Working memory and discourse production abilities following closed-head injury

Article *in* Brain Injury · November 2005

DOI: 10.1080/02699050500109951

2 authors:

Kathleen Marie Youse
Salus University

Carl A Coelho
University of Connecticut

Brain Injury, November 2005; 19(12): 1001–1009

Taylor & Francis
Taylor & Francis Group

ORIGINAL PAPER

Working memory and discourse production abilities following closed-head injury

K. M. YOUSE & C. A. COELHO

University of Connecticut, Storrs, CT, USA

(Received 17 March 2004; accepted 14 February 2005)

Abstract
Primary objectives: This study investigated the relationship between working memory (WM) and narrative discourse production in individuals with closed head injury (CHI). It was hypothesized that those individuals with higher performance on tests of WM would demonstrate better performance on measures of discourse production.
Research design: Correlation coefficients were calculated among five discourse measures from two story narratives and scores from three sub-tests of the Wechsler Memory Scale (WMS).
Methods and procedures: Fifty-five individuals with moderate-to-severe CHI were studied. Participants included 16 females and 39 males ranging in age from 16–69. Narrative discourse samples were elicited from all participants under two conditions: story retelling and story generation.
Main outcomes and results: The results revealed a number of modest, significant correlations ($r = 0.29$–0.39, $p < 0.05$) between sub-tests of the WMS and measures of discourse production.
Conclusions: Results supported the hypothesis. Story elicitation task differences, limitations of using simple memory span tests as indices of WM and clinical implications of the relationship between WM and discourse production are discussed.

Keywords: *Working memory, discourse production, closed-head injury*

Introduction

Just as traumatic brain injury (TBI) is a sub-set of the broad category acquired brain injury (ABI), closed head injury (CHI) and open (penetrating) head injury denote specific sub-sets of TBI. These distinct sub-types of TBI differ in terms of both array of deficits and recovery [1]. Recent reports pertaining to communication abilities following CHI have demonstrated an increasing appreciation of discourse as a clinically relevant and functional measure for detecting subtle, non-aphasic impairments in this population [2, 3]. Discourse has been described as a unit of language that conveys a message; the length of the message being determined by the communicative function [4]. Individuals with CHI demonstrate deficits in both non-interactive (narrative) and interactive (conversation) discourse tasks [5]. Narrative discourse includes such tasks as story retelling, story generation, picture description and procedural description. Individuals with CHI have been noted to have difficulty with the use of cohesion [6, 7], failed to appropriately utilise essential story grammar components [7, 8], have produced fewer words and fewer content units [6, 9, 10], have demonstrated increased verbal disruptions (e.g. mazes, false starts, filled pauses) [6, 9, 11], produced inaccurate information [6, 9, 10] and experienced difficulty with implied meanings [10].

Effective communication skills require the integrity of a number of cognitive abilities that are frequently disrupted following CHI [12]. It has been suggested that the cognitive impairments typically associated with CHI such as decreased attention, memory and executive functions result in a reduced ability to organize one's thoughts for language expression reflected in the production of irrelevant utterances, word finding problems and impaired sequencing at the word and propositional

Correspondence: Kathleen M. Youse, MA, CCC-SLP, University of Connecticut, Department of Communication Sciences, Unit 1085, Storrs, CT 06269-1085, USA. Tel: 860-896-4797. Fax: 860-486-5422. E-mail: kyouse@prodigy.net

ISSN 0269–9052 print/ISSN 1362–301X online
DOI: 10.1080/02699050500109951

level [12–14]. Tangential language, impaired abstraction and verbosity have also been attributed to general cognitive disorganization leading to communication deficits following CHI [15]. Body et al. [16] suggest that, while there is a considerable amount of individual variation in cognitive impairments following CHI, the general descriptions of the relationship between cognitive impairment and communicative function demonstrate that the outcome is fairly uniform. In other words, communication deficits following CHI appear to reflect cognitive impairments in the context of intact language abilities. However, a systematic relationship between specific cognitive impairments and communication profiles has not been established [16]. Such information may play a key role in the effective rehabilitation of individuals with CHI and it has been suggested that clinical approaches to the treatment of discourse should be dependent upon the underlying deficits that are present [5].

