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Differing Prefrontal Cortical Activation Across Multiple Forms of Discourse Production

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Abstract

Traumatic brain injury (TBI) can leave an individual with communicative impairment that may only be detected through the analysis of complex speech production, or discourse. This communicative impairment is thought to arise from the disruption of extrasylvian language centers, specifically areas of the prefrontal cortex (PFC). There a paucity of information in the neuroimaging world regarding the involvement of prefrontal regions during naturalistic productive discourse in both healthy and brain-injured populations. The lack of information is due in part to the methodological constraints of common neuroimaging techniques. This paper investigated the involvement of the PFC in four types of orally produced discourse (procedural, personal narrative, fictional narrative and conversational) in a naturalistic setting by using functional near-infrared spectroscopy (fNIRS) to circumvent the methodological constraints of other neuroimaging modalities. The results of this study suggest that the four examined genres of discourse all place significant task demands on the PFC. While these demands are variable between tasks for an individual as well as variable among individuals for a given task, there are regions that are commonly activated throughout individuals.

Introduction

Traumatic Brain Injury

Traumatic brain injury (TBI) is defined as a disruption in the normal functioning of the brain as a result of a blow, bump, jolt or penetrating injury to the head. With such a broadly inclusive definition, it is no surprise that the Center for Disease Control (CDC) estimates that 1.7 million Americans are afflicted by TBI each year (Faul, Xu, Wald & Coronado, 2010). Furthermore, Finkelstein and associates (2006), calculated the total cost of TBI to be $60.4 billion in 2000 and 85% of the total cost was due to productivity losses, not medical expenses. With such a high frequency of occurrence compounded with a massive economic impact, TBI is a major plight harming America.

TBI can range from mild to moderate to severe with different symptoms attributable to each tier. Each tier is defined by a range on the Glasgow Coma Scale where a score of 3-8 classifies a TBI as severe, 9-12 as moderate, and 13-15 as mild (National Center for Injury Prevention and Control, CDC, 2016). The immediate symptoms of mild and moderate TBI include headache, dizziness, confusion, emotional disturbances, and fatigue (National Institute of Neurological Disorder and Stroke, NIH, 2015; CDC, 2016), whereas severe TBI can induce a coma or even death (CDC, 2016). Cognitive deficits that may arise in the days following a TBI of any magnitude include attentional deficits, memory impairments such as diminished recall speed, and dampened information processing (Carroll et al., 2004; CDC 2016). Cognitive symptoms vary among individuals depending on the quality and severity of the head injury but in the adult population, typically resolve themselves in 3 months (Carroll et al., 2004). Some of the more severe cognitive symptoms can be quite insidious with one of the most persistent obstacles experienced by TBI patients being delayed reintegration into social situations as a result of diminished communication abilities (Marsh & Knight, 1991). These communicative impairments are not due to a disruption in basic language functions but rather are attributed to an impairment in the interaction of basic language functions and more complex cognitive processes (Mentis & Prutting, 1987; Coelho, Liles & Duffy, 1995; Coelho, Ylvisaker & Turkstra, 2005; Carlomagno, Giannotti, Vorano, Marini, 2011; Galetto, Andreetta, Zettin & Marini, 2013), which are best analyzed through the medium of discourse (Galski, Tompkins & Johnston, 1998; Coelho, 2007).

Discourse

Discourse is the oral or written transmission of a message through the use of language (Cherney, Shadden & Coelho, 1998). Discourse can vary in length and presentation as a function of its intended purpose yielding multiple forms of discourse which have variable cognitive and linguistic demands. A multitude of studies have linked TBI with impaired discourse production (Mentis & Prutting, 1987; Snow, Douglas & Ponsford, 1997; Coelho et al., 2005; Coelho, 2007), suggesting the variation in cognitive and linguistic demands of different forms of discourse sets the occasion for discourse analysis to aid in the treatment of those suffering from cognitive impairment which may have been a result of TBI. While the productive deficits in discourse are rather well described in the TBI population (Coelho, 2007), the cortical demands corresponding to the various genres of discourse are poorly understood in both in both the TBI population and in the normal healthy population (AbdulSabur et al., 2014). The experiment at hand investigated four types of orally produced discourse (procedural, personal narrative, fictional narrative, conversational) in an attempt to illuminate varied cortical task demands across the various genres.

Procedural Discourse

Procedural discourse is a goal-oriented process of which the purpose is to instruct a listener how to perform a task (Cherney et al., 1998). Procedural discourse is thought to be a valid measure of macrolinguistic ability because it requires the speaker to choose and properly order the steps necessary to achieving a goal (Snow et al., 1997; Coelho, 2007). Patients suffering communicatively from TBI may show impaired organization of content, inaccurate content and reduced verbal efficiency during a procedural discourse task (Coelho et al., 2005).

The first procedural task was adapted from earlier work performed by Kiran, Harris and Marquardt (2005), and required participants to verbally describe the steps involved with planning a trip to New York City. This procedure, referred to as “Trip to New York”, is a complex, cognitively challenging discourse task because it requires the use of planning, organization, and participant generation of the conceptual and semantic content involved in traveling to New York City. Research has shown “Trip to New York” to be sensitive to subtle differences in language abilities between individuals with brain injury and those without (Fleming & Harris, 2008). Specifically, those with cognitive impairment show deficits in length, planning and organization as measured by a lack of previously determined core elements (Kiran et al., 2005; Fleming & Harris, 2008), making “Trip to New York” a valuable discourse production task for detecting subtle changes in macrolinguistic abilities that are best analyzed through discourse.

