1 h
P31	Right frontal	MVA	SAH	42	11	2 d
P32	Left frontal	MVA	Frontal contusion	20	12	2 d
P33	Right frontal	MVA	Frontal contusion	36	15	< 1 h
P34	Left frontal	MVA	Frontal contusion and SAH	38	14	2 h
P35	Left frontal	MVA	Frontal contusion	25	13	1 d

[a]Motor Vehicle Accident

Farsi language. The score of "0" was interpreted in such a way that using that sentence structure was unusual and with low frequency, in the Farsi language, while the score "1" indicated the usual and highly frequent use of the sentence structure. The sentences, where over 80% of the people gave them the score of "1", were considered as canonical. Accordingly, the affirmative standard sentences, negative sentences, and the sentences that their processing depends on pronouns were considered as canonical sentences, while the cleft sentences (It-Cleft) and those with object + subject + verb structure were considered as non-canonical sentences. It is noteworthy that sentences in the official Farsi language follow the subject-object-verb (SOV) structure. In Farsi, verbs have no signs for object and the direct objects and indirect objects are defined by specific markers including "Ra" and "Be", respectively. The pronouns in the Farsi language are considered as personal pronouns, indefinite pronouns, relative pronouns (connect parts of sentences), and reciprocal or reflexive pronouns. Regarding the various roles that pronouns have in sentences, they sometimes increase the processing loads for sentence comprehension (24).

In evaluating sentence comprehension, they were given to the participating subjects in the order that was defined for the test, and the participant had to select the required image based on the heard sentence. The score given for each sentence was either "0" or "1", according to the wrong or right answers, and the total score for the sentences comprehension was determined by summing up the scores. Finally, two scores were obtained for each testing participant with regards to the division of the sentences based on the canonical and non-canonical sentences.

2.4. Working Memory Tasks

The digit span forward and the backward tasks taken from the Wechsler intelligence scale-IV (WISC-IV) were administered. This test includes multiple sequences of numbers given to the subject in hearing mode, where the subject should repeat the numbers in forward or backward forms.

The N-back task was used to measure the working memory (25). The general trend was to give a stepwise sequence of stimuli (visual) to the participating subject and the subject had to find out whether the given stimulus was in conformity with the stimulus given "n" steps before that. The computerized version of the 1-back task was used in the present study. In this task, 120 numbers, including the digits from 1 to 9, appeared in the center of a monitor in a semi-random manner with the 2-second intervals.

2.5. Statistical Analysis

All analyses were run using SPSS software. Statistical analyses were performed using one-way ANOVA and Tukey post hoc test at the 95% confidence level. Pearson test was carried out for calculating the correlation between working memory and sentence comprehension in the TBI group.

3. Results

Demographic information related to age and education for both of the TBI groups and the non-TBI group are shown in Table 2. Owing to the effect of education on the estimation of results, the two groups were compared in this regard, wherein no statistically significant difference was observed (P value > 0.05).

3.1. Sentences Comprehension

3.1.1. Canonical Sentences Comprehension

The one-way ANOVA showed a significant difference among mild TBI, moderate TBI, and non-TBI people in terms of canonical sentences comprehension (Table 3). The post hoc test showed a significant difference only between moderate TBI with other groups.

3.1.2. Non-Canonical Sentences Comprehension

The one-way ANOVA showed a significant difference between three groups in terms of non-canonical sentences comprehension (Table 3). The post hoc test showed a statistically significant difference among moderate TBI, mild TBI, and non-TBI group in terms of non-canonical sentences comprehension. In addition, this was significantly different between mild TBI and non-TBI group ($P < 0.05$).

3.2. Working Memory Tasks

3.2.1. Forward Digit Span

The one-way ANOVA showed a significant difference among mild TBI, moderate TBI, and non-TBI people in the terms of forward digit span (Table 3). Post hoc test showed that only forward digit span in moderate TBI was significantly different from other age groups ($P < 0.05$) (Table 3).