Of the many cognitive deficits associated with CHI, memory may have the most direct affect on communication abilities in this population [17]. Current research of memory impairments has shifted from short-term memory to working memory (WM). WM is conceptualized as a limited capacity store that is capable of holding and manipulating information while performing a range of cognitive tasks (e.g. comprehension, retrieval, learning) associated with that information [18–20]. According to Baddeley [18, 19], the WM model consists of a central executive that is considered to assume a supervisory role, allocating attention and processing resources to two or more subsidiary systems. The co-ordination of resources is considered to be the prime function of WM and information storage is only one of the demands made on the system [18]. Although some tasks can be performed on a semi-automatic level and require little conscious attention, novel or complex tasks require WM in order to control and integrate more than one cognitive resource at a time and to guide such resources in a goal-directed fashion. However, WM is considered to be limited in capacity and can only process a restricted amount of information at one time at a limited pace. If the confines of WM are exceeded by increasing the amount of information to be processed, then the rate at which a task is performed will increase. If the demands on the system continue to be increased, accuracy will then be sacrificed [12, 17, 19]. In theory, deficits in WM will reduce the speed and efficiency with which individuals with CHI comprehend discourse. It is, therefore, reasonable to assume that impairments in WM will also reduce the efficiency and overall organization of language production in this population [16].

In recent years, the literature regarding the impact of memory deficits on the comprehension of discourse following brain injury has grown, demonstrating the importance of memory for functional communication [12]. Conversely, research regarding the impact of memory deficits on discourse production in the brain-injured population is less comprehensive [21]. In fact, only two studies have demonstrated an association between independent measures of WM and discourse production [6, 21]. Hartley and Jensen [6] found significant correlations between WM and linguistic cohesion in 11 individuals with CHI who were tested on three narrative discourse tasks: story retelling, story generation and procedural description. In this study, WM was measured using the repetition sub-test from the Western Aphasia Battery (WAB) [22] and logical memory and digit span sub-tests of the Wechsler Memory Scale (WMS) [23]. The participants with CHI demonstrated impairments in cohesion and scored significantly below 21 non-brain injured (NBI) controls on each of the memory measures. The authors conclude that the production of discourse following CHI is limited in efficiency, accurate content and semantic connectivity and that these deficits are significantly correlated with WM ability.

Unlike Hartley and Jensen [6], Caspari et al. [21] failed to demonstrate a significant relationship between WM and discourse production, although these authors report that reduced WM ability may have played a part in the atypical discourse production of an individual with amnesia secondary to CHI. Performance on two genres of discourse, narrative and conversation, was compared to WM ability tested via the WMS [23] and a modified version of Daneman and Carpenter's [24] Reading Span Task which is considered to be a measure of WM. The individual with CHI demonstrated decreased productivity (e.g. reduced *t*-units) and reduced syntactic complexity when compared to four age-matched NBI participants. The authors concluded that, while it is unlikely that WM is the sole explanation of poor discourse performance following CHI, discourse production does appear to be affected by impairments in WM.

On the basis of the preceding review of the literature, there appears to be a paucity of empirical data regarding the effect of specific cognitive deficits on functional communication following CHI. In particular, what little information is available regarding the effect of WM impairments on discourse production is equivocal. This lack of information may hinder assessment and intervention techniques applied with the CHI population. Greater knowledge of the relationship between cognitive deficits and discourse production may assist clinicians in developing more effective and efficacious treatment plans for individuals with CHI. The present study was undertaken as a first step in investigating the relationship between a specific cognitive deficit, that of WM, and discourse production abilities in a larger group of individuals with CHI. It was hypothesized that those individuals with higher performance on tests of WM would demonstrate better performance on measures of narrative discourse production.

Method

Participants

Fifty-five native speakers of English who had sustained a CHI were studied. Participants were selected because they had recovered a high level of functional language; that is they had achieved fluent conversation and did not demonstrate appreciable deficits on traditional clinical language tests. Participant characteristics are shown in Table I. There were 16 females and 39 males ranging in age from 16–69 (mean = 28.6). Years of education ranged from 9–21 (mean = 13.0). All of the participants' injuries were rated as either moderate (duration of coma less than 6 hours) or severe (duration of coma greater than 6 hours) on the basis of criterion established by Lezak [25]. Time post-onset ranged from 1–99 months (mean = 10.5).

