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Characterizing discourse deficits following penetrating head injury: A preliminary model

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Abstract

Purpose—Discourse analyses have demonstrated utility for delineating subtle communication deficits following closed head injuries (CHI). The present investigation examined the discourse performance of a large group of individuals with penetrating head injury (PHI). Performance was also compared across six PHI subgroups based on lesion locale. A preliminary model of discourse production following PHI was proposed and tested.

Method—Story narratives were elicited from two groups, 167 with PHI and 46 non-brain-injured (NBI). Micro- and macro-structural components of each story were analyzed. Measures of memory, executive functions, and intelligence were also administered. All measures were compared across groups and PHI subgroups. The proposed model was tested with a structural equation modeling procedure.

Results—No differences for the discourse measures were noted across PHI subgroups. Three measures distinguished the PHI and NBI groups: narrative length, story grammar, and completeness. The model had an adequate-to-good fit with the cognitive and discourse data.

Conclusions—In spite of differing mechanisms of injury, the PHI group's discourse performance was consistent with what has been reported for individuals with CHI. The model tested represents a preliminary step towards understanding discourse production following TBI.

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Penetrating head injury (PHI) is caused by a missile wound to the brain, often resulting in a focal lesion with behavioral deficits linked to the specific region of the brain damaged. By comparison, closed head injury (CHI) is caused by acceleration and deceleration of the moving head or by blunt trauma producing rotational acceleration of the brain resulting in diffuse axonal injury (DAI: Dikmen et al., 2009). DAI, also referred to as "shear injury," is typically widespread and bilateral and tends to occur where the gray and white matter of the brain interface, resulting in disruption of neurons connecting various functional brain areas (Scheid, Walther, Guthke, Preul, & Von Cramon, 2006).

Given the disparate mechanisms of injury, it seems intuitive that CHI and PHI would yield distinct cognitive-communicative sequelae. For instance, DAI is often associated with slowed processing speed and attention problems that are typically present following moderate to severe CHI (Ylioja, Hanks, Baird, & Millis, 2010). Conversely, deficits following a focal injury secondary to PHI would be expected to vary depending on the injury location. The question of whether or not different mechanisms of TBI yield different outcomes was addressed in a recent study in which survivors of civilian gunshot wounds (PHI: $N = 61$) were compared with a CHI group ($N = 61$) at three points in time: inpatient rehabilitation, one year post-injury and two years post-injury. Exploratory analysis suggested the degree of cognitive recovery of both the PHI and CHI groups was comparable during the first two years (Ylioja et al., 2010). In addition, functional outcomes (e.g., self-care, communication skills, psychosocial integration, and employability) have been noted to be similar at two years post-injury for individuals with PHI and CHI following inpatient rehabilitation (Wertheimer, Hanks, Hasenau, 2008; Zafonte et al., 1997). These findings suggest that the different etiologic processes for PHI and CHI do not yield distinct cognitive or functional outcomes. However, in both the Wertheimer et al. (2008) and Zafonte et al. (1997) studies, communication skills were not formally evaluated but, rather, based on patient-reported or clinician-reported ratings. Consequently, the question of whether or not PHI and CHI result in different cognitive-linguistic deficits remains unanswered.

Numerous studies have reported on language impairments subsequent to TBI, including several involving survivors of PHI. Focal damage to language areas is more common in PHI and, thus, more likely to result in aphasia. For example, a variety of reports from the Vietnam Head Injury Study (VHIS) focused on post-PHI aphasia (see Raymont, Salazar, Krueger, & Grafman, 2011). One study (Mohr et al., 1980) noted aphasia was present in 244 of the 1,030 survivors of missile wounds. Those individuals with motor aphasia recovered completely, while sensory aphasia in others persisted. These improvements continued for years despite lack of change in concomitant hemiparesis, and were not related to site of injury, lesion depth, or whether the wound was caused by gunshot or shrapnel.

As alluded to in the study by Raymont and colleagues (2011), most TBI (CHI or PHI) survivors do not present with aphasia (Heilman, Safran, & Geschwind, 1971; Schwartz-Cowley & Stepanik, 1989). Early investigations focused on identifying patterns of communication deficits that distinguished individuals with TBI (primarily CHI) from those with aphasia, and selecting appropriate assessment procedures to characterize their difficulties with functional communication. Use of aphasia batteries, which evaluated vocabulary and grammatical abilities at the single word and sentence levels, were not sensitive to the subtle nature of these impairments. Therefore, researchers shifted their focus to longer units of language, specifically discourse (Duff, Mutlu, Byom, & Turkstra, 2011). Discourse impairments, such as those affecting narrative ability, have been shown to impact CHI outcomes as diverse as job attainment and the development and maintenance of social relationships (Coelho, Liles, & Duffy, 1991; Galski, Tompkins, & Johnston, 1998).

A variety of reports have documented the clinical utility of discourse analyses for examining cognitive-communication impairments in CHI (e.g., Body & Perkins, 2004; Chapman, et al., 2006; Coelho, 2007). In a review of evidence on the use of nonstandardized procedures, including discourse analysis, for the assessment of individuals with TBI, indications for such practices were highlighted (Coelho,Ylvisaker & Turkstra, 2005). The findings of this review indicated that useful narrative discourse measures included productivity, efficiency, content accuracy and organization, story grammar, and coherence. The authors concluded that there is substantial evidence to support the assessment of communication beyond what is included in standardized aphasia or child language batteries. It is important to emphasize that nearly all of the 30 studies reviewed involved individuals with CHI and whether the findings are directly applicable to PHI has yet to be empirically tested.