Procedural discourse was analyzed using a second prompt derived from an experiment in which researchers had multiple demographics, including TBI patients, explain all the necessary steps involved in withdrawing money from a bank (Snow et al., 1997). Individuals with TBI produced fewer of the predetermined essential steps as well as having a smaller proportion of their syllables be on target compared to healthy university age students. Syllables were said to be on target if they were either an essential or an optional step. Essential and optional steps were predetermined by a panel of speech-language pathologists (Snow et al., 1997). The experiment at hand altered the prompt to focus on ATM (automatic teller machine) usage because the Cannizzaro lab believes ATM usage is currently a more common practice than over the counter withdrawals. The ATM task was considered to be a less complex measure of procedural discourse than the NYC task because the NYC task requires complex cognitive planning whereas the ATM task may call upon procedural memory (Snow et al., 1997).

Personal Narrative Discourse

Narrative discourse is defined as conveying actions and events as they unfold in time (Cherney et al., 1998). This broad definition allows for the distinction of various types of narrative with the most common types being personal and fictional. Personal narrative is the recollection of a previous experience (McCabe, Bliss & Bennett, 2008). Prior research on the generation of spontaneous personal narratives in both adults and children suffering from TBI revealed deficits in the components of narratives associated with executive functioning (Biddle, McCabe & Bliss, 1996). For example, Biddle et al. (1996), found significantly more false starts, fillers and internal corrections within the narratives of the TBI populations indicating reduced competency in organizing and self-monitoring of narratives. These findings illustrate the importance of analyzing discourse in the TBI population because linguistic abilities may be impaired at the level of discourse production but intact at the word and sentence level (Mentis & Prutting, 1987; Tucker & Hanlon, 1998; Coelho, 2007).

For personal narrative elicitation, a series a prompts derived from McCabe, Hillier, & Shapiro (2013), were employed, although the original procedure for the elicitation of personal narratives is much older (Labov, 1972). Two prompts were chosen, one involved the recall of an injury that happened to the subject or someone close to the subject and the other asked subjects to simply recall their most recent vacation. The reasoning behind eliciting two different personal narratives is that the emotional salience of the two narratives may vary and emotion is known to alter the prefrontal cortical activity (Partiot, Grafman, Sadato, Wachs & Hallett, 1995).

Fictional Narrative Discourse

Fictional narratives are the second half of narrative discourse analyzed in this experiment. Fictional narratives are strikingly similar to personal narratives in the sense that they rely on the elaboration of events or actions as they play out in time but the key distinction is that fictional narratives can be derived from imagination (Cherney et al., 1998). Measuring content accuracy and narrative cohesion has revealed deficits in fictional narratives produced by TBI patients (Coelho, 2007), as well as decreases verbal output and efficiency (Coelho et al., 2005).

One common method for eliciting a fictional narrative is to use a complex action picture (Cherney et al., 1998). Tucker and Hanlon (1998), had subjects arrange pictures in sequence to produce a framework which the subjects could use to produce a narrative. They showed that individuals with either moderate or mild TBI incorrectly arranged the pictures more frequently than healthy controls. Given the proper order of events, both TBI groups still omitted more relevant details than did healthy controls. The authors speculated that the improper sequencing of narrative events and lack of completeness may be due to cognitive disruption (Tucker & Hanlon, 1998). The utility of discourse analysis in identifying subtle cognitive changes is highlighted by these results.

For the study at hand, a task previously used by the Cannizzaro lab was recycled (Cannizzaro, Stephens, Breidenstein & Crovo, 2016), during which subjects viewed *The Runaway* by Normal Rockwell in order to standardize the topic of the generated fictional narrative. In this experiment Cannizzaro et at. (2016), found that the expressive fictional narrative task produced significantly greater prefrontal activation in 8/13 participants compared to receptive narrative tasks as measured by functional near-infrared spectroscopy. These results assert the role of the PFC in complex discourse production. Taken in conjunction with the behavioral data suggesting that the impairment of complex cognitive functioning in the TBI population produces deficits in discourse, the PFC seems like a viable region to investigate to identify possible regional dysfunctions that may produce disruptions in discourse as a result of TBI.

<u>Conversational Discourse</u>

Conversational discourse is defined as the interactive and cooperative communication of thoughts, ideas and feelings (Cherney et al., 1998), and is without a doubt an essential part of everyday communication skills. Studies of conversational discourse in TBI patients reveal decreased initiation of conversation as well as topic maintenance troubles (Coelho, 2007). For example, in an Australian study which analyzed the conversational abilities of individuals with

TBI at least 2 years post injury, researchers noted insufficient information, redundancy of information and unstructured discourse in up to 96% of their sample (Snow, Douglas & Ponsford, 1998). They postulated that these impairments could contribute to the commonly noted trend of TBI speakers failing to provide enough information to the listener for the conversation to be considered engaging. Utilizing the analysis of conversational discourse to assess cognitive dysfunction in the TBI population could better aid in their recovery allowing for easier reintegration into the workforce and lowering the magnitude of productivity loss caused by TBI. Concurrent with this idea, research suggests that more speech-language pathology feedback trends toward a greater recovery (Snow et al., 1998). The final experimental condition in this study was brief conversation between the examiner and the subject.