All CHI participants met the following criteria:

(a) no history of substance abuse or psychiatric illness;
(b) visual acuity and visual perceptual abilities adequate to distinguish stimulus materials as determined by screening procedures;
(c) hearing acuity adequate to follow directions in each task as determined by screening procedures;
(d) an aphasia quotient (AQ) from the *Western Aphasia Battery* [22] above 93;
(e) no significant motor speech disorder as determined by an experienced speech-language pathologist;
(f) Rancho Los Amigos Level of Cognitive Functioning [26] of VII (automatic-appropriate) or above;
(g) *Galveston Orientation and Amnesia Test* [27] score of 75 or above; and
(h) a score of 120 or above on the *Dementia Rating Scale* [28], a general screen of cognitive processing.

Table I. Characteristics of the CHI participants.

Participant	Age	Gender	EDU	MPO
1	21	M	14	4
2	22	M	16	1
3	27	F	14	1
4	17	M	11	3
5	22	F	16	2
6	18	M	12	3
7	49	M	21	2
8	47	M	18	2
9	22	M	16	2
10	20	F	12	33
11	54	M	16	8
12	16	F	11	1
13	42	M	16	7
14	33	F	15	12
15	47	M	18	12
16	40	F	16	26
17	18	M	12	2
18	55	M	18	1
19	21	F	12	8
20	24	M	14	6
21	17	M	13	2
22	20	M	13	21
23	30	M	12	2
24	33	M	14	1
25	19	F	12	2
26	26	M	13	2
27	27	M	12	2
28	24	F	13	9
29	19	M	12	2
30	17	M	11	4
31	60	M	12	28
32	18	F	12	8
33	69	F	13	75
34	34	M	13	99
35	27	M	12	1
36	45	F	15	10
37	21	M	10	8
38	39	M	10	2
39	28	M	12	1
40	23	M	12	3
41	21	M	12	9
42	19	M	12	2
43	33	F	14	17
44	20	M	9	43
45	20	F	12	3
46	21	M	12	6
47	16	M	10	1
48	29	M	12	2
49	28	M	12	1
50	28	F	12	2
51	21	F	11	1
52	31	M	12	29
53	29	M	10	7
54	19	M	10	18
55	25	M	12	8
Range, *M*	16–69, 28.6	16 F; 39 M	9–21, 13	1–99, 10.5

EDU = years of education; MPO = months post-onset.

Discourse elicitation procedures

Two discourse samples were elicited from all participants under two conditions: story retelling and story generation. Each discourse task took ~15 min to complete.

Story retelling task. Participants were presented the picture story, *The Bear and the Fly* [29], by filmstrip projector on a 23 × 30.5 cm screen. The picture story has 19 frames with no sound track and shows how a Father Bear inadvertently wrecks his house and mistreats his family in an attempt to kill a bothersome fly. After viewing the filmstrip the participants were given the following instruction: 'Tell me that story'. When a participant stopped telling the story, the examiner would wait 10 seconds and then ask, 'Is that the end of the story?' If the participant answered affirmatively, the task was ended.

Story generation task. Participants were presented with a copy of the Norman Rockwell painting, *The Runaway*. This picture depicts a small boy and a large, friendly policeman sitting at a diner counter. The boy has a knapsack attached to a stick lying on the floor by his feet. A counterman is facing the boy and the policeman and seems to be amused by the situation. The participants were given the following instruction: 'Tell me a story about what you think is happening in this picture'. The picture remained in view of the examiner and participant until the task was completed. When a participant stopped telling the story, the examiner would wait 10 seconds and then ask, 'Is that the end of the story?' If the participant answered affirmatively, the task was ended.

Discourse measures

Each story was audiotaped and later transcribed verbatim. Transcriptions of the stories were distributed into T-units prior to analysis. A T-unit is an independent clause plus any sub-ordinate clauses associated with it [30]. A T-unit is similar to a sentence but is more readily identifiable [31]. Story narrative performance was measured at two levels, within and between sentences. Examples of all measures are provided in Table II.