Story narratives have been the focus of a number of recent discourse studies because of the opportunity afforded for the systematic analysis of information given the rule-based structure/organization of narratives. For example, two categories of discourse analyses that may be considered are macro-structure (e.g., story grammar or how intentions and events logically relate in time through cause-effect relations) and micro-structure (e.g., linguistic organization of the text within and across sentences; Liles, Duffy, Merritt, & Purcell, 1995) measures. In a large study of discourse production in TBI, story narratives from two groups of participants (55 CHI, 47 non-brain-injured) were sampled (Coelho, 2002). Analyses of sentence production, cohesive adequacy (the ability to tie meaning across sentences) and story grammar were conducted. Overall, participants with CHI demonstrated relatively intact micro-structure (within and across sentences) but exhibited difficulty with macro-structure (story grammar) of story narratives. Whether a comparable pattern of discourse impairment would be seen in individuals with PHI is an area for further investigation.

Discourse proficiency involves the interaction of cognitive and linguistic organizational processes (Ylvisaker, Szekeres & Feeney, 2008). In an attempt to explain the role of nonlinguistic factors in discourse following acquired brain injury, investigators have examined cognitive measures with discourse production. For instance in studies involving individuals with CHI, Chapman and colleagues (2006) noted correlations between working memory and gist identification. Similarly, correlations have been documented for measures of story grammar and immediate memory (Youse & Coelho, 2005). Executive functions (EF), involving planning and the application of organizational schemata, have also been correlated with measures of informational content and organization (Brookshire et al., 2000) and story grammar (Coelho, 2002; Coelho, Liles, & Duffy, 1995) and PHI (Mozeiko, Lê, Coelho, Krueger, & Grafman, 2011). A recent study employing regression analyses examined the relative contribution of cognitive processes to story completeness and story grammar (organization) following PHI (Lê, Coelho, Mozeiko, Krueger, & Grafman, 2012). Results indicated that EF, working memory (WM), and immediate memory differentially predicted performance on measures of story completeness and organization. The authors proposed that the Structure Building Framework (SBF; Gernsbacher, 1990), a cognitively-based explanation of discourse comprehension, might serve as a conceptualization for interpreting the discourse impairments in TBI.

The SBF specifies that successful comprehension requires the construction of a mental depiction of the information to be comprehended. This depiction or “structure” serves as a foundation for the incoming message (described as laying a foundation). As additional information is presented, if it is coherent and consistent with the previous information, it is added to the existing structure. If the information is inconsistent, a shift occurs and a new structure is established (referred to as shifting). Over the course of a longer message, several structures may be created and the subsequent incoming information is mapped onto the appropriate structure. Gernsbacher (1990) suggests that the critical elements of these structures are memory cells, the activation of which is triggered by the incoming messages. Once the processing of a message has begun, the memory cells may initiate other processes to either enhance or suppress activation of other cells. The SBF has also been applied to explanations of discourse production. For example, the verbose and disorganized discourse of some individuals with schizophrenia has been attributed to difficulty laying a foundation, shifting too rapidly, and ineffective suppression (Gernsbacher, Tallent, & Bollinger, 1999). Applied to story narratives, the discourse genre studied in the current investigation, the SBF would suggest that aspects of memory are involved in laying a foundation and mapping, while shifting, enhancement, and suppression would require EF.

Of interest then is what cognitive measure would best predict performance on narrative discourse tasks following PHI. A variety of cognitive measures have been correlated with narrative discourse production (i.e., immediate memory, WM and EF) in individuals with TBI. However, pre-injury intelligence was reported to be the most consistent predictor of long-term cognitive outcome for 520 survivors of PHI studied in Phase 2 of the VHIS (Grafman et al., 1988). In the present study, we proposed and tested a preliminary model of discourse production following PHI, which included measures of immediate memory and WM, EF, and intelligence. Structural equation modeling (SEM), a statistical technique for estimating effects using a combination of statistical data and theoretical assumptions, was used to examine the relationships among the variables. SEM allows for the analysis of multiple predictor variables and multiple outcome variables simultaneously. Using SEM, it was predicted that the cognitive processes found to correlate with discourse production in CHI would be comparable in PHI.

The following questions and hypotheses were addressed:

1. Is the discourse performance of the PHI group comparable to that of the non-brain-injured (NBI) comparison group?

   H_1: The discourse performance of the PHI group and that of the NBI group will not be comparable (PHI ≠ NBI).

2. Can the discourse performance of the PHI group be fit to a preliminary model based on theoretical relationships with and correlations of various cognitive measures to discourse ability that have been reported in the TBI literature?

H$_2$: The discourse performance of the PHI group can be fit to a model based on theoretical relationships with and correlations of various cognitive measures to discourse ability that have been reported in the TBI literature.