The Cortex and Discourse

Beyond the traditional perisylvian language centers, Broca's and Wernicke's areas, exist additional interconnected anatomical regions that are associated with complex language production and in particular, discourse production. These regions are said to a be a part of the Extended Language Network (ELN) which functions in comprehending language through the use of background knowledge and context (Ferstl, Neumann, Bogler & von Cramon, 2008). Specifically, regions involved in the ELN include the anterior temporal lobes which are implicated in text comprehension (Mar, 2004; Awad, Warren, Scott, Turkheimer & Wise, 2007; Ferstl et al., 2008), the middle and posterior temporal lobes which are involved in perception and interpretation of language, respectively (Ferstl et al., 2008), the left lateral prefrontal cortex which is involved in word and sentence processing (Ferstl et al., 2008), the right dorsolateral prefrontal cortex which is involved in ordering sequences of narrative events (Mar,

2004) and the medial prefrontal cortex which is involved in coherence monitoring and emotion processing (Mar, 2004; Ferstl et al., 2008; Partiot et al., 1995).

Previous work by the Cannizzaro lab has confirmed the involvement of the PFC in discourse (Cannizzaro, Dumas, Prelock & Newhouse 2012; Cannizzaro et al., 2016), but these studies focused on discourse processing rather than production as is the case with much of the neuroimaging research on discourse (Mar, 2004; Mason & Just, 2006; Ferstl et al., 2008). While there is likely overlap between the regions associated with comprehension and production, the details of this relationship remain unknown (AbdulSabur et al., 2014), with only three known studies comparing comprehension and production of discourse (Awad et al., 2007; AbdulSabur et al., 2014; Cannizzaro et al., 2016). Interestingly, all three of these studies, and studies which have examined discourse production on its own (Troiani, Fernández-Seara, Wang, Detre, Ash & Grossman, 2008), have suggested involvement of the PFC in discourse production.

The 2007 study by Awad used PET (positron emission tomography) to examine brain regions activated by the production of personal narratives. To elicit personal narratives, researchers used prompts like, "Tell me about of the last Christmas presents you received." They noted the most significant activation in the anterior temporal lobes but were able to observe activation in the medial prefrontal cortex (mPFC) (Awad et al., 2007). They did not postulate what he role of the mPFC may be in speech due to methodological constraints of using PET (i.e., poor spatial resolution).

Similar to the PET study carried out by Awad in 2007, Troiani et al. (2008), used fMRI (functional magnetic resonance imaging) to examine neural activity during discourse produced by subjects who were instructed to describe pictures from a wordless children's book. They found activation in the left dorsolateral prefrontal cortex (dlPFC; Bromann Area [BA] 10, 46) and in the left ventral inferior prefrontal cortex (viPFC; BA 11, 47) (Troiani et al., 2008). Troiani concluded that bilateral activation of the inferior frontal cortex was correlated with narrative organization and left lateral activation was correlated with working memory.

The study by AbdulSabur and colleagues (2014), used both fMRI and PET to examine regions tied to both narrative comprehension and production in conjunction and in isolation. To do this, researchers had participants memorize prewritten stories and traditional nursery rhymes which they rehearsed during the scans. Considering only frontal regions, they found activation above baseline of the left dlPFC (BA 10, 46) and the left dorsal medial prefrontal cortex (dmPFC; BA 8) that were unique to narrative production (AbdulSabur et al., 2014). It was speculated that the activation of these prefrontal regions supports cognitive processes like mentalizing – the ability to imagine the goals, beliefs and intentions of others (AbdulSabur et al., 2014). The ecological validity of this study is called into question because the stories participants produced were memorized which may limit the involvement of regions contributing the production of spontaneous naturalistic discourse.

The aforementioned studies (Awad et al., 2007; Troiani et al., 2008; AbdulSabur et al., 2014; Cannizzaro et al., 2016) illustrate that the prefrontal cortex is a major player in discourse production. Specifically it appears to be involved in the organization of higher level cognitive processes necessary for adequate discourse production. It is important to consider why the research on such a relevant modality of language production is so limited. The primary reason discourse production hasn't made its way to the forefront of the neuroimaging realm is that common imaging modalities like BOLD (blood-oxygen level dependent) fMRI are greatly affected by motion artifacts that arise during spoken language (Kemeny, Ye, Birn & Braun, 2005; Hull, Bortfeld & Koons, 2009; AbdulSabur et al., 2014). It is also difficult to obtain audio recordings during overt speech production in an fMRI machine because the presence of recording devices can tamper with the magnetic fields in the room and if that obstacle is overcome, the machine is loud enough to drown out the sounds produced by the participant (Barch, Sabb, Carter, Braver, Noll & Cohen, 1999). Neuroimaging technologies like PET are more robust to the motion artifacts produced by overt speech but they lack the spatial and temporal resolution of fMRI. Additionally, the injection of a radioactive substance limits the level of signal that can be acquired on a given trial (Hull et al., 2009; AbdulSabur et al., 2014). Functional near-infrared spectroscopy (fNIRS) may be the solution to these methodological constraints.

Functional Near-Infrared Spectroscopy (fNIRS)

fNIRS is based off the principle that oxygenated (HbO) and deoxygenated (Hb) hemoglobin absorb infrared light differently (Delpy & Cope, 1997; fNIRS Devices, L.L.C., 2013). The same assumption made for fMRI and PET is made for fNIRS, namely that activation of a neural region increases the energy demands of that region resulting in increased blood flow to said region. This change in blood flow brings with it more HbO. fNIRS is able to measure the concentration of HbO and Hb by calculating the change in optical density of the signal that arises from differential absorption of infrared light by the two forms of hemoglobin. Four light emitting diodes (LEDs) located on the headband of the fNIRS machine transmit infrared light at two wavelengths (730nm & 850nm) through biological tissue at a depth of ~1-2cm. The head band also possesses 10 optical detectors which measure the change in optical density of the signal. Each optode is paired with 4 detectors yielding 16 optode/detectors pairs called channels.