Within-sentence. Two measures of sentence production were examined:

(1) *Number of words per T-unit*: the total number of words divided by the number of T-units. Number of words per T-unit is considered a measure of sentence length.
(2) *Number of sub-ordinate clauses per T-unit*: the total number of sub-ordinate clauses in each story divided by the total number of T-units. This ratio was obtained in order to permit comparisons across stories that varied in length. The frequency of sub-ordinate clause use may be considered a measure of the complexity of sentence-level grammar.

Between-sentence. Between-sentence measures included:

(1) *Cohesive adequacy*: The measure of cohesive adequacy used in this study was *percent complete ties out of total ties*. Cohesive ties pertain to how meaning is conjoined across sentences. A word is considered to be a cohesive tie if the listener must search outside the sentence for the completed meaning. Procedures for identifying cohesive markers and categories of cohesive markers have been described in previous investigations [7, 8, 33]. Each occurrence of a cohesive marker (i.e. tie) was judged according

Table II. Examples of discourse measures used to analyse story narratives.

Discourse measure	Description
Number of words per T-Unit	Total number of words divided by the number of T-units, example: 125 words/7 T-units = 17.9
Number of sub-ordinate clauses per T-unit	Total number of sub-ordinate clauses in each story divided by the total number of T-units, example: 4 sub-ordinate clauses/7 T-units = 0.6
Percentage complete ties out of total ties	Percentage of complete ties out of total ties in each story, examples: *Complete tie*—The dog was tired. *He* slept in the sun. *Incomplete tie*—The kids travelled home from school. They spent the night at *his* uncle's house. *Erroneous tie*—Chris and Alex walked to the concert. *He* lost his wallet.
Number of total episodes	Number of complete and incomplete episodes in a story, examples: *Complete episode*—[Initiating event] and this fly comes in and the Father's bothered by this [Attempt] so he decides to swat or hit the fly and he hits his wife [Direct consequence] and she goes down *Incomplete episode*—[Attempt] and he hits his daughter [Direct consequence] and the daughter goes down to the floor
Proportion of T-units within episode structure	Number of T-units in episode structure divided by total number of T-units in each story, example: 14 T-units in episodes/18 total T-units = 0.78

to its adequacy using Liles' [32] procedure. Three categories of adequacy were used: (a) a tie was judged to be *complete* if the information referred to by the cohesive marker was easily found and defined with no ambiguity, (b) a tie was judged to be *incomplete* if the information referred to by the cohesive marker was not provided in the text and (c) a tie was judged to be *erroneous* if the listener was guided to ambiguous information elsewhere in the text.

(2) *Story grammar*: Two measures of story grammar performance were used: number of total episodes and proportion of T-units contained within episode structure. According to Stein and Glenn [34], an episode consists of (a) an initiating event which prompts a character to formulate a goal-directed behaviour, (b) an action and (c) a direct consequence marking attainment or non-attainment of the goal. An episode was considered complete only if it contained all three components. An incomplete episode contained two of the three components. Examples of complete and incomplete episodes are provided in the Appendix. *Number of total episodes*, the number of complete and incomplete episodes, was considered to be a measure of content organization. Incomplete episodes were included in the tally of total episodes because it was felt that the presence of even two episode components represented a degree of content organization that should be noted. *Proportion of T-units contained within episode structure*, the number of T-units in episode structure divided by the total number of T-units in the story, is an indication of a participant's ability to use story grammar as an organizational plan for language. For example, certain participants often inserted comments during the retelling or generation of a story that may have been related to the story but did not contribute to the actual story. Although such stories were longer in terms of the total number of T-units produced, the proportion of T-units that contributed to the episodic structure was often quite small.

Reliability

One examiner analysed all the story narratives. Ten per cent of the story narratives were re-analysed by a second examiner in order to assess inter-examiner reliability. An additional 10% of the story narratives were re-analysed by the first examiner ~ 6 months after the initial analyses were completed to assess intra-examiner reliability. Reliability measures were based on point-to-point scoring. Inter-examiner reliability scores ranged from 90–96%. Intra-examiner reliability scores ranged from 92–98%.

Measures of working memory

Sub-tests from the Wechsler Memory Scale (WMS) [23] were administered and used as the measures of WM. The WMS is a measure of memory commonly utilised in the clinical setting. Three sub-tests were used from this test: (a) *digit span*, which measures immediate recall of a list of numbers, (b) *logical memory*, which measures immediate and delayed recall of paragraph length information, and (c) *associative learning*, which measures new learning for a list of paired words presented over three trials.