3.2.2. Backward Digit Span

The one-way ANOVA showed a difference between various age groups in terms of backward digit span (Table 3). The post hoc test showed that moderate TBI was significantly different from mild TBI and non-TBI group groups in backward digit span ($P < 0.05$) (Table 3). There was also a significant difference between mild TBI and non-TBI group groups in backward digit span ($P < 0.05$) (Table 3).

3.2.3. N-Back Task

The one-way ANOVA showed a significant difference between three groups in terms of N-back task (Table 3). The post hoc test showed a significant difference between moderate TBI and non-TBI group in terms of N-back task. Furthermore, N-back task was significantly different between mild TBI group and non-TBI people ($P < 0.05$).

The results Parson Correlation analysis showed no-significant correlation between the forward digit span and the canonical and non-canonical sentences comprehension scores in mild and moderate TBI groups (Table 4). There is a considerable correlation between the canonical and non-canonical sentence comprehension scores and N-back and backward digit span in moderate TBI group. Besides, a significant correlation was detected between non-canonical sentence comprehension scores and N-back and backward digit span in the mild TBI group (Table 4).

4. Discussion

The present study was conducted to evaluate the ability of sentence comprehension and working memory in

Table 2. Descriptive Information of Non-TBI and TBI Participants

Groups	Years of Schooling	No.		Age			
		Male	Female	Min	Max	Mean	SD
Mild TBI	12.7 ± 2.5	4	16	18	40	25.7	7.1
Moderate TBI	12.1 ± 2.8	2	15	20	45	29.59	7.9
Non TBI	12 + 4	5	13	19	40	26.4	6.2

Table 3. The Comparison Variables Mean Scores Between Mild, Moderate and Non TBI Groups

	Mild TBI[a]	Moderate TBI[a]	Healthy Group[a]	ANOVA		Mild TBI vs. Healthy Group		Moderate TBI vs. Healthy Group		Mild TBI vs. Moderate TBI	
				F (2, 45)	P Value	Mean Diff (SD)	P Value	Mean Diff (SD)	P Value	Mean Diff (SD)	P Value
Canonical sentences comprehension	53 (3.68)	52 (5.61)	55 (1.16)	3.39	0.03	-2.05 (2.76)	0.7	-2.98 (2.3)	0.04	3.8 (2.72)	0.03
Non canonical sentences comprehension	22 (3.82)	17.78 (7.22)	27.22 (2.7)	5	0.01	-5.22 (2.03)	0.03	-9.4 (1.7)	0.008	5.25 (2.04)	0.04
Digit span											
Forward	9.4 (1.6)	6 (1.71)	10 (2.06)	32.08	< 0.001	-0.44 (0.76)	0.42	-64.44 (0.76)	< 0.001	3.65 (0.39)	0.02
Backward	6.4 (1.2)	3.05 (1.05)	9.2 (0.94)	47.64	< 0.001	-3.45 (1.96)	0.035	5.65 (0.61)	< 0.001	3.33 (0.4)	0.003
N-back	86.7 (22.81)	86.44 (26.29)	111.6 (6.5)	8.62	0.001	-24 (7.8)	0.08	-25.16 (6.6)	0.001	0.25 (7.8)	0.98

[a] Values are presented as Mean (SD).

Table 4. Pearson Correlations Between Sentences Comprehension and the Components of Working Memory for Each the TBI Groups

	Mild TBI Group		Moderate TBI Group	
	Canonical Sentences Comprehension	Non-Canonical Sentences Comprehension	Canonical Sentences Comprehension	Non-Canonical Sentences Comprehension
Forward digit span				
Pearson correlation	0.28	0.38	0.34	0.28
P	0.8	0. 2	0.39	0.1
Backward digit span				
Pearson correlation	0.4	0.59	0.49	0.69
P	0.09	0.008	0.02	0.001
N- back				
Pearson correlation	0.41	0.5	0.56	0.61
P	0.4	0.004	0.001	< 0.001