Methods

Participants

All participants were native English-speaking male Vietnam War veterans. Participants were recruited through the Vietnam Head Injury Study – Phase 3, to investigate the long-term consequences of head injury. The Vietnam Head Injury Study (VHIS) began as a registry of 1,211 Vietnam veterans who survived a head wound between 1967 and 1970. A retrospective review of those individuals' military and Veterans Affairs medical records was undertaken in Phase 1 of the VHIS, 5-years post injury. In Phase 2, at 15-years post injury, 520 veterans with PHI from the original registry and 85, age-matched, non-injured Vietnam veterans were recruited and evaluated prospectively. Assessments included neurological, neuropsychological, and speech and language testing as well as brain imaging. Similarly, VHIS Phase 3 was conducted prospectively at 35-years post injury with 199 of the original participants with PHI and 55 from the non-injured comparison group (for specific information on the VHIS see Raymont, Salazar, Krueger, & Grafman (2011). In the present study, PHI group included 167 individuals, 52 to 70 years of age, who survived severe head wounds during the Vietnam War. The injuries were caused primarily by low velocity shrapnel, resulting in relatively focal lesions. Brain lesions were identified by CT scan, and the data were reconstructed with a 3-mm overlapping slice thickness and a 1-mm interval. Lesions were processed using "analysis of brain lesions" software (ABLe; Makale, Solomon, Patronas, Danek, Butman, 2002).

At the time of testing, the PHI group was 34 to 37 years post-injury. All were living at home and either traveled to the testing facility alone or with a companion. Records pertaining to post-injury medical care and rehabilitation through the Department of Veterans Affairs were often incomplete or missing, which made comparisons regarding post-injury care across participants very difficult. None of the participants with PHI included in the present study were judged to be aphasic. This determination was based upon their performance on three tests: the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1983), the Token Test (DeRenzi & Vignolo, 1962), and the Discourse Comprehension Test (DCT: Brookshire & Nicholas, 1993, as well as the analyses of their discourse production (see Discourse Analysis Procedures).

Given the heterogenous nature of PHI, a lesion group analysis was performed to ensure there were no differences between subgroups on the discourse and cognitive measures prior to combining the subgroups into one PHI group. Although many of the participants presented with lesions which encompassed cortical and subcortical structures as well as white matter pathways, based on CT scan data, six relatively broad subgroups were delineated. The six subgroups were composed of participants with lesions predominantly in: a) the left prefrontal cortex (PFC), b) the right PFC, c) bilateral PFC regions, d) left non-PFC regions, e) right non-PFC, or f) bilateral non-PFC. Only 152 of 167 PHI participants were able to be definitively placed in one of the six subgroups.

The comparison group was comprised of 46 individuals, 55 to 76 years of age, with no history of neurologic disease or injury. The participant groups were matched for age, education, and scores on three tests (the BNT, the Token Test, and the DCT) and the Armed Forces Qualification Test (AFQT; U.S. Department of Defense, 1984). The AFQT is a measure of aptitude administered by the military to determine qualification for enlistment and placement of accepted recruits to military occupations commensurate with their abilities. Since scores are obtained at the time of enlistment, the AFQT provides a measure of pre-morbid intelligence (Plag & Goffman, 1967).

To examine for differences among the demographic variables across the six PHI subgroups a MANOVA was performed. Pillai's trace revealed no significant effect of group, $V = .23$, $F(30, 620) = 1.00$, $p = .49$ (see Table 1). Individual ANOVAs were examined and indicated no differences among subgroups on any demographic variable. Independent *t*-tests were performed to examine differences in demographic variables between the PHI and comparison groups. A Bonferroni adjustment was made to adjust for multiple comparisons, resulting in an alpha level of .008 (.05/6). Results indicated that none of the six demographic variables were significantly different across the matched groups (see Table 2).

Discourse Analysis Procedures

The discourse analysis procedures employed in the present study have been explained in detail in previous studies (Coelho et al., 2012; Lê, Coelho, Mozeiko, Krueger, & Grafman, 2011). Therefore these procedures are only described briefly in this paper. Narrative discourse samples were elicited by presenting visual stimuli. Participants were shown a 16-frame picture story, *Old McDonald had an Apartment House* (Barrett, 1998), with no soundtrack, on a computer screen. Viewing of the story frames was self-paced. Following stimulus presentation, the pictures were removed and each participant was instructed to "tell me that story you just watched." Each retelling was video-recorded. Recordings were transcribed verbatim. Each transcript was then parsed into T-units. A T-unit is defined as an independent clause and any of its associated dependent clauses (Hunt, 1970).

Discourse Measures

Sentence production. Two measures of sentence production were examined and compared across groups: *Number of words per T-unit (*the total words in each story divided by the number of T-units), considered a measure of sentence length, and *Number of subordinate clauses per T-unit* (the total number of subordinate clauses in each story divided by the total number of T-units), a ratio that facilitated comparisons across stories that varied in length. The frequency of subordinate clause use was considered a measure of the complexity of sentence-level grammar.

Cohesive adequacy—Descriptions of the procedures for cohesive marker identification and categorization are available in previous publications (e.g., Liles, 1985; Liles & Coelho, 1998). Each incidence of a cohesive marker or tie was evaluated for adequacy according to Liles's procedure. Categories of adequacy included: (a) *complete*, a tie was considered to be "complete" if the information denoted by the cohesive marker was easily found and unambiguously defined, (b) *incomplete*, a tie was judged to be "incomplete" if the information referred to by the cohesive marker could not be found in the text, and (c) *error*, a tie was designated an "error" if the listener was directed to vague information elsewhere in the text. Cohesive adequacy was the percent complete ties out of total ties.