Results

Pearson correlation coefficients were calculated among the discourse measures and the sub-test scores from the WMS (Table III). The results of the correlational analyses revealed five modest but significant correlations ($r = 0.29$–0.39, $p < 0.05$).

Story retelling measures

Of the coefficients that were significant, four discourse measures from the story retelling task correlated with scores from the WMS sub-test for associate learning. These included number of words per T-unit ($r = 0.29$, $p = 0.04$), number of sub-ordinate clauses per T-unit ($r = 0.32$, $p = 0.02$), complete ties out of total ties ($r = 0.34$, $p = 0.01$) and number of total episodes ($r = 0.36$, $p = 0.01$).

Table III. Pearson correlation coefficients for subtests from the Wechsler Memory Scale (WMS) and discourse measures.

		Digit span	Logical memory	Associate learning
Words per T-unit	Retelling	0.22	0.12	0.29*
	Generation	0.11	0.25	−0.02
Sub-ordinate clauses per T-unit	Retelling	0.17	0.15	0.32*
	Generation	0.30*	0.23	−0.15
Complete ties out of total ties	Retelling	0.01	0.11	0.34**
	Generation	−0.06	−0.01	−0.16
Number total episodes	Retelling	0.18	0.21	0.36**
	Generation	0.05	0.14	0.27
T-units within episode structure	Retelling	−0.07	0.03	0.02
	Generation	−0.01	0.05	0.24

*$p < 0.05$; **$p < 0.01$.

Story generation measures

One measure from the story generation task correlated with the WMS sub-test score for digit span, number of sub-ordinate clauses per T-unit ($r = 0.30$, $p = 0.03$).

Discussion

The purpose of this study was to investigate the relationship between WM and discourse production in individuals with CHI. The results indicated modest significant correlations between measures of WM and narrative discourse, thus supporting the hypothesis that higher scores on the measures of WM would be associated with better discourse production abilities.

With regard to the measurement of WM, recent research suggests that simple list span measurements may be poor predictors of language performance because memory capacity for sentence processing is distinct from span memory [35]. List span measures, such as the digit span sub-test in the WMS, include memory for lists of numbers or words. As such, they determine only storage capacity and do not take into account the dual role of processing and storage often thought to be carried out by WM [21]. Efficient production of discourse depends on a myriad of cognitive functions working in concert to process, store and manipulate information. This notion is supported by the findings of the present study which noted a limited number of correlations found between the digit span sub-test from the WMS and the discourse measures. A measure that may be more representative of the complex nature of WM is Daneman and Carpenter's [24] Reading Span Task (RST). The RST requires participants to read or listen to a set of unrelated sentences and then recall the last word in each sentence. During the task, each sentence must be verified as being true or false. At the completion of the set, the participant must then recall the last word of each sentence. The sets of sentences gradually increase (e.g. two sentences per set, three sentences per set, etc.). The test determines the largest number of sentences per set for which the participant can recall all of the final words across three of five trials. This number is called his or her reading span. The RST is considered to be a more sensitive measure of WM because it takes into account both processing and storage of information [21]. Future investigations of the underlying relationship between WM and language functions should employ a more complex measure of WM such as the RST.

A second factor that influenced the results of this study was that the two story narrative elicitation tasks were different. Four of the five significant correlations noted between the WM scores and the discourse measures were from the story retelling task. In this task participants were required to watch a picture story presented via a filmstrip and then to retell the story. In the story generation task participants generated a story from a static picture. The present findings suggest that the story retelling task placed a greater demand on WM by not only requiring information processing, that is comprehension of the story, but also temporary storage of the information necessary for an accurate retelling. This implies that story retelling may be a more useful task for studying the relationships between WM and discourse production.