patients with mild and moderate traumatic brain injury in the frontal lobe and to compare it with those of non-TBI subjects. The results of data analysis indicated that the comprehension of non-canonical sentences was damaged in patients with mild and moderate frontal lobe TBI. Non-canonical sentences do not follow the formal structure of a language. For example, the place of the subject is changed with the object. These changes in the formal structure of a language needs more attention and memory and allocation of more processing resources (26). During the sentence comprehension process, the listener should remember the previously said words and their meanings and link them to other words in the sentence. Furthermore, in sentence comprehension, different phonological, semantic, and syntax processing are performed (27). Besides, in this process, in addition to extracting the meaning of words, familiarity with the structure of the language and the grammatical roles of the words have to be considered (28). Therefore, sentences with little frequency in that language or formed using non-canonical language constructors need to be processed online. They are parts of complex sentences and require attention and allocation of processing resources. Moreover in this study, TBI participants were different from non-TBI people in the task related to the central executive system, and there was a correlation between the scores of the central executive system and the comprehension of non-canonical sentences. According to the working memory theory, the central executive section

is responsible for controlling the attention and allocation of processing resources (29). Probably, the defect in this section of the working memory has caused the problems of sentence comprehension in these patients. Given that the working memory central executive system assumes a more controlling share of cognitive resource processing, it is more vulnerable to traumatic brain injury, and the injury to this section is likely to be associated with less access to other working memory processing resources (28).

In this study, patients with moderate injury also had problems in the comprehension of canonical sentences. The reason for this result is that sentences related to pronouns are considered as canonical sentences in this study. Given the various roles that the pronouns have in the sentence, this can sometimes increase the processing load for sentence comprehension.

The present study demonstrated that working memory deficits are present in both mild and moderate TBI.

The moderate TBI group, compared to other groups, performed significantly lower on forward digit span. Mild and moderate TBI showed lower performance than the non-TBI group in backward digit span. Forward digit span is typically used to assess the capacity of the phonological loop (12). With regard to this decline in the capacity of the phonological loop, comprehension of long sentences and discourses may be difficult in moderate TBI. Backward digit span requires information manipulation and can show the central executive performance (29). Therefore, backward digit span task is more difficult than forward digit span task. Forward digit span needs the relatively automatic processing. The immediate serial recall, without reorganization of material, is assessed in this task. Consequently, allocation of other cognitive sources is minimal. In contrast, backward digit span requires information storing while manipulation.

In the case of n-back assignments, the performance of the mild and moderate group was lower than that of the non-TBI group. In these assignments, in addition to information manipulation, information also needs to be maintained; besides, the cognitive capacity of memory and attention play a key role in this regard. The results showed that mild and moderate patients with frontal lobe injuries have problems in cognitive skills in attention, memory, information manipulation, and maintenance (29).

There was also a correlation between the comprehension of canonical and non-canonical sentences with the performance of working memory tasks in patients with moderate injury, suggesting that these patients need attention and allocation of processing resources to process these sentences, which may lead to a longer processing time and a reduction in the processing speed. In the case of mild patients, this difference was only observed at the level of non-canonical sentences.

Although mild patients were lower than the non-TBI group in the context of the comprehension of non-canonical sentences and working memory performance, their performance was higher than the moderate group.

We had qualitative and quantitative limitations in the implementation of this study. For example, the selected sample size for investigation was small, and it is necessary for future studies to use a larger sample size for a more detailed and comprehensive investigation. The patients in this study had local injuries in the frontal lobe, where patients with diffuse lesions can be used in subsequent studies and even comparisons between the two groups can be done. In addition to the phonological circuit and the central executive system, it is recommended to study the relationship between sentence comprehension and episodic memory, which is a part of the working memory. Further studies can investigate rehabilitation strategies based on working memory exercises.

It can be concluded from the results of the analysis of the study data that the frontal lobe injury can affect the comprehension of language and the working memory. In addition, it can be stated that cognitive problems (attention, memory, and allocation of processing resources) can create problems in this group of patients in their everyday lives and their social activities. In healthcare planning, to increase the quality of the communication of people with traumatic brain injury, it seems that more attention should be paid to working memory and language issues.

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