Coherence—Each story was read completely, then T-units within a story were rated for the adequacy of global and local coherence on a five-point scale (Van Leer & Turkstra, 1999). *Global coherence* pertains to the relationship of the meaning or content of an utterance to the overall topic of the story. Ratings for global coherence ranged from 1 (The utterance is unrelated to the general topic or is a comment on the discourse) to 5 (The utterance provides substantive information related to the general topic). The relationship of the content of an utterance to that of the preceding utterance is *local coherence*. Ratings of local coherence ranged from 1 (The utterance has no relationship to the content of the immediately preceding utterance) to 5 (The topic of the preceding utterance is continued by elaboration; temporal sequencing; enumeration of related examples; or maintaining the same actor, subject, action or argument as the focus). Two means were calculated, one for global coherence and a second for local coherence, after the ratings were completed.

Story Grammar—The primary measure of story grammar was the *proportion of T-units within episode structure*. An episode is defined as (a) an *initiating event* prompting a character to formulate goal-directed behavior, (b) an *attempt* at achieving the goal, and (c) *a direct consequence* marking attainment or nonattainment of the goal (Stein & Glenn, 1979). Proportion of T-units contained within episode structure was considered to be an indication of participants' ability to use story grammar as an organizational plan for language. Examples of transcripts coded and scored for story grammar may be found in Lê, Coelho, Mozeiko, and Grafman (2011).

Completeness—All narratives from both comparison and PHI groups were examined for the presence of the five main components (events and characters). The completeness score was the total number of critical components produced in each participant's story retelling. Examples of transcripts coded and scored for story completeness may be found in Lê, Coelho, Mozeiko, and Grafman (2011).

Reliability—Point-to-point reliability for the measures utilized in the present study was established by re-analyzing 10% of the transcripts from each of the comparison and PHI groups. Intra-rater reliability for identification of T-units and subordinate clauses was 96% and 97% respectively; inter-rater reliability was 92% and 95% respectively. For cohesive adequacy intra- and inter-judge reliability scores were 92% and 89% respectively. Intra- and inter-rater reliability scores for local coherence ratings were 94% and 85% respectively and 96% and 90% for global coherence. For the proportion of T-units within episode structure (story grammar) intra-rater and inter-rater reliability was 93% and 84%, respectively. Reliability for the completeness analysis was 98% for intra-rater and 96% for inter-rater. The lower inter-rater reliability scores for local coherence and story grammar were a reflection of the subjective nature of these measures. Disagreements between raters were resolved via discussion which typically resulted in the development of more detailed guidelines for these analyses.

Cognitive Measures

Scores from four measures tapping cognitive ability were examined for each of the participant groups: executive functions (EF), working memory (WM), immediate memory (IM), and intelligence.

Executive Functions—The EF score selected was the Sorting Test composite scaled score from the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001). This test purportedly draws on a variety of EFs, such as concept formation, cognitive flexibility, and regulation of behavior (Dimitrov, Grafman, Soares, & Clark, 1999).

Working Memory—The Working Memory Primary Index from the Wechsler Memory Scale-Third Edition (WMS-III; Wechsler, 1997) was the measure of WM. This WM score reflects performance on verbal (letter-number sequencing) and nonverbal (spatial span) tasks.

Immediate Memory—The Immediate Memory Primary Index, also from the WMS-III, was selected as the measure of immediate declarative memory. The IM score reflects the ability to remember verbal and nonverbal information across four tasks.

Intelligence Quotient—The measure used for IQ was the Wechsler Adult Intelligence Scale–III (WAIS-III; Wechsler, 1997) Full Scale IQ percentile. The WAIS-III provided scores for Verbal IQ, Performance IQ, and Full Scale IQ. The Full Scale IQ is a combination of the Verbal and Performance IQ scores.

Data Analysis

A MANOVA was performed with the seven discourse measures as the dependent variables and subgroup (L PFC, R PFC, Bi PFC, L non-PFC, R non-PFC, Bi non-PFC) as the independent variable. Individual ANOVAs were then examined to determine which measures differentiated the subgroups. Similarly, a MANOVA and follow-up ANOVAs were performed with the discourse measures and group (PHI, NBI). The same procedures were performed with the four cognitive measures.

Data Modeling

In SEM, confirmatory factor analysis (CFA) is used to test a specified measurement model, and path analysis is used to test the structural (theoretical) model. CFA involves examination of the relationships between observed variables and latent variables (factors). Observed variables are also referred to as measured variables. In the proposed model of narrative discourse production, the observed variables are IQ, EF, WM, IM, and all discourse measures. Latent variables are abstract, underlying constructs that are not directly measurable. The sole latent variable in the proposed model is cognitive ability. Indicators are a class of observed variables that are used to indirectly measure the latent construct. In models with a single latent variable, such as the current model, it is necessary for the latent variable to have at least three indicators for the purposes of model identification. The indicators of cognitive ability in the proposed model are the measures of EF, WM, and IM.

The structural model is tested using path analysis with latent variables where possible (Hooper, Coughlan, & Mullen, 2008). Path analysis examines the effects that predictor variables have on multiple outcome variables. Some of the predictor variables are exogenous to the rest of the variables in the model, meaning that they are not caused by those other variables in the model. The sole exogenous variable in the model is IQ. Endogenous variables (e.g, cognitive ability, story completeness) are those that can be caused by other variables in the model. Some endogenous variables are both predictor and outcome variables (e.g., IQ, story grammar). A distinct advantage of SEM over multiple regression is its capacity to examine the relationships among multiple outcome variables, where some of the outcome variables serve as predictors to other outcome variables or may be shown to be spuriously related to those outcome variables.

