

## Impaired discourse gist and working memory in children after brain injury

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### Abstract

Emerging evidence suggests that a traumatic brain injury (TBI) in childhood may disrupt the ability to abstract the central meaning or gist-based memory from connected language (discourse). The current study adopts a novel approach to elucidate the role of immediate and working memory processes in producing a cohesive and coherent gist-based text in the form of a summary in children with mild and severe TBI as compared to typically developing children, ages 8–14 years at test. Both TBI groups showed decreased performance on a summary production task as well as retrieval of specific content from a long narrative. Working memory on n-back tasks was also impaired in children with severe TBI, whereas immediate memory performance for recall of a simple word list in both TBI groups was comparable to controls. Interestingly, working memory, but not simple immediate memory for a word list, was significantly correlated with summarization ability and ability to recall discourse content.

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### 1. Introduction

Typically developing children are capable of processing prodigious amounts of incoming information (Laughlin & Sejnowski, 2003). This impressive capacity is purportedly accomplished by conceptualizing rules and condensing vast information in an abstract or gist form (Schacter, 2002). In the language domain, van Dijk (1995) postulated that gist processing was one crucial way that the human brain efficiently stored and retrieved vast amounts of textual or verbal information. Individuals show a bias toward gist processing as evidenced by extant literature that verbatim recall of the details from textual information fades rapidly, whereas meaning at an abstracted level persists over long intervals in children and adults (Adams, Smith, Nyquist, &

Perlmutter, 1997; Bartlett, 1936; Brainerd & Reyna, 1998; Radvansky, 1999).

The present study explored the effects of brain injury in childhood on discourse gist production and two supporting memory systems, i.e., immediate and working memory. Discourse refers to connected language, either written (e.g., newspaper articles, books) or verbal (e.g., class lecture). For the purpose of this paper discourse gist is defined as the ability to extract and convey the central meaning from connected language and is achieved through processes of information reduction and transformation (van Dijk, 1995). Formation of gist-based texts involves manipulation of incoming details to develop generalized representations of meaning (Lyytinen & Lehto, 1998). Examples of gist-based texts include summaries, main ideas, and interpretive statements, to mention a few (Ulatowska & Chapman, 1994; van Dijk, 1995; Wittrock & Alesandrini, 1990). Each of these gist-based texts represents a condensed version of the original information that conveys the central meaning at a

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generalized level while omitting details. The gist-based text of interest in the present paper is summarization.

### *1.1. Discourse gist in childhood: Typical development and brain injury*

Production of well-formed summaries follows a protracted course of cognitive and linguistic development in typically developing children that emerges beginning in the elementary school years with refinement into adulthood (Brown & Day, 1983). The ability to produce condensed texts, while retaining the central meaning, has been linked to learning potential in children (Brown & Day, 1983). For example, high achievers in the classroom are more successful in producing well-formed summaries as compared with lower achievers who exhibit poorer performance on summarization (Johnson, 1983; Malone & Mastropieri, 1992; Stein & Kirby, 1992).

Emerging research suggests that children with severe traumatic brain injury (TBI), when compared to their uninjured peers, may be particularly poor at producing gist-based responses (Chapman et al., 2004). The deficits in discourse gist are characterized by a diminished ability to make transformed statements that depart from the explicit statements in the text. Specifically, the information in the children's summaries is either verbatim or minimally paraphrased in relation to the original content. In particular, children with severe TBI rarely combine, condense, or transform information to form generalized statements during summary production when compared to typically developing peers (Chapman et al., 2004).

Additional evidence reveals other forms of impaired discourse gist-based abilities after severe TBI in children. Reilly, Bates, and Marchman (1998) identified decreased narrative complexity, especially at the global level. Another example is the impaired ability to produce an interpretive statement for a story after severe TBI (Chapman et al., 1997, 2001, 2004).

### *1.2. Cognitive factors in discourse gist*

Producing well-formed summaries involves a wide array of cognitive processes to manipulate the original information in a condensed form. Summarization relies on the ability to retrieve, select, reduce, and organize information in a coherent and logical progression of ideas, using stored schemas and prior world knowledge to make necessary inferences (Ferstl, Guthke, & von Cramon, 1999; Graesser, Millis, & Zwaan, 1997; van Dijk, 1995). In particular, models of discourse gist production implicate both immediate memory and the executive processes of working memory as two of the key prerequisites to constructing well-formed summaries (Caspari & Parkinson, 2000). Immediate memory involves the encoding and recall of information and is measured on tasks requiring participants to recall isolated information, such as word lists (Gathercole, Pickering, Ambridge, & Wearing, 2004). Clearly, summary production

requires retrieval of information encountered in the original discourse text from immediate memory (Singer & Kintsch, 2001).

In tandem with the “information-in, information-out” processes of immediate memory, working memory serves as a limited-capacity, age-dependent work space where information can be manipulated, monitored, and temporarily stored (Baddeley, 1992). The executive processes of working memory (referred to herein as higher level working memory) are fundamental to the development of many complex learning skills that involve information that needs to be maintained and updated (Gathercole et al., 2004), such as reading, writing (Daneman & Carpenter, 1980), and auditory language comprehension (Hanten, Levin, & Song, 1999). Although some have postulated a role of working memory in summary production (Tannock, Schachar, & Logan, 1995), no study has specifically investigated the relation between higher level working memory processes and discourse production. Discourse summarization skills may require not only immediate memory but also higher level working memory processes, as information must be actively held and manipulated in order to condense and transform information to produce a gist-based response (Chapman et al., 2004).