Finally, four of the five significant correlations from the WMS were on the Associate Learning sub-test. Further, those four correlations were all with the story retelling task. Conversely, no significant correlations were noted between the discourse measures and the Logical Memory sub-test. This finding was unexpected given that the Logical Memory sub-test, which measures memory for oral-verbally presented paragraph length information, appears to be more comparable to the retelling task. This may suggest that the associate learning sub-test, which measures memory for paired lists of words, is a stronger measure of WM because during this task both storage and processing are at work. In other words, storage must occur for an individual to recall the list of words while processing is necessary in order for an association to be made between the word pairs. For example, some of the word pairs are related (e.g. metal–iron, baby–cries) while others are not (e.g. cabbage–pen, obey–inch). While it is interesting that the logical memory sub-test did not significantly correlate with any of the discourse measures, it is possible that this sub-test measures storage as opposed to processing.

Study limitations

As indicated previously, this study was a first investigation into the relationship between WM and discourse production in a larger group of individuals with CHI. It is important to note that results are based on a limited evaluation of WM as well as limited samples of discourse production. As such, these data are wholly representative of neither WM nor discourse production ability in the CHI population at large but simply suggest a relationship worthy of continued investigation. Given the heterogeneity of the CHI population and the complexity of discourse sampling and analysis, future research should incorporate analysis across a wider variety of WM measures, discourse genres and discourse measures.

Clinical implications

Differences in participant performance during the two narrative conditions, story retelling and story generation, supports the importance of utilizing more than one genre of discourse during assessment. Likewise, the correlations found between the WM and discourse measures in the participants studied suggest that greater consideration should be given to specific cognitive deficits and their consequences with respect to treatment design and expected outcome for functional communication. The results of this study suggest that many different factors may influence discourse performance and that approaches to treatment should be tailored to each individual's specific needs.

Conclusions

In conclusion, the results of this study suggest a relationship between WM ability and discourse production in individuals with CHI. These findings are encouraging in that they provide direction for future studies on the nature of discourse deficits following brain injury. A better understanding of the underlying nature of discourse processes will facilitate the development of more sensitive assessment and treatment procedures for the communicative impairments of individuals with CHI.

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Appendix: Examples of discourse samples that have been coded into T-units and analysed for story grammar

Story grammar episode components: IE = Initiating events; A = Attempts; DC = Direct consequence.

Story retelling task

		[OK] It's about a family of three bears
		And they're all cooking dinner and getting along amiably
Complete episode	IE	And along comes a little pesty fly
	A	And the papa bear pulls out a fly swatter attempts to [hit the bear] hit the fly
	DC	And he misses and knocks out his wife
Complete episode	IE	And the fly still [is] [is] aggravates him
	A	so [he keeps] [he doesn't] he doesn't give up
		he keeps on flying
	DC	And a couple more swats and passes and he knocks out his child
Inco mplete episode	IE	[then] and then [then] he leaves the kid's table
	A	and he keeps on hitting at the fly
		And [ah] he [he] has a dog nipping at his heels
		and it really looks like a nice [a nice] little dog
Inco mplete episode	IE	And then [and then] the fly lands on the ceiling
	A	and so papa bear gets [a table] a chair
		and he goes to put it down on the kid's table
		and unknown [unknown] to him his wife is now awake and watching him
		and [she says] she knows he's gonna fall off the table
		but she doesn't say a word
		so he does so
		And then he lands on the floor and knocks his self out
		And the fly goes out the window
		All this for a measly, pesky fly

Story generation task

		[Well] one [one] day this [um] little boy was mad
Complete	IE	he was having a fight with his parents
episode	A	and he decided to pack his bags and run away from home
		So he got his little knapsack
		and he threw a bunch of clothes in it
	DC	And then on the way [he says] [well] he decided well, ‘I’m
		hungry’.
		‘I’m going to get something to eat at the local deli’.
		So he climbs up on the seat
Complete	IE	and [um the um] the man he sees [um] the kid [you know] with the
episode		[um backpack I mean] knapsack
		and he’s concerned
		And he thinks [oh gee] maybe I should call a police officer and
		maybe have him talk him [into it] [I mean] out of this idea of
		running away from home
		because he realized it wasn’t very safe out there alone for a little
		kid of his age to be
	A	And so he called up his friend who was an officer
		And he was on duty right by the store
	DC	so he [um] stopped in and sat down and started talking to the kid,
		just telling him [how you know] how dangerous it is out in the
		wild, wild, world
		And it worked out OK
		The kid decided to hang in