Six measures of overall goodness of fit were examined for the present model: 1) the Chi-Square Goodness-of-Fit test, 2) the Root Mean Square Error of Approximation (RMSEA), 3) the 90% confidence interval (CI) for RMSEA, 4) p of Close Fit (PCLOSE), 5) the Comparative Fit Index (CFI), and 6) the Tucker-Lewis Index (TLI). For the Chi-Square Goodness-of-Fit Test, good fit is indicated by a nonsignificant chi-square value. The RMSEA estimates the amount of model error per model degrees of freedom. RMSEA values of .05 or less indicate good fit. Ideally, the 90% CI on RMSEA should be very close to zero for the lower bound and less than .10 for the upper bound. PCLOSE values greater than .05 would indicate that the fit of the model is close and has an acceptable level of specification error. The CFI and TLI are incremental fit measures in which the current model is compared to a “best model”. For both the CFI and TLI values of .95 or greater are indicative of good fit, and values of .90 to less than .95 are considered mediocre. More detailed information regarding SEM and fit indices may be found in Kline (2011) and Kenny (2012).

Results

Discourse Measures

When the discourse measures were compared across the six PHI subgroups, the MANOVA (Pillai’s trace) revealed no significant effect of group $V = .26$, $F(35, 720) = 1.24$, $p = .16$ (see Table 3). All discourse data from the subgroups was then pooled and analyzed for the entire PHI group.

MANOVA (Pillai’s trace) indicated a significant effect of group on the discourse measures, $V = .085$, $F(7, 204) = 2.72$, $p = .01$. The ANOVAs indicated that three discourse measures distinguished the PHI and NBI groups: number of T-units (story length or productivity; $F(1, 211) = 4.62$, $p = .03$), proportion of T-units within episode structure (story grammar; $F(1, 211) = 4.93$, $p = .03$), and completeness (number of critical story components; $F(1, 211) =$

10.97, $p = .001$). In all three instances, the NBI comparison group had higher mean scores for these measures than the PHI group (see Table 4). Effect sizes for these differences were small to medium. The four discourse measures that were not significantly different were subordinate clauses per T-unit (grammatical complexity; $F(1, 211) = <.001$, $p = .99$), cohesive adequacy ($F(1, 211) = .86$, $p = .35$), local coherence ($F(1, 211) = .001$, $p = .98$), and global coherence ($F(1, 211) = 3.33$, $p = .07$).

Cognitive Measures

The cognitive measures were also compared across the six PHI subgroups. MANOVA (Pillai's trace) revealed no significant effect of group $V = .15$, $F(20, 568) = 1.10$, $p = .34$ (see Table 5). Data from the cognitive measures for the subgroups was then combined and examined for the complete PHI group.

MANOVA (Pillai's trace) indicated a significant effect of group on the cognitive measures, $V = .074$, $F(4, 201) = 4.021$, $p = .004$ for the PHI and NBI groups. The ANOVAs identified significant group differences for the PHI and NBI participants on the measures of IM ($F(1, 204) = 5.89$, $p = .02$), WM ($F(1, 204) = 9.07$, $p = .003$), and IQ ($F(1, 204) = 8.97$, $p = .003$). Effect sizes for these differences were small to medium (see Table 4). The EF measure was not significantly different ($F(1, 204) = 1.02$, $p = .32$) between the NBI and PHI groups (see Table 6).

Data Modeling

Cognitive ability was a latent variable comprised of three indicators: EF, WM, and IM. Because the effect of IQ on the discourse measures was a key question, IQ was specified as a separate, observed variable. The internal consistency of the cognitive ability factor was measured with a standard score coefficient alpha (Cronbach's alpha). The alpha reliability of the conceptual performance scale was .62 and considered adequate (Clark & Watson, 1995). Data from the PHI group were entered into the model. The NBI group was not included in the model since the PHI and NBI groups were not comparable on the correlations among the variables. A separate model for the comparison group was not tenable given the sample size of 46, which is considered quite small for a large sample technique like SEM.

Based upon the preliminary correlational analysis, IQ was found to be distinct from the individual cognitive measures (Table 7). The correlations between IQ and the EF, WM, and IM measures ranged from moderate to moderately large ($r = .60$ –.78). The correlations among the EF, WM, and IM measures themselves were in the moderate range ($r = .48$ – .55). Based on the relationships among the cognitive measures, EF, WM, and IM were thought to reflect an underlying construct of cognitive ability. Therefore, the latent variable of Cognitive Ability was created with the EF, WM, and IM measures as indicators. In the preliminary CFA, IQ correlated more strongly with the Cognitive Ability ($r = .94$) than it did with the individual EF, WM, and IM measures.

In an earlier version of the model none of the paths from IQ and Cognitive Ability to any of the discourse measures was significant. Given that this finding was contrary to empirical evidence regarding the relationship between cognition and discourse production, potential sources of errors in the model were explored. Most notable was the very high correlation between the exogenous variable IQ and the latent variable Cognitive Ability, r = .94, as noted before. By having two highly correlated variables as predictors of the discourse measures in the model, the paths between IQ and Cognitive Ability were thought to be potentially redundant. Therefore in the current model the path to the discourse measures originated from IQ only.