Immediate memory deficits are a common sequelae of severe TBI in children; however, the role of immediate memory impairments in discourse production is inconclusive (Levin & Eisenberg, 1979). For example, Chapman, Levin, Wanek, Weyrauch, and Kufera (1998) found a relation between immediate memory for word lists and straightforward retells of discourse content in pediatric TBI. Nonetheless, discourse deficits persisted even after controlling for immediate memory. Moreover, discourse gist deficits as measured by an interpretive statement showed slower rate of improvement as compared to recovery of immediate memory of textual content (Chapman et al., 2001). Summarization places different demands on memory systems than does straightforward retell. The relations between immediate memory for word lists or discourse content and summary production have yet to be examined in children after brain injury (Chapman et al., 2004).

In addition to immediate memory deficits, higher level working memory impairments have been recently identified as lasting symptoms in children with severe TBI using n-back tasks as described below (Levin et al., 2002, 2004). To date, no published studies have examined the relation of immediate memory and higher level working memory processes to discourse gist production (e.g., summary) in pediatric TBI. Since immediate memory is integral to working memory, examining the relation of summary production to both immediate and working memory may clarify underlying difficulties in producing gist-based summaries after TBI in childhood.

### *1.3. Purpose*

This study examined the effects of TBI severity in childhood on production of well-formed discourse gist in

the form a summary, ability to recall explicit and implicit information from the original narrative text, and performance on separate measures of immediate memory and higher level working memory processes. We also investigated the relationship between gist-based summary production and both working and immediate memory to ascertain how performance in these memory domains is implicated in formulating summaries. We hypothesized that the severity of childhood TBI would have a detrimental long term effect on the ability to produce well-formed summaries; that is, the more severe the injury the poorer the summary. We postulated, however, that severity of TBI would not reduce the performance on the two measures of immediate memory, that is recall of a word list and recall of discourse content (explicit and implicit) from the original discourse text based on previous evidence that recall of discourse details improves sooner than discourse gist. In addition, we hypothesized that higher level working memory ability would be more strongly associated with gist-based summary abilities than a distinct measure of immediate memory ability (recall of a word list).

## 2. Methods

### 2.1. Participants

The study participants were 62 children, ages 8–14 years at the time of testing. All participants were recruited from a larger research project examining cognitive and linguistic recovery after TBI. Of the 38 children with TBI, 25 suffered a mild TBI and 13 suffered a severe TBI. Severity of injury was based on the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974). Specifically, a GCS score of 13–15 determined mild TBI and a GCS score of 3–8 determined severe TBI. The TBI group was compared to a group of 24 typically developing children of comparable age.

Children with TBI were eligible for inclusion according to the following criteria: (1) suffered a TBI requiring hospitalization at least 2 years prior to assessment, (2) case history evidence that the injury resulted from a nonpenetrating head trauma, (3) documentation that the injury was mild (GCS  $\geq$  13 upon hospital admittance) or severe (GCS  $\leq$  8 upon hospital admittance), (4) age 8 through 14 years at time of assessment, and (5) English as the primary language of at least one of the child's caregivers. Exclusion criteria for the study included: (1) a prior history of neurologic or psychiatric disorder, (2) grade failure or previous diagnosis of learning disability or mental deficiency, (3) evidence of child abuse, and (4) a previous head injury resulting in hospitalization.

Table 1 summarizes demographic and clinical features of the control and the two TBI groups. Univariate analyses revealed no significant differences for age at test or parental socioeconomic level, as reflected by the mother's level of education, across the three groups.

Table 1  
Demographic and clinical features of control and TBI participants

Characteristic	Controls ( <i>n</i> = 24)		Mild TBI ( <i>n</i> = 25)		Severe TBI ( <i>n</i> = 13)	
	Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>
Age at test (in years)	13.1	1.9	13.6	1.3	12.7	1.7
Age at injury (in years)	—	—	8.2	1.9	7.4	1.4
Education of parents (in years)	15.5	1.1	16.0	1.0	15.6	1.0

*Note.* The control group consisted of 15 males and 9 females. The mild TBI group consisted of 22 males and 3 females, and the severe TBI group consisted of 11 males and 2 females. TBI, traumatic brain injury; *SD*, standard deviation.

### 2.2. Narrative stimulus

The experimental discourse stimulus consisted of a long (578-word) didactic narrative about a man's life. A lengthy discourse narrative was chosen to reduce the chances of being able to retell the information verbatim. The goal of the task was to produce a condensed and abstracted version in the form of a summary.

Each child was read an example summary and instructed in how to give a shortened version of the story prior to the experimental task. The example summary was the synopsis on the back of a popular children's video, "The Lion King." The instructions indicated that like the description of the video, a good summary did not contain a lot of unnecessary detail. Subsequently, the examiner instructed the child to listen carefully to the story (discourse narrative). After hearing the discourse narrative, the child was asked to verbally provide a shortened version of the story in his or her own words. The child was reminded to leave out the unimportant details but to make sure that the important information was included. After the child gave a summary, memory for discourse content was measured using four questions regarding explicit information and four questions regarding implicit (i.e., inferential) information from the original text.