The advantages and disadvantages of fNIRS are summarized in a thorough review by Quaresima, Bisconti and Ferrari (2012). Some of the more notable advantages of fNIRS are: it is safe and non-invasive, imaging can take place in a more naturalistic setting, it is more robust to motion artifacts, the high temporal resolution, the low cost of operation. The most significant disadvantage is the inability to image subcortical areas and the inability to simultaneously monitor the entire brain (Quaresima, Bisconti & Ferrari 2012). Regarding the experiment at hand, while it would be ideal to monitor prefrontal regions and subcortical regions throughout the entire brain simultaneously, the constraints of the fNIRS machine limit recording to prefrontal regions alone. This is not detrimental to the goal of this study however, because previous studies have strongly suggested the role of the PFC in discourse production (Awad et al., 2007; Troiani et al., 2008; AbdulSabur et al., 2014; Cannizzaro et al., 2016).

Rachel Hull et al. (2009), performed a study with the intention of comparing fNIRS to more traditional imaging methods used to examine speech production such as fMRI and PET. They found that fNIRS results aligned with current knowledge of temporal involvement in speech production (Hull et al., 2009), validating fNIRS as a reliable imaging modality, concurrent with prior research (Kleinschmidt et al., 1996).

Hull's research examined the temporal cortex but other researchers have utilized fNIRS to examine the PFC. Researchers in Italy have shown that fNIRS is sensitive to hemodynamic changes in the PFC associated with the encoding and retrieval of memory (Moro, Cutini, Ursini, Ferrari & Quaresima, 2013), concluding fNIRS has the potential to aid in the diagnostic and treatment process of those with cognitive impairment. Even more recent work has supported these conclusions and demonstrated frontal lobe inefficiency in TBI patients during the Stroop task using fNIRS (Plenger, Krishnan, Cloud, Bosworth, Qualls & de la Plata, 2015). These results first, support previous findings that TBI affects cognitive functioning and second, demonstrate that fNIRS can accurately be used to examine this dysfunction in the PFC.

The most recent published study using fNIRS from the Cannizzaro lab even demonstrated PFC activity during discourse production tasks (Cannizzaro et al., 2016). This pilot study examined PFC activity during receptive narrative tasks as well as during two expressive narrative tasks (i.e., procedural discourse and fictional narrative discourse). The results revealed a diverse range of activation patterns across the types of produced discourse with a general trend of the “Trip to New York” procedural task demanding more of the PFC than the *Runaway* fictional narrative condition.

Hypotheses

Behavioral evidence indicates an impairment in the discourse production of individuals with TBI. There is however, a short coming in the neuroimaging field investigating the neural correlates of discourse production which is, in part, due to methodological constraints. Additionally, the demands of discourse assessment tools on the PFC of healthy and brain-injured adults are relatively under investigated. As a step forward, the current study bypassed the typical methodological constraints by utilizing fNIRS to investigate two hypotheses to help better understand the involvement of the prefrontal cortex in discourse production in healthy, non-brain-injured adults:

1. Complex discourse production tasks (i.e., procedural, personal narrative, fictional narrative, conversational) demand significant activation of the PFC as measured by fNIRS.
2. The tasks demands placed on the PFC by different discourse genres (i.e., procedural, personal narrative, fictional narrative, conversational) can be topographically distinguished using fNIRS.

Materials and Methods

Participants

Eleven healthy participants (1 male, 10 female, mean age=20.6 years, range = 18-22) volunteered for this study. Participants had between 1-4 years of college education with no personal history of TBI, neurological impairment, psychiatric disorders or learning disabilities. All subjects were primary speakers of American English (Table 1). Informed consent was obtained in accordance with the University of Vermont's Institutional Review Board approved protocol. Each participant underwent cognitive assessment before the testing period began in order to better control for cognitive variation in language functions. Cognitive assessment was carried out using the Montreal Cognitive Assessment (Nasreddine et al., 2005).

Instrumentation

A Biopac fNIRS-100 16 channel continuous wave system (Biopac Systems, Camino Goleta, CA) was used to monitor changes in the concentration of oxygenated and deoxygenated blood flow in the PFC. The head band was secured to the subjects' forehead according to the standardized 10-20 system of electroencephalography electrode placement where the vertical axis of the headband is aligned with the symmetrical axis of the head (i.e., along the midsagittal plane). The horizontal axis of the bottom row of detectors is then aligned with Fp1, Fpz, and Fp2 which positions the headband to cover Brodmann's Areas 44, 45, 46, 9, & 10 (fNIRS Devices, L.L.C., 2013). A soft foam tape was placed around the edge of the headband to limit the intrusion of ambient light and more securely fasten the headband to the participants head. Before recordings began, the characteristics of the signals were examined for each subject to assure that the steady state value was between 800-4,000mv during the no task condition (fNIRS Devices, L.L.C., 2013).