The model was tested, resulting in adequate fit in terms of chi-square, χ^2 (13, N = 167) = 29.03, p = .006) (Figure 1). All paths in the model were significant. IQ had a large effect on story completeness (β = .54) and a very large effect on the latent variable Cognitive Ability (β = .94). Therefore, IQ accounted for almost 30%of the variance in story completeness. As expected, IQ had a strong relationship with the latent variable representing the EF, IM, and WM measures, accounting for 88% of the variance.

There were small to large effects among the three discourse measures. Story completeness predicted 29% of the variance in story grammar (β = .54), which is a large effect, and had a smaller effect on productivity (β = .36) of the variables predicting productivity. Story grammar had a medium effect on productivity (β = .25). Together, story completeness, and story grammar predicted 29% of the variance in productivity. Overall, the model predicted almost 30% of the variance in each discourse measure.

Overall, the fit of the model was adequate-to-good across the fit indices. The Chi Square Goodness-of-Fit Test was significant, χ^2 (13, N = 167) = 29.03, p = .006, as reported above. RMSEA was .086. The 90% CI on RMSEA was .0444 to .129. PCLOSE was .075. For the incremental fit indices, the CFI was .967, the TLI was .929.

Discussion

The first question addressed the issue of differences across the PHI and comparison groups: *Is the discourse performance of PHI group comparable to that of the non-brain-injured (NBI) comparison group?* Three discourse measures (number of T-units, story grammar, and completeness) distinguished the PHI group’s performance. For all three measures, the NBI comparison group’s scores were significantly higher. The NBI group produced longer stories that were better organized and more complete than those of the PHI group. No differences were noted between the participant groups for measures of grammatical complexity, cohesive adequacy, or coherence. The findings indicate that PHI, like CHI, resulted in discourse deficits not attributable to aphasia. These impairments were also not simply a consequence of aging or level of education as the participant groups were closely matched on these demographic variables. Further, the participants with PHI produced fewer T-units and less complete and organized stories which is consistent with several studies which have noted decreased verbal output and efficiency in the discourse of individuals with CHI (Body & Perkins, 2004; Brookshire, Chapman, Song, & Levin, 2000; Stout, Yorkston, & Pimental, 2000). There are also numerous reports that the story narratives of these individuals are characterized by problems with content accuracy and organization, story grammar, and coherence (Body & Perkins; Brookshire et al.; Chapman et al.; Davis & Coelho, 2004; Tucker & Hanlon, 1998). Coherence was not a measure the PHI group appeared to have difficulty with, which is consistent with Van Leer and Turkstra’s (1999) report that their participants with TBI were no worse than a matched group of normal teens on ratings of local and global coherence. The finding that the PHI group's discourse performance was characterized by difficulty with the measures focused on macro-structural components (i.e., story grammar and completeness) is consistent with what has been observed in the discourse of a large group of individuals with CHI ($N = 55$) (Coelho, 2002).

Of particular interest is how these macro-structural impairments may be interpreted in terms of the Gernsbacher's (1990) Structure Building Framework (SBF). The PHI group also demonstrated impairments in WM and IM but not EF. As suggested in the introduction, the SBF processes of laying a foundation and mapping are linked to memory, therefore, the PHI participants' difficulty with completeness (content) and story grammar (organization) may be a reflection of difficulty developing a mental representation of the story they watched and were asked to retell. Without a foundation or with ineffective mapping, the story was unable to be completely processed and, thus, the retelling was incomplete and disorganized.

With regard to clinical implications of these findings, regardless of the mechanism of TBI (CHI or PHI), survivors are at risk for discourse impairments. These impairments may result from disruption of any of several brain regions secondary to relatively focal or diffuse brain injury. This interpretation is consistent with the findings of Ferstl and colleagues (2008) who identified a fronto-temporal network for discourse processing. Further, the chronicity of discourse deficits has been documented in adults (Snow, Douglas, & Ponsford, 1998) and children (Brookshire et al., 2000; Chapman et al., 2001) two to three years post-injury. The participants in the PHI group from the present study demonstrated difficulties with discourse production 34 to 37 years post injury. Findings from these studies indicate that discourse impairments do not diminish with time and discourse impairments have significant impacts on social integration and quality of life following TBI (Galski et al., 1998). Given the persistence of discourse deficits, time-efficient discourse analysis techniques and treatment strategies are needed.

The second question asked: *Can the discourse performance of the PHI group be fit to a model based theoretical relationships with and on correlations of various cognitive measures that have been reported in the TBI literature?* Based on theoretical relationships and correlations between discourse and cognitive measures, we proposed a preliminary model to explain the present findings. Overall, the proposed model demonstrated adequate-to-good fit with the data. Consistent with the previous findings on cognitive and functional outcomes (Wertheimer, et al., 2008; Ylioja et al., 2010; Zafonte, et al.,1997) following PHI, IQ was a better predictor of narrative discourse production ability than the other measures of cognitive ability. Given the high correlation between IQ and Cognitive Ability, it was posited that IQ would account for Cognitive Ability, story completeness, and story grammar. There is little theoretical and empirical support for a direct relationship between IQ and productivity. It seemed a reasonable assumption that story completeness and story grammar would directly predict productivity rather than IQ. This would imply that narrative content and organization influence the number of utterances produced rather than intelligence. This specification suggests that narrative content drives narrative organization, reflecting an assumption of the Structure Building Framework (Gernsbacher, 1990).