### 2.3. Discourse gist/summary production measures

We evaluated the quality of summaries through the constructs of cohesion and coherence based on the work of Stein and Kirby (1992) and van Dijk (1995). Discourse cohesion refers to the degree to which the words and sentences comprising a text are syntactically and thematically linked together (Lehman & Schraw, 2002). With regard to summaries, cohesion entails local continuity of meaning within an organized structure across the flow of information. Local cohesion in summaries is achieved by the use of appropriate syntax and connectors within and between sentences. As such, local cohesion is realized by manipulating linguistic devices to form logical connections between current and preceding sentences such that referents and actions are linked from sentence to sentence (Graesser et al., 1997). Overall cohesion is achieved through a sequential and

logical organization of propositions. Cohesion provides continuity and connectedness of topical ideas across the text (St. George, Kutas, Martinez, & Sereno, 1999).

Discourse coherence is achieved through bridging information across ideas to convey a global interpretation of the original discourse text that is generalized beyond the original verbatim text (Singer & Ritchot, 1996). Coherence is realized by production of global inferences that engender themes, synthesized ideas, and interpretive statements (Graesser et al., 1997).

The summary responses were analyzed by trained raters for well-formedness according to indices of cohesion and coherence (See Appendix A) as outlined by Stein and Kirby (1992). The raters were naïve to both demographic and group information. Both cohesion and coherence were rated on scales ranging from 0 to 9 for a possible total of 18 points. Examples of summaries are illustrated in Appendix B.

#### 2.4. Reliability

To establish reliability for the analysis, two trained raters independently scored 33% of the summaries. The reliability between raters yielded point to point agreement of 90% for the summary production scores, which included cohesion and coherence combined.

#### 2.5. Immediate memory task: Discourse content measures

The answers to eight questions (four regarding explicit and four regarding implicit information) about the original discourse narrative content were rated from 0 to 2 according to the correctness and completeness of each response. Thus, the maximum score possible was 8 for each set of explicit and implicit content questions.

#### 2.6. Reliability

To establish reliability, two trained raters individually scored 33% of the responses to the eight questions. The reliability between raters yielded point to point agreement of 93% for both explicit and implicit responses combined.

#### 2.7. Working memory task

The working memory task involved an “n-back task” consisting of three levels of memory load (e.g., 1-back, 2-back, 3-back) in both letter identity and letter rhyming conditions. The tasks were presented in central vision using a Macintosh Powerbook. The letter identity condition consisted of the child identifying a letter in a different case than one that occurred previously (e.g., for the 1-back level: R, r). The rhyming condition consisted of the child identifying a letter name that rhymed with a previously occurring letter’s name (e.g., for the 2-back level: Q, L, U, P). In each paradigm, the child responded to the appearance of a target letter by pressing a button on the keyboard.

Prior to the letter identity task, each child was given a paper and pencil pretest to verify that the child could match uppercase and lowercase letters of the alphabet. Prior to the rhyming task, each child was given a paper and pencil pretest to verify that the child understood how letter names rhymed. The child was given explicit verbal and visual instructions prior to the training, practice, and test session for each n-back level. A 0-back condition, wherein the child was asked to press a button on the computer when a specific letter (e.g., z) appeared, was used as a baseline measurement of memory span.

For each memory load level there was a practice session consisting of 10 trials followed by 40 test trials. Each of the test trials consisted of a string of 40 letters (12 targets and 28 distractors) that appeared individually on the computer screen for 2 s.

#### 2.8. N-back measures

A net percent score of each level of n-back task was used in the analysis to assess working memory load. The net percent score was calculated by subtracting the percentage of errors of commission (false alarms) from the percentage of correct responses (target detections). Our method eliminates the possibility of a child getting a perfect score (if errors of omission were the sole measurement) by continuously striking a key regardless of the correctness of response (see Levin et al., 2002). As children with TBI often display deficits in inhibition, our working memory measure considers this by removing the potential miscalculation that could occur if only errors of omission were calculated.

#### 2.9. Immediate memory task: Word list recall

The first trial of the California Verbal Learning Test (CVLT)—Children’s Version (Delis, Kramer, Kaplan, & Obler, 1986) was administered as a measure of immediate memory for word lists. The first trial of the CVLT involves immediate recall of a 15-word list presented orally. The immediate memory score used in the present study was the number of words correctly recalled in the first trial. We chose to use only the first trial of the CVLT as the story was only read one time.

### 3. Statistical analyses

We used a generalized linear model with a negative binomial distribution to fit the summary production score data and a binomial distribution to fit the discourse content measures and the immediate memory measure. A general linear mixed model was applied for the working memory net score on n-back identity and n-back rhyme measures with load as a within-subject factor. For all these models, group (severe TBI, mild TBI, or control) was a predictor variable, along with age at test and gender as covariates. All final results were considered significant at an alpha level of .05. In addition, Spearman Correlation Coefficients were

used to analyze the relationships between the various measures. Simple correlation coefficients were used for the discourse summary production score, as there was no significant effect of age. We performed correlations with age at test as a partial variable for all other measures due to a significant effect of age.  $\chi^2$  tests were applied to assess the group differences on the correlation matrices. If there were no significant group differences, then the three groups were pooled together for calculation of the correlations.