All fNIRS signal data was recorded via the Cognitive Optical Brain Imaging Studio (COBI) software package (Ayaz, 2005). A modified version of the Beer-Lambert law was then used to calculate HbO concentrations from the optical density recordings taken from the channels at a sampling rate of 2 Hz.

Experimental Procedure

Prior to entering the exam room, subjects were given verbal instructions outlining the format of the test to come. Participants were instructed to refrain from body movement and to limit facial movement, especially forehead movement as best they could. Subjects were seated a comfortable distance from a 20" computer monitor which guided them through the test with spoken and written instructions. In an attempt to reduce anxiety that may arise from the novel and unfamiliar environment, subjects were allowed to sit before the screen wearing the fNIRS headband and acclimate themselves to the new environment. Once the acclimation period had ceased, subjects were asked to relax and passively stare at the fixation cross on the monitor while a baseline measurement was taken. After steady baseline measurements were confirmed by the fNIRS machine, subjects were asked if they were ready to begin. Once the participants signaled they wished to begin, the timed stimuli sequence was initiated via an automated Microsoft PowerPoint slideshow and optical data measurements began simultaneously.

Baseline Tasks

Each experimental condition was preceeded by a slide containing written and spoken instructions explaining the participant's assignment. The experimental conditions were followed by a 15 second fixation period in which participants passively stared at a cross in the center of the screen. The purpose of this task was to act as a wash out period as is common practice in neuroimaging experimentation (e.g., AbdulSabur et al., 2014; Cannizzaro et al. 2016). A productive recitation task (i.e. counting from 1-100 and then 100-1) and was used as a simple spoken baseline to contrast against more complex discourse tasks in order to highlight regions specific to complex discourse (Moro et al., 2013; AbdulSabur et al., 2014; Cannizzaro et al., 2016).

Procedural Discourse

The first procedural discourse task was the "Trip to New York" task (Kiran et al., 2005). Subjects were read the following passage:

> *Imagine that you are going on a vacation a week from now. You are traveling to New York City for a two-week stay. Think about all you will have to do to get ready to go, such as how you will get there, what you will bring, and what you will do. When the slide changes, describe in detail all the activities associated with the trip.*

Subjects had 60 seconds to complete the task and were halted when the time limit concluded.

The second task examining procedural discourse was the ATM task (Snow et al., 1997). Subjects were presented the following prompt:

When the slide changes, please tell me all the steps involved in withdrawing money from an automatic teller machine (ATM), as if I had never done it before.

Subjects had 60 seconds to complete the task and were halted when the time limit concluded.

Personal Narrative Discourse

Subjects were given two prompts to elicit personal narratives. The first prompt asked subjects to talk about a time they, or someone close to them, was injured (McCabe et al., 2013). It was presented in the following manner:

Last year my uncle was severely injured in a car accident. So far it has been a long and difficult recovery. Can you tell me about a time when you or someone close to you was seriously injured?

The second personal narrative prompt asked subjects to discuss a vacation they recently went on and was presented as so (McCabe et al., 2013):

On my last vacation, my family and I went to Florida. What did you do during your last vacation or over summer vacation?

Subjects had 60 seconds to complete each task and were halted when the time limit concluded.

Fictional Narrative Discourse

Subjects were presented the painting *The Runaway*, by Norman Rockwell, and the following instructions were delivered via automated PowerPoint slides:

Tell me a story about the picture on the screen. The scene in this picture represents a moment in time. Something happened to cause the pictured event and something is going to happen afterwards. When the slide changes, please tell me the whole story from what happened before the pictured event through what will happen after this scene.

Participants were allocated 60 seconds to complete the fictional narrative task.

Conversational Discourse

The final experimental condition was a brief conversation between the participant and the examiner. Once the slideshow changed from the instructional slide, the examiner initiated the conversation by saying, "Tell me about your family." The subject was then allowed to respond however they saw fit. The examiner would respond vaguely with statements like, "Uh, huh," and, "Is there anything else you can tell me?" If the topic failed to elicit two minutes worth of conversation, the examiner selected another topic from the list to fill the allotted time. Other topic options included: "Tell me about the sort of work or study that you do.", "What do you do on the weekends?", "Do you have any particular favorite TV programs?"

Data Analysis

Data obtained from the fNIRS machine was analyzed using the computer program Near-Infrared Spectroscopy Statistical Parametric Mapping (Version 4.1; Ye, Tak, Jang, Jung, & Jang, 2009) and specifications for best practice were followed (Tak, 2011) in the same manner they were for previous work from this lab (Cannizzaro et al., 2016). Before the contrasts were performed, each channel's signal for each participant was visually inspected for its temporal alignment with the experimental design timeline. Initially, the hrf (hemodynamic response function) was applied to each subject's dataset in order to smooth the data and correct residual fluctuations that are due to gradual increases in hemodynamic function that occur as the brain is active. Each participant's data then had a wavelet-MDL detrending function applied in order to remove extraneous non-relevant biological signals such as breathing, cardiac rhythms and vaso-motion (Ye et al., 2009). As per recommendation of the user's manual, further data correction included a low-pass filter (hrf shape, fwhm=4sec). NIRS-SPM used a general linear model to detect parameter estimates and temporal correlations in the data with a Euler characteristic approach to control family-wise error in the data (Ye et al., 2009). The significance level for beta weights and corresponding activation maps were reported as significant at $p<0.05$ while employing Lipschitz-Killing curvature with Euler characteristic to account for expected correlations (Tak, 2011).