The proposed model should be viewed as a potential starting foundation that can be modified and respecified as our understanding of the relationships between various aspects of discourse production and specific cognitive processes evolve. The fit of the current model is adequate-to-good, meaning there is room for improvement. There are likely other latent factors that need to be considered. For example, the treatment of EF, WM, and IM as indicators of cognitive ability is a somewhat coarse-grained approach. Although there is general consensus that all three measures are cognitive measures, the model does not identify the particular aspects of cognition that underlie story completeness, story grammar, and productivity and whether cognitive substrates differ among the discourse measures. However, the model does provide evidence for the cognitive bases of the three discourse measures examined. Future studies should use multiple different measures of each cognitive process such as the distinct components of EF, such as updating, inhibition, and shifting (Miyake, Emerson, & Friedman, 2000; Miyake & Friedman, 2012) and subscales of the WAIS. Similarly, in future models, immediate memory and working memory should be treated as latent variables with multiple indicators of each. For example, a model that may improve upon the current model would be one in which EF, WM, and IM are treated as three separate latent constructs rather than as observed measures. EF, WM, and IM are good candidates as latent variable predictors in the modeling of discourse production because these particular cognitive processes have been shown to correlate or predict discourse performance in the literature. As the model develops, there may be a need to remove or add variables. Respecification of the model should be theoretically based, logical and reasonable and not simply a means to achieve statistical goodness-of-fit.

The proposed relationship between the discourse measures depicted in the model was interesting. Completeness influenced story grammar and productivity directly and, additionally, productivity indirectly. If completeness is thought of as content and story grammar as a means of organizing content, then logically story grammar facilitates the production of content. The indirect link between completeness and productivity can be illustrated by an individual’s production of simple, more automatic or overlearned, content not requiring organization. The relationship between story grammar and productivity implies that organized stories tend to be longer while unorganized stories tend to be shorter. What this may mean is that story grammar allows the storyteller to communicate more efficiently by “chunking” story information into episodes. Perhaps story grammar facilitates access to narrative content, and, by doing so, allows the storyteller to produce more of the story.

Conclusion

This study compared the narrative discourse performance of two groups of Vietnam veterans, 167 with PHI and 46 NBI individuals. The PHI group was divided into six subgroups based on general locale of lesion. There were no distinct discourse patterns which characterized individual subgroups however macro-structural measures (story grammar and completeness) did distinguish the PHI group from the NBI participants. These findings are comparable to what has been reported for individuals with CHI and suggest that discourse processes may be disrupted by focal or diffuse brain injury. In addition, a preliminary model of discourse production following PHI was proposed and tested. Results indicated the model had an adequate fit with the data and confirms the complex relationship between cognitive and discourse processes. Continued refinement of this model will help to elucidate this dynamic interaction.

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For more information on the Vietnam Head Injury Study, please contact Dr. Grafman (jgrafman@ric.org).

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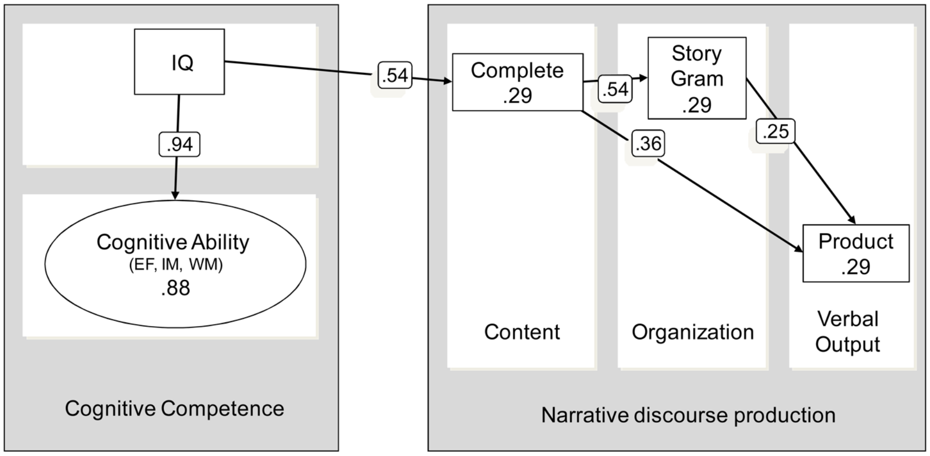

Figure 1.
The Proposed Model of Narrative Discourse Production Following PHI

Table 1

Demographic Data for Six PHI Subgroups.

Measure	LPFC (*N* = 23)		R PFC (*N* = 28)		Bi PFC (*N* = 15)		L nonPFC (*N* = 20)		R nonPFC (*N* = 28)		Bi nonPFC (*N* = 17)		
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***p***
Age (years)	58.80	1.35	57.40	2.54	57.80	2.34	58.50	2.44	58.54	2.30	57.65	2.60	.40
Education (years)	14.61	2.24	14.20	2.45	14.03	2.50	15.25	2.90	15.00	1.93	15.00	1.90	.47
AFQT	60.30	22.00	59.60	25.35	53.40	27.66	73.95	21.20	62.43	24.46	59.23	28.73	.22
BNT	52.60	7.10	54.82	3.22	52.33	5.12	53.60	9.43	55.50	3.60	55.90	3.70	.22
TT	97.80	3.52	98.14	2.50	97.00	3.40	98.05	2.60	98.80	1.64	99.00	1.40	.35
DCT	35.43	2.83	35.96	2.10	34.33	3.42	35.70	3.23	36.25	2.60	35.82	1.80	.19

Note. AFQT = Armed Forces Qualification Test (pre-injury), BNT = Boston Naming Test, TT = Token Test, DCT = Discourse Comprehension Test.