#### 4. Results

Table 2 displays the mean group scores for the discourse summary and memory measures.

##### 4.1. Summary production score

For the summary production score, there was a significant effect of group, with significantly higher scores in the control group than the severe TBI group [ $\chi^2(1)=8.25$ ,  $p=0.004$ ]. The difference between the control and the mild TBI groups was significant [ $\chi^2(1)=3.72$ ,  $p=.05$ ], but the severe TBI group did not significantly differ from the mild TBI group [ $\chi^2(1)=1.84$ ,  $p=.175$ ].

In addition to the qualitative differences in summaries produced by the TBI groups, there were quantitative differences in the summary productions. With regard to the number of words used, analysis revealed a significant group effect [ $\chi^2(2)=6.01$ ,  $p=.047$ ]. Specifically, the children with severe and mild TBI tended to use fewer words when compared to control children.

##### 4.2. Immediate memory task: Explicit and implicit discourse information

For the explicit discourse content score, analysis revealed a significant group effect [ $\chi^2(2)=15.44$ ,  $p=.0004$ ]. The control group demonstrated the highest performance and the severe TBI group demonstrated the lowest performance. In addition, the overall difference depended on age [ $\chi^2(2)=16.37$ ,  $p=.0003$ ]. Age was positively related to explicit discourse content in the mild [ $\chi^2(1)=13.10$ ,  $p=.0003$ ] and severe TBI groups [ $\chi^2(1)=12.94$ ,  $p=.0003$ ],

with older children performing better than younger children.

With regard to the implicit discourse content score, analysis revealed a significant group effect [ $\chi^2(2)=7.53$ ,  $p=.023$ ], with the control group performing the highest and the severe TBI group performing the lowest. This difference depended on age [ $\chi^2(2)=8.06$ ,  $p=.018$ ]. Age was positively related to the implicit discourse content score, but it was only significant in the severe TBI group [ $\chi^2(1)=11.56$ ,  $p=.0007$ ], with older children performing better than younger children.

##### 4.3. Memory measures

###### 4.3.1. Working memory

Analysis of the repeated measures data for the working memory letter identity net score revealed that the groups were significantly different [ $F(2,58)=10.38$ ,  $p=.0001$ ], with the control group performing the highest and the severe TBI group performing the lowest. Comparisons between groups yielded significant differences between the control and severe TBI groups [ $t(58)=4.34$ ,  $p<.0001$ ] as well as between the mild TBI and severe TBI groups [ $t(58)=(3.88)$ ,  $p=.0003$ ]. There was no significant difference between control and mild TBI groups for the working memory letter identity net score [ $t(58)=(0.56)$ ,  $p=.575$ ]. Performance on the working memory letter rhyme net score did not differ significantly between groups [ $F(2,58)=2.02$ ,  $p=.142$ ].

Immediate memory task: word list recall. There were no significant differences between the groups for the immediate memory measure (CVLT Trial 1 recall) [ $\chi^2(2)=0.26$ ,  $p=.878$ ].

##### 4.4. Relation between summary production and memory measures

Initial  $\chi^2$  analysis of the correlation matrices revealed that the relation between summary production score and all memory measures did not significantly differ by group; as such, correlations were performed across groups. Because there was no significant age effect for summary production, simple Spearman rank-order correlations were calculated. The correlation between the summary production

Table 2  
Mean group scores for the discourse and memory measures

Score	Controls			Mild TBI			Severe TBI		
	Mean	SD	(Range)	Mean	SD	(Range)	Mean	SD	(Range)
Summary production (0–18)	7.4	4.3	(2–15)	6.0	3.3	(2–12)	4.5	3.6	(0–12)
Explicit content (0–8)	6.4	1.7	(3–8)	6.3	1.7	(2–8)	6.2	2.3	(0–8)
Implicit content (0–8)	4.4	1.9	(1–7)	3.8	1.3	(2–7)	4.5	1.9	(3–7)
<i>Working memory</i>									
Letter ID net score (%)	85	10	(62–100)	84	12	(47–97)	73	16	(33–93)
Letter rhyme net score (%)	64	18	(20–89)	66	15	(16–86)	54	20	(22–78)
<i>Immediate short term memory</i>									
CVLT/total recall trial 1	7.1	1.6	(4–10)	7.3	2.5	(2–14)	7.5	1.9	(3–10)

TBI, traumatic brain injury; SD, standard deviation; ID, identification; CVLT, California verbal learning test.

score and the immediate memory word list measure was not significant ( $r = .10, p = .438$ ). The correlations between the summary production score and memory for explicit and implicit discourse content were significant (explicit:  $r = .33, p = .010$ ; implicit:  $r = .36, p = .005$ ). The correlation between summary production score and working memory letter identity net score was significant ( $r = .27, p = .035$ ). The correlation between summary production score and working memory letter rhyme net score was also significant ( $r = .33, p = .009$ ).