In order to test hypothesis 1 (complex discourse production tasks produce significant activity in the PFC), two families of contrasts were carried out for each individual. The first family highlighted the significant prefrontal activity that each task elicited regardless of whether or not the activity was discourse specific. In order to examine what significant prefrontal cortical activity was discourse specific, the second family of contrasts subtracted the simple productive recitation task from each task specific activation. All contrasts were considered significant at $p<0.05$. The laterality of each pattern of significant activation was assessed visually and reported as either left hemisphere (L), right hemisphere (R), or bilateral hemispheric activation (B). Visual inspection entailed determining where statistically significant activation fell relative to the longitudinal fissure on the rendered brain. Activation was considered bilateral even if one hemisphere had a greater magnitude of activation because all reported activation was statistically significant.

To test hypothesis 2 (complex discourse production tasks produce topographically distinguishable patterns of activity in the PFC), the same two families of contrasts were carried out using group analysis instead of individual analysis. Group analysis revealed any task specific regional activity that was common amongst all subjects which would effectively demonstrate topographic differences between tasks. All contrasts were considered significant at $p<0.05$ and family wise error rate was controlled for using the expected Euler characteristic approach based on Lipschitz-Killing curvature (Ye et al., 2009; Tak, 2011).

Results

Individual Analysis

Procedural discourse

For the "Trip to New York" task, 8/11 participants showed significant prefrontal activation when the task was analyzed on its own. This activation was localized to the left hemisphere for four subjects, the right hemisphere for two subjects, and the activation was bilateral for the remaining two subjects (Table 2). 7/11 participants showed significant prefrontal activation when the recitation baseline task was subtracted from the task specific activation. For this contrast condition, four subjects had bilateral activation, one had right hemisphere activation and two had left hemispheric activation (Table 3).

For the ATM task, 4/11 participants showed significant prefrontal activation when the task was analyzed on its own with two subjects having right hemispheric activation, one having left hemisphere activation and one having bilateral activation (Table 2). 6/11 participants showed significant prefrontal activation when the recitation baseline task was subtracted from the task specific activation. Of these six with significant activation, two showed left hemisphere activation, one showed right hemisphere activation and three demonstrated bilateral activation (Table 3).

When the two procedural discourse tasks (i.e., NYC and ATM) were pooled, 5/11 participants showed significant prefrontal activation. There were two subjects with left hemisphere activation, two with right hemisphere activation and one with bilateral activation (Table 2). 7/11 participants showed significant prefrontal activation when the recitation task was subtracted from the combined task activation. Under these conditions, one subject showed left hemispheric activation and the remaining six showed bilateral activation (Table 3).

Personal Narrative Discourse

For the Injury task, 8/11 participants showed significant prefrontal activation when the task was analyzed on its own. Half of these eight showed bilateral activation, two showed right hemisphere activation and two showed left hemisphere activation (Table 2). 9/11 participants showed significant prefrontal activation when the recitation baseline task was subtracted from the task specific activation but under these contrast conditions, eight showed bilateral activation and one showed left hemisphere activation (Table 3).

For the Vacation task, only 2/11 participants showed significant prefrontal activation when the task was analyzed on its own and for both individuals the activity was localized to the right hemisphere (Table 2). 3/11 participants showed significant prefrontal activation when the recitation baseline task was subtracted from the task specific activation. Two of those with significant activation showed it bilaterally whereas only one showed right hemisphere activation (Table 3).

When the two personal narrative discourse tasks (i.e., Injury and Vacation) were pooled, 6/11 participants showed significant prefrontal activation. For three individuals this activity was localized to the left hemisphere, for two it was localized to the right hemisphere and one subject demonstrated bilateral activation (Table 2). 8/11 participants show significant prefrontal activation when the recitation task was subtracted from the combined task activation. 5/8 displayed bilateral activation, 2/8 showed left hemispheric activation and 1 showed activity in the right hemisphere (Table 3).

Fictional Narrative Discourse

For the *Runaway* task, 4/11 participants showed significant prefrontal activation when the task was analyzed on its own. Left hemisphere activity was seen in one subject, right hemispheric activity in another, and bilateral activity in the remaining two (Table 2). 6/11 participants showed significant prefrontal activation when the recitation baseline task was subtracted from the task specific activation. For 4/6 individuals the activity was bilateral and for the remaining two the activity was localized to the left hemisphere (Table 3).

Conversational Discourse

For the conversational task, 5/11 participants showed significant prefrontal activation when the task was analyzed on its own. Two subjects showed activity in the left hemisphere, one in the right hemisphere and two bilaterally (Table 2). 8/11 participants showed significant prefrontal activation when the recitation baseline task was subtracted from the task specific activation. Three of these eight individuals had activation isolated to the left hemisphere, one to the right hemisphere, and four individuals had bilateral activation (Table 3).

Group Analysis

When group analysis is performed, interpolated maps of weighted activation for each individual are compared amongst each other to highlight commonalities in regional activation that may not have been significant for an individual given that the activation observed by fNIRS is relative. NIRS-SPM allows for the user to specify the threshold number of subjects who must have common overlap for the commonality to be deemed statistically significant. For this experiment, the initial threshold was 8/11 (73%) subjects having overlap. A second threshold of 11/11 subjects was then implemented and identical results were obtained. Therefore this paper only reports the 11/11 subject overlap results for the sake of brevity.