Table 2

Demographic Data for Matched Groups

Measure	NBI Comparison			PHI				
	M	*SD*	Range	*M*	*SD*	Range	*df*	*p*
Age (Years)	59.07	3.52	55–76	58.11	2.63	52–70 *p*	211	.04
Education (Years)	15.09	2.39	12–20	14.91	2.44	8–22	200	.65
AFQT	67.17	22.17	14–85	60.51	25.21	1–99	185	.19
BNT	55.67	3.70	46–60	54.31	5.69	25–60	210	.13
TT	98.74	1.57	94–100	98.30	2.43	87–100	206	.25
DCT	35.52	3.06	26–40	35.60	2.70	27–40	211	.86

Note. α = .008 (.05/6). NBI = non-brain-injured, PHI = penetrating head-injured, AFQT = Armed Forces Qualification Test (pre-injury), BNT = Boston Naming Test, TT = Token Test, DCT = Discourse Comprehension Test.

Table 3

Means and Standard Deviations of Discourse Measures for PHI Subgroup Comparisons.

Measure	L PFC (N = 23)		R PFC (N = 28)		Bi PFC (N = 15)		L non-PFC (N = 20)		R non-PFC (N = 28)		Bi non-PFC (N = 17)		
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***p***
Number T-units	20.00	15.21	20.30	10.43	15.81	6.09	21.86	15.61	23.23	18.43	25.40	16.44	.45
Subordinate clauses/T-unit	.17	.14	.21	.18	.26	.27	.24	.21	.25	.19	.28	.19	.38
Cohesive adequacy	.61	.21	.65	.11	.61	.16	.69	.17	.66	.15	.72	.13	.12
Local coherence	3.40	1.16	4.52	.46	4.22	.81	4.50	.74	4.50	.70	4.54	.76	.08
Global coherence	4.26	.84	4.61	.35	4.31	.48	4.42	.94	4.54	.49	4.60	.74	.30
Proportion T-units in episodes	.55	.31	.64	.16	.64	.21	.60	.28	.54	.25	.71	.16	.09
Completeness	3.00	1.72	3.90	1.35	3.31	1.45	3.80	1.70	3.70	1.51	4.13	1.22	.09

Table 4

Means and Standard Deviations of Discourse Measures for Matched Group Comparisons.

Measure	NBI Comparison		PHI			
	M	***SD***	***M***	***SD***	***p***	***Cohen's d***
Number T-units	26.20	15.30	21.00	14.52	.03	.35
Subordinate clauses/T-unit	.24	.16	.24	.20	.99	
Cohesive adequacy	.68	.17	.66	.16	.35	
Local coherence	4.40	.61	4.40	.86	.98	
Global coherence	4.70	.46	4.50	.64	.07	
Proportion T-units in episodes	.70	.21	.61	.24	.03	.40
Completeness	4.41	1.10	3.63	1.52	.001	.59

Note. NBI = non-brain-injured, PHI = penetrating head-injured

Table 5

Means and Standard Deviations of Cognitive Measures for PHI Subgroup Comparisons.

Measure	L PFC (N = 23)		R PFC (N = 28)		Bi PFC (N = 15)		L non-PFC (N = 20)		R non-PFC (N = 28)		Bi non-PFC (N = 17)		
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***p***
Executive functions	10.12	3.85	10.41	2.50	8.50	3.31	10.75	3.54	11.00	3.50	11.20	3.22	.17
Working memory	98.32	13.65	99.00	12.63	97.75	16.30	99.95	9.00	102.73	13.80	100.00	15.70	.80
Immediate Memory	93.04	17.50	97.60	14.18	94.31	10.90	93.70	14.02	98.51	15.72	101.36	14.70	.36
WAIS full scale IQ	57.70	29.15	53.20	25.50	43.31	26.06	61.40	30.00	58.45	28.33	60.45	28.40	.39

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Table 6

Means and Standard Deviations of Cognitive Measures for Matched Group Comparisons.

Measure	NBI Comparison		PHI			
	M	***SD***	***M***	***SD***	***p***	***Cohen's d***
Executive functions	11. 0	2.80	10.4	3.30	.32	
Working memory	106.53	13.60	99.80	13.41	.003	.50
Immediate memory	102.70	12.70	96.84	15.10	.02	.42
WAIS full scale IQ	69.60	20.33	56.33	27.69	.003	.55

Note. NBI = non-brain-injured, PHI = penetrating head-injured

Table 7

Pearson Correlation Matrix among Cognitive and Discourse Measures for the PHI Group.

	IQ	EF	IM	WM	Product	Complete
EF	.77**					
IM	.63**	.51**				
WM	.60**	.55**	.48**			
Product	.32**	.19*	.24**	.11		
Complete	.54**	.43**	.49**	.29**	.38*	
Story Gram	.33**	33**	.31**	.104	.03	.54**

Note. IQ = WAIS-III Full Scale percentile; EF = DKEFS Sorting Test; IM = WMS-III Immediate Memory Primary Index; WM = WMS-III Working Memory Primary Index; Product = Productivity score; Complete = Completeness score; Story Gram = Story Grammar score.

* $p \le .05$;

** $p \le .001$