#### 4.5. Relation among discourse content and memory measures

Initial  $\chi^2$  analysis of the correlation matrices revealed that the relations between both explicit and implicit discourse content and all memory measures did not significantly differ by group; as such, correlations were performed across groups. Because there was a significant age effect for discourse content, Spearman partial correlations were calculated with age as a partial variable.

The correlation between explicit discourse content score and working memory letter identity net score was significant ( $r = .28, p = .034$ ). In addition, there was a significant positive correlation between explicit discourse content score and working memory letter rhyme net score ( $r = .29, p = .026$ ). The correlation between explicit discourse content and the immediate memory measure was not significant ( $r = .003, p = .985$ ).

The correlation between implicit discourse content score and working memory letter identity net score approached significance ( $r = .23, p = .086$ ). There was a significant positive correlation between implicit discourse content score and working memory letter rhyme net score ( $r = .32, p = .013$ ). The correlation between implicit discourse content and the immediate memory of word list recall was not significant ( $r = .19, p = .142$ ).

## 5. Discussion

Four important findings emerged from the current study. First, this study provides additional evidence that the ability to produce gist-based texts on a novel measure of summarization is impaired after severe TBI in childhood. Moreover, the evidence suggests that summarization may be vulnerable after mild TBI. As expected, the children with severe TBI performed the lowest on the summary task, followed by children with mild TBI. The present study extends previous evidence of discourse impairments after severe TBI on story retelling tasks (Chapman et al., 1992; Chapman, Levin, Matejka, Harward, & Kufera, 1995; Chapman et al., 1997, 1998) and inference generation measures (Barnes & Dennis, 2001) to include disturbance in summarization tasks. The study also provides a new, relatively simple and systematic way to characterize summary performance.

Second, working memory but not immediate memory for words, was impaired in the children with mild and severe TBI. Third, immediate memory for discourse content was

impaired despite our hypothesis that the groups would not differ. Fourth, the ability to produce a well-formed summary was correlated with both immediate memory for explicit and implicit discourse content and working memory.

In contrast, simple immediate memory (CVLT) was not correlated with either discourse summary production or memory for explicit and implicit discourse content. The discussion below considers these findings and their potential to explicate why gist-based processing is disrupted after pediatric TBI.

#### 5.1. Severity effects on discourse gist summary production

The present study extends previous findings of discourse gist deficits manifested after TBI in childhood and elucidates associated memory processes. We found that children with both mild and severe TBI produced summaries that were less cohesive and coherent than those of typically developing children. The majority of previous research indicates that children with mild TBI recover cognitive-linguistic function to perform within the normal range two years after injury (Chapman et al., 2004; Levin et al., 2002). Counter to this pattern, the present evidence suggests that full recovery after mild TBI may not extend to all children with mild injuries, especially when more complex cognitive functions such as those required for discourse gist production are considered. Similarly, Dennis and colleagues (Dennis, Purvis, Barnes, Wilkinson, & Winner, 2001) found that comprehension of nonliteral information was impaired in children with both mild and severe TBI. The likelihood of residual neurocognitive deficits after mild TBI continues to be a highly debated issue and one that warrants careful investigation to ensure development of appropriate and sensitive assessment protocols.

Previous evidence revealed that children with severe TBI ages 7–14 condensed information during summarization to a similar degree as typically developing peers when tested 2 years after injury (Chapman et al., 2004). Nonetheless, their summaries were qualitatively different in the strategies used to reduce information. Specifically, children with severe TBI condensed the information using an immature strategy of “copy and delete” instead of the more age-appropriate strategy of combining ideas into transformed statements that was characteristic of the typically developing control group (Stein & Kirby, 1992). Developmental norms indicate that children typically begin to transform verbal information at approximately 6 years of age (Johnson, 1983).

What was not evident from the Chapman and colleagues (2004) study was whether the ability to summarize the central meaning in a well organized sequence of ideas was impaired in pediatric TBI. The present results directly address this issue and reveal that children with mild and severe TBI are likely to have difficulty logically organizing information and conveying the central meaning or gist of the original discourse content in their summary productions. Despite a high risk of gist vulnerability after TBI, it is important to recognize that some of the children with mild

TBI and some with severe TBI produced good summaries, as evidenced by overlap in the range of scores (see Table 2).

One potential confound of the study results is the effect of reduced language output (i.e., number of words) among participants with TBI, which could account for summarization differences across groups. From a theoretical perspective, amount of language does not directly correspond to ability to produce well formed summaries. Evidence indicates that more language may be just as disrupting as too little language in gist-based responses (Ulatowska & Chapman, 1994). In fact, a well formed summary may consist of only a few sentences (see Appendix B), whereas a poor summary may be comprised of a multitude of statements. Thus, while quantity is an important variable to consider, amount of language alone does not account for reduced summary skills in children with TBI.

### 5.2. Immediate and working memory

Counter to our prediction, we found impaired performance for the TBI groups on measures of memory for explicit and implicit discourse content. Based upon previous literature (Chapman et al., 2001), we had postulated that recall of explicit and implicit discourse content would not be reduced two years after mild or severe TBI. In consideration of our results, we realize this view was limited. Indeed, retrieving explicit and implicit content places demands on immediate and higher level working memory, as the discourse content must be held in a temporary mental work space and retrieved to answer probes. Thus the positive relationship between the discourse content measures (explicit and implicit) and both working memory measures supports a revised view. That is, the ability to retrieve and pinpoint the necessary information to answer explicit and implicit probes is likely to involve higher level working memory processes. We postulate that the children with TBI had deficits in summary production not only because of working memory deficits but also impaired retrieval of specific information from the discourse content.