Procedural Discourse

Group analysis of the "Trip to New York" task revealed that when only examining activation (i.e., no baselines were subtracted), all participants has significant bilateral activation which was stronger in the right hemisphere (Figure 1). Significance at the group level was not found for the "Trip to New York" task when the simple productive recitation task was subtracted from the activation.

Group analysis of the ATM task revealed no significant activation for any of the contrast conditions.

Group analysis of the combined procedural tasks revealed significant right hemisphere activation when the combination was examined without the subtraction of any baseline tasks (Figure 2). Subtraction of the recitation task yielded no significant activation.

Personal Narrative Discourse

Group analysis of the Injury task revealed significant bilateral activation, which was stronger in the right hemisphere, when activation was viewed with no baselines subtracted (Figure 3). Significant bilateral activation was also observed when the recitation task was subtracted from the Injury task (Figure 4).

Group analysis of the Vacation task revealed no significant activation for any of the contrast conditions.

Group analysis of the combined personal narrative tasks revealed significant right hemisphere activation when the combination was examined without the subtraction of any baseline tasks (Figure 5). Subtraction of the simple productive recitation task yielded no significant activation.

Fictional Narrative Discourse

Group analysis of the *Runaway* task yielded no significant activation for any of the three contrast conditions.

Conversational Discourse

Group analysis of the conversational discourse task yielded significant right hemisphere activation when no baseline tasks were subtracted (Figure 6). Subtraction of the recitation task nullified the significant activation.

Discussion

General

Taken as a whole, the results of this study indicate the involvement of the PFC during discourse production is variable between tasks for an individual as well as variable between individuals for a given task, but that complex discourse production tasks do require significant activation of the PFC for the majority of participants, across the majority of tasks as measured by fNIRS. These findings support the first hypothesis. One task even showed regional activation that was unanimous among subjects which partially supports the second hypothesis that tasks are topographically distinguishable. Further research may better support the second hypothesis.

Prefrontal activity that was observed when the recitation baseline was subtracted from the elicited activity is likely the most representative of the demands placed on the PFC unique to discourse. By subtracting a basic recitation task, any activity unique to discourse is brought forth because prefrontal activity that arose from automatic language production is removed.

Individual Analysis

Each task, when the recitation baseline was subtracted, elicited significant activation in greater than 50% of participants save for the Vacation task (Table 3). This supports the hypothesis that complex discourse productions tasks produce significant activation of the PFC. Examination of individual activation patters reveals that only one subject (Subject 11) had the same general pattern of activation (bilateral) across all six tasks (Table 3), indicating that for the majority of people, each task imposes significant yet different demands on the PFC.

It is interesting to consider that the Vacation task didn't elicit significant activation in more than 50% of subjects because within the genre of personal narrative discourse, the Vacation task had less emotional salience than did the Injury task. Emotionally salient plans have been shown to recruit more prefrontal activity than non-salient plans (Partiot et al., 1995), which likely contributes to why more subjects showed activation during the Injury task than they did during the Vacation task. The results obtained from this study support that assertion that emotionally salient content is more demanding of the prefrontal cortex than non-emotionally salient content. This idea may be fruitfully applied in a clinical setting. If a speech-language pathologist were attempting to examine the personal narratives of an individual with TBI in order to examine possible cognitive disruptions, they may benefit from selecting a prompt with emotional content as it may be more demanding on the PFC.

To illustrate the point that PFC task demands are variable between individuals for a given task, consider the contrast condition where the recitation task was subtracted from the activation elicited by the conversation (Table 3). While 8/11 individuals demonstrated statistically significant activation, three of these eight individuals had activation isolated to the left hemisphere, one to the right hemisphere and four individuals had bilateral activation. Similar trends of variable hemispheric localization were observed for each task regardless of whether or not the recitation task was subtracted. These results align with other imaging studies which suggest a variable role of the PFC in discourse production among individuals for a given task (Cannizzaro et al., 2016), but are novel in their own right because they examined previously unexplored genres of discourse like personal narratives and conversational discourse. Therefore, it seems that regardless of the genre, productive discourse is demanding on the prefrontal cortex.

Group Analysis

Even though there was a high level of individual variation within each task, there were common regions of activity shared by all subjects for particular tasks that were revealed through group analysis, partially supporting the second hypothesis. The caveat here is that the significant activation observed through group analysis was primarily found when examining tasks without the simple productive recitation task subtracted meaning that it is not possible to confirm the activation as being discourse specific or as a product of general overt language.

The "Trip to New York" (Figure 1), Injury (Figure 3) and Conversational (Figure 6) tasks all showed significant activation through group analysis. Additionally, the pooled procedural tasks ("Trip to New York" and ATM; Figure 2) and the pooled personal narrative tasks (Injury and

Vacation; Figure 5) showed significant activation through group analysis. The activation was focused in the right dlPFC (BA 10, 46) for every significant contrast run using group analysis. The role of the dlPFC will be discussed in greater detail below.

Only one task revealed significant activation at the group level when the recitation task was subtracted – the personal narrative Injury task (Figure 4). The activation was bilateral but not symmetric. There was minimal activation in the left hemisphere but it was found at approximately BA 44/45 which is considered Broca's area and is involved in speech and syntax production (Trans Cranial Technologies, 2012). The strongest activation was in the right hemisphere in the dlPFC (BA 10, 46). The dlPFC has been observed in discourse production by other researchers using fMRI (Troiani et al., 2008), and PET (AbdulSabur et al., 2014) and has now been witnessed using fNIRS.