The comparable performance on the simple immediate memory measure (CVLT) across all three groups is contrary to previous findings that children with TBI exhibit memory deficits as compared to typically developing children (Levin & Eisenberg, 1979). The failure to find differences in immediate memory for a word list among the control and two TBI groups may be a reflection of the insensitivity of the 15 word single list recall. That is, recall of a single list of 15 items may be inadequate to identify deficits in immediate memory after TBI. Previous studies reporting differences in CVLT used all five trials (Levin et al., 2000). We, however, used only the first trial of the CVLT for our immediate memory measure, as the discourse narrative was not repeated, and we wanted to minimize learning effects produced by the five trials. Another possible contributing factor for the lack of group differences is the longer recovery interval since sustaining a brain injury. Previous study participants were evaluated as early

as 3 months after injury (Levin & Eisenberg, 1979), whereas the participants in the present study were at least 2 years post injury. Given the extant literature documenting immediate memory deficits and the present evidence of reduced recall of explicit and implicit discourse content in pediatric TBI, it is likely that more complex immediate memory is indeed impaired after TBI in childhood.

Our failure to find group differences in the working memory letter rhyme measure was similar to the findings of Levin and colleagues (2002), who suggested that the difficulty of the task may have been a major factor. In other words, the n-back letter rhyme task may have taxed working memory abilities in the control group as well as in the children with TBI.

The failure to find a significant relationship between the immediate memory word list measure and both summary production and discourse content measures (explicit and implicit) supports the idea that simple immediate memory for individual words may not provide an index of the ability to construct gist-based summaries, at least for the populations studied. Nonetheless, the pivotal role of immediate memory for factual content cannot be ignored. Summarization requires retrieving the relevant content as well as combining and integrating concepts and knowledge in a mental work space provided by working memory (Singer & Ritchot, 1996). The ability to select and retrieve the discourse content appears to be more reflective of an intermediate and more complex form of memory than the simple word list measure used in the present study. As such, reduced retrieval of discourse content in individual children may underlie disturbances in producing cohesive and coherent summaries along with reduced working memory abilities. The differences found herein may be influenced by task complexity. Future studies should incorporate independent, yet more complex, tasks of immediate memory.

From a methodological perspective, we decided at the outset of the current study to use independent measures of immediate (word list recall) and working memory (n-back) from the discourse task. Nonetheless, we wanted to be able to decipher if the children were able to recall the discourse content in order to derive a gist-based interpretation. The limitation in interpreting the role of immediate memory abilities is that retrieving the content and summarizing the same content are intricately interrelated. Unraveling the contribution of memory for discourse content and working memory to impaired gist is important for future study. Clearly, deficits in retrieving the content may be a fundamental limitation precluding manipulation of the information in working memory.

### 5.3. Possible explanations

The present study raises questions as to why gist-based processing, working memory, and retrieval of specific discourse content are impaired after TBI. We propose that the long term consequences of TBI may hinder top-down processing as revealed by impaired discourse gist production.

Our results support previous evidence indicating that children with severe TBI are more likely to use a bottom-up approach of “copy–delete” (Brown & Day, 1983; Stein & Kirby, 1992) rather than a top-down generalization strategy. The current study extends these findings to mild TBI.

What is not clear from the current study is whether children with TBI rely on bottom-up processing because of limitations in information retrieval and/or inadequate acquisition of inferential abilities. Either one alone could impede gist-based productions. One way to examine a differential role of fact retrieval versus inferential impairments would be to train the children in recall of the facts through repeated trials. If gist processing improved to a level comparable to typically developing children when the children with TBI could successfully retrieve the facts, this would lead one to suspect that gist-based deficits arise mainly from difficulty encoding and retrieving the relevant facts. As is typically the case, the explanation is not likely to be an ‘either/or’ situation, but rather both retrieval of facts and working memory are likely to play a role.

Based on growing evidence, however, we postulate that gist-based processing would remain disturbed even when retrieval of facts is achieved, but this remains to be investigated. Supporting evidence comes from Barnes and Dennis (2001), who found impaired inferencing in children with severe brain injury. These researchers offer the view that inferencing problems may be due to the inability to integrate textual information with general knowledge during online narrative comprehension. Clearly, the role of working memory is implicated in discourse summary production as well as in other tasks requiring inferencing.

Theoretically, the current study supports the view set forth by Engle and Kane (2004) that controlled retrieval and working memory are important to complex cognitive functions, which in this case involve summarization skills. Specifically, working memory may be one of the key factors in explaining the differences between good and poor summarizers in the general population as well as in children with TBI. Although the gist-based deficits following TBI are less likely to be accounted for by immediate simple memory per se, the role of a more complex form of memory (i.e., retrieving specific content) is certainly a factor.

The correspondence between working memory and summary production may occur because good summarizers are able to keep more information active, allowing the necessary inferences and generalizations to be made. Additionally, inferencing difficulties may reduce working memory efficiency. For example, deficiencies in allocating attention to the most important points in the text or to chunk information through inferencing may result in working with information at too detailed a level. Alternatively, reduced working memory may result from inefficiencies in retrieving information. Our results do not elucidate which alternative explanation is more likely to account for the present findings.

The disparity observed between simple immediate memory and working memory in this study raises an intriguing question as to whether children with TBI strive to overcome early deficits in immediate memory, as reflected by recovered abilities on straightforward recall of items from lists. Evidence from neuroscience raises the possibility that strengthening immediate memory weakens working memory (Ramos et al., 2003). Hypothetically, an effort to overcome memory deficits could lead to strengthened immediate memory and possibly the underlying hippocampal networks. In strengthening these hippocampally dependent neural networks, the frontally mediated cognitive systems, such as working memory, controlled retrieval of information, and discourse gist production, may either lag behind in recovery, become weakened, or fail to emerge at all if frontal neural networks are injured prior to full maturation. The imbalance in processing isolated versus gist-based information could provide a valuable framework for future investigations in normal and brain injured populations.

## 6. Implications and conclusion

This research illuminates one of the major paradoxes in pediatric brain injury. That is, why do children with brain injury regain basic levels of functioning (i.e., recall of a word list) but remain at risk for delayed or failed development of more complex cognitive milestones (i.e., summarization) (Levin, Ewing-Cobbs, & Eisenberg, 1995). The present findings have both clinical and theoretical significance. Clinically, this study provides a novel and complex cognitive-linguistic paradigm. Specifically, discourse gist, as measured by summaries, may serve to further elucidate the long-term outcome of TBI. Our discourse task is unique as compared to previously adopted discourse methods because we characterized summary production of an expository discourse. Previous methods did not examine the ability to reduce, transform, and synthesize information in the form of a cohesive and coherent mini-text. Potentially, summary production has clinical application for facilitating assessment of high level cognitive-linguistic deficits in children with TBI who otherwise appear to have fully recovered from their injury. Further research is needed to explore the relations among problems in discourse gist, academic achievement, intellectual functioning, and age at injury.

In closing, we propose that children who suffer a TBI remain at risk for developing the skills to select and retrieve information, to manipulate information, and to abstract generalized meaning from discourse as compared to typically developing peers when tested two years after injury. The present evidence of persisting impairments in gist-based processing raises the question as to whether the ability to construct gist-based texts could be remediated after TBI in children. Hence, the next important step is to determine whether the present findings can be translated into new treatment development.

## Appendix A. Rating scale for summary well-formedness

Rating	Description
	<i>Cohesion</i>
0	Absence of cohesion <ul style="list-style-type: none"> <li>• Interconnections among propositions are completely lacking</li> <li>• No logical succession of ideas</li> </ul>
1	Weak cohesion <ul style="list-style-type: none"> <li>• Marked vague or erroneous referential ties and/or intrusions</li> <li>• Severe disruption in logical succession of ideas</li> </ul>
3	Moderate cohesion <ul style="list-style-type: none"> <li>• Including some erroneous referential ties and/or intrusions</li> <li>• Moderate disruption in logical succession of ideas</li> </ul>
6	Good cohesion <ul style="list-style-type: none"> <li>• Few problems with explicit referential ties between statements</li> <li>• Mild disruption in logical succession of ideas</li> </ul>
9	Strong cohesion <ul style="list-style-type: none"> <li>• Referential ties are explicit and accurate on all textual levels</li> <li>• Very clear logical succession of ideas</li> </ul>
	<i>Coherence</i>
0	Incorrect central meaning; no attempt to abstract, generalize, or integrate
1	(a) No reduction of information, like an elaborated retell, information predominantly copied, no rearrangement of ideas from the text, no instances of abstraction or integration, and not global in the interpretation of the text –OR– (b) Including inappropriate reductions focusing primarily on only one episode; may include fragments of information related to the central meaning, showing some attempt at abstraction or integration –OR– (c) Including too much reduction, resulting in no clear central meaning
3	Showing a reduction of ideas that are predominantly copied; ideas from the text are presented in a highly linear fashion, primarily copy-delete strategy; lack of abstraction or global inferencing
6	Including either linear presentation of textual ideas or reordered ideas, indicating that the summarizer used his/her own words in presenting the information or attempted to integrate or use connectives. Provides an interpretative statement that attempts to convey the central meaning
9	Primarily produced in the summarizer's own words, with rearranged order and bridging of information across ideas to convey a generalized interpretation of the text; demonstrates correct use of global inferencing to abstract the central meaning
18	Total Possible Score

## Appendix B. Examples

### B.1. Strong cohesion and coherence

The following are two examples of summaries that received the highest ratings (total score = 18) for both cohesion (score = 9) and coherence (score = 9):

The first summary (A) demonstrates strong cohesion in that referential ties remain clear and the story is relayed in a sequential manner; the use of descriptive vocabulary serves

to elucidate the storytelling without being too wordy. Strong coherence is reflected in the use of the summarizer's own words and her apparent insight into the emotions and motivations of the story character (i.e., "theory of mind"). She provides an abstract interpretation of the story, conveying the central meaning.

(A) "John Pierpont, I think, was actually really brilliant. I mean, he was able to do many careers. And he started out trying to be a teacher, and he started out trying to be a lawyer, and just going through many different jobs, and then going into politics and going into being a minister and then finally just being a file clerk. And so, very broad span of jobs that he held. But still, he saw himself as a failure because he wasn't able to succeed in any of these. And the way that success appears at that time is, you know, being the best lawyer and bringing in the most money. He wasn't able to do that because of his care for humankind. But in the end of the story, you find this legacy that he's left that lasts so much longer than just the money he would have brought into his office. He showed the world, you know, and just that, having a kind heart and just so many things were reformed because of the way he did them, like education, and slavery was abolished, and major differences like that. And it was all due to him. And maybe his success wasn't short-lived, but rather yet long, long-lived and was so much deeper and able to survive so much longer than just money is. And even his song, Jingle Bells, is sung like around the world, and, to remember him. And I think his legacy still lives on."

The second summary (B) also demonstrates strong cohesion by means of clear referential ties and a fairly concise description of the story action, followed by a higher-level generalized discussion of the central meaning. Strong coherence is once again reflected in the summarizer's paraphrasing; the central meaning of the story is made very clear with wonderful elaboration and application of the character's actions to real-world correlates (i.e., abstraction).

(B) "Throughout his life, John Pierpont seemed to, to himself, to have been a failure. Basically, everything he tried, he didn't seem to be very good at, whether it be education, law, politics, poetry, you name it, he felt that he wasn't very good at it and, therefore, a failure. But as his, as time has moved on and we've come to see John Pierpont as a revolutionary reformer and helped to bring about so many changes in our social and social, economic, and political system of life here in America, and so we don't view him as a failure, but we view him as an asset to the American society. And the lesson learned here is that even though your actions, even though you may not see some immediate product from your actions, along the road, there may be something to come out of it, even though you don't see that at the moment. It kind of shows, John Pierpont did so many of these things throughout his life, pursued so many different careers and so many different pursuits that he had a big impact on many different aspects of our society, and he affected many different aspects as well. And so even

though he didn't see the immediate results, he did affect how our society and government and economy has been shaped though the years because of his actions. So that's the lesson we've learned from history and John Pierpont."

The third example (C) demonstrates a summary that, unlike the first two examples (A and B), was made up of very few words yet received high ratings (total score = 15) for both cohesion (score = 6) and coherence (score = 9). This summary (C) demonstrates fairly strong cohesion by means of clear referential ties, a concise (though somewhat vague) summary of the story action, and an appropriate higher-level interpretation of the character's actions. Strong coherence is demonstrated in the summarizer's use of inferencing to produce descriptive language that reflects the thoughts and virtues of the story character. She provides an abstract interpretation of the story, conveying the central meaning.

(C) "Throughout John Pierpont's life, he expressed bravery, courage, and honesty. He tried many different tasks and put his heart into many things that he did. He stood up for his beliefs and the righteousness of mankind. He was a very strong believer in good humanity."

## B.2. Weak cohesion and coherence

The following is an example of a summary that received low ratings (total score = 1) for both cohesion (score = 1) and coherence (score = 0). This summary (D) demonstrates weak cohesion in that information from the story is relayed using vague language (i.e., "stuff", "something"), resulting in no clear understanding of or connection between events. Though loosely sequential, only the beginning and ending of the story are addressed, leaving out important points from the majority of the narrative. The summarizer reflects lack of coherence by failing to make reference to the main character's motivations, whether he was ultimately a success or a failure, and/or how others perceive his actions in the story. She makes no attempt to abstract and convey the central meaning of the story.

(D) "It's about, um, this guy who would try to do, he tried to, to succeed at work, but he couldn't. So he tried a lot of different stuff until he was seventy. And then this person, thing, something, found him and sent him to this place where he could find a job, and he, he did that for the last five years of his life, and then he passed away. That's so sad."

The following is another example of a summary that received low ratings (total score = 2) for both cohesion (score = 1) and coherence (score = 1). This summary (E) also demonstrates weak cohesion by means of unclear language and an incomplete description of the main points of the story action. Lack of coherence is reflected in the summarizer's focus on two specific occupations and subsequent incorrect evaluation of the character's motivations (i.e., "he just quit because he didn't like the things that he got into"). The central meaning of the story is never addressed.

(E) "John was a failure at everything mostly that he did because he would always, like, in math, um, give, treat the students like easily and make their homework really easy and like make them get good grades when they really shouldn't have gotten that, and the stuff was too easy. And like when he was, um, selling things, he'd sell the things way too low. But the things that he could, he did get in, he quit. And he just quit because he didn't like the things that he got into. And when, when he was older, he um, wrote some poetry and some songs that we still use today."

It is interesting to note that both the mild TBI (example D) and severe TBI participants (example E) exhibited performance within normal limits on the immediate memory and discourse content measures and comparatively decreased performance on working memory measures. As compared to the control group means, each had scores that were similar for both explicit and implicit discourse content questions and for the CVLT. Each achieved working memory net scores for letter identity and letter rhyme that were one standard deviation from the control group means.

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