Interestingly though, previous involvement of the dlPFC in discourse production has been observed in primarily the left hemisphere where as in this study it was found to be active in the right hemisphere. The reason for this is not obvious but one likely explanation considers functional hemispheric differences. The right dlPFC has been associated with properly ordering narrative events and with episodic memory retrieval (Mar, 2004). Mar goes on to explain that the region of dlPFC associated with episodic memory retrieval is slightly posterior to the region associated with narrative sequencing. Given that the spatial resolution of fNIRS is ~1cm (Quaresima et al., 2012), the significant activity of the right dlPFC noted during group analysis could be reflective of narrative sequencing, episodic memory retrieval, or both.

Consider the contrast where the recitation task was subtracted from the Injury task. Because participants had likely told the story about when they or someone they knew was injured before, it is possible they were retelling the story from episodic memory rather than spontaneously generating the proper sequence of events. This explanation of why the dlPFC was active in the right hemisphere is also supported by the lack of medial activation that was observed for the Injury task. PET studies regarding the generation of emotionally salient plans suggest the mPFC as an involved region (Partiot et al., 1995), yet no medial activation was detected for the emotionally salient Injury task. As was mentioned, this could be accounted for if participants were relying on episodic memory rather than spontaneous generation.

Limitations of this Study

The most potent limitation of this study is the lack of male participants (10 females, 1 male). Fortunately, research has suggested that the most significant sex difference between males and females regarding language production is that males tend to have larger magnitudes of activation (Buckner, Raichle & Petersen, 1995). Regardless, the validity of this study could only be bolstered by an equal sex distribution.

The reason for the imbalance in the sex of the subjects is in part due to the exclusion criteria of the study. Because the goal of the study was to assess prefrontal activity in healthy controls in order to build a baseline with which TBI patients can later be compared, a history of TBI was an exclusion criteria for the study. When recruiting male subjects, there were consistent reports of a history of TBI (usually concussion). This seems plausible given that men are 26% more likely to sustain a TBI (CDC, 2016).

Another limitation was the restricted region of the cortex that was able to be sampled using the fNIRS device. Obtaining measurements from all throughout the cortex would provide a more accurate representation of extrasylvian regions involved in discourse production.

Additionally, a greater number of channels in the fNIRS device could improve the spatial resolution of the device.

One other point to consider is the score of participant #2 on the MoCA cognitive examination (Table 1). The subject scored a 24 which is below the recommended cut off point of 26 (Nasreddine et al., 2005).

Conclusion

In conclusion, complex discourse production tasks do produce significant activation of the PFC for the majority of individuals that is measurable using fNIRS in an ecologically valid setting, agreeing with the first hypothesis. This supports the notion that fNIRS could be applied clinically in combination with traditional discourse analysis to better cater to the individuals communicative impairment that may have resulted from TBI by monitoring improvements in discourse production abilities concurrently with changes in prefrontal activity. Furthermore, it appears as if fNIRS has the potential to topographically distinguish task demands various genres of discourse place on the PFC, suggesting the second hypothesis may be better supported in future studies. Future research may be better able to topographically distinguish the task demands of various genres of discourse by using larger sample of subjects representing more demographics and through the use of more control tasks in order to highlight discourse specific activation.

References

AbdulSabur, N. Y., Xu, Y., Liu, S., Chow, H. M., Baxter, M., Carson, J., & Braun, A. R. (2014). Neural correlates and network connectivity underlying narrative production and comprehension: A combined fMRI and PET study. *Cortex*, *57*, 107-127.

Awad, M., Warren, J. E., Scott, S. K., Turkheimer, F. E., & Wise, R. J. (2007). A common system for the comprehension and production of narrative speech. *The Journal of Neuroscience*, *27*(43), 11455-11464.

Ayaz, H. (2005). *Analytical software and stimulus-presentation platform to utilize, visualize and analyze near-infrared spectroscopy measures*. Masters Thesis Project, Drexel University, Philidelphia, PA.

Barch, D. M., Sabb, F. W., Carter, C. S., Braver, T. S., Noll, D. C., & Cohen, J. D. (1999). Overt verbal responding during fMRI scanning: Empirical investigations of problems and potential solutions. *Neuroimage*, *10*(6), 642-657.

Biddle, K. R., McCabe, A., & Bliss, L. S. (1996). Narrative skills following traumatic brain injury in children and adults. *Journal of Communication Disorders*, *29*(6), 447-469.

Buckner, R. L., Raichle, M. E., & Petersen, S. E. (1995). Dissociation of human prefrontal cortical areas across different speech production tasks and gender groups. *Journal of Neurophysiology*, *74*(5), 2163-2173.

Cannizzaro, M. S., Dumas, J., Prelock, P., & Newhouse, P. (2012). Organizational structure reduces processing load in the prefrontal cortex during discourse processing of written text: Implications for high-level reading issues after TBI. *Perspectives on Neurophysiology and Neurogenic Speech and Language Disorders*, *22*(2), 67–78.

Cannizzaro, M. S., Stephens, S. R., Breidenstein, M., & Crovo, C. (2016). Prefrontal cortical activity during discourse processing: An observational fNIRS study. *Topics in Language Disorders*, *36*(1), 65-79.

Carlomagno, S., Giannotti, S., Vorano, L., & Marini, A. (2011). Discourse information content in non-aphasic adults with brain injury: A pilot study. *Brain injury*, *25*(10), 1010-1018.

Carroll, L., Cassidy, J. D., Peloso, P., Borg, J., Von Holst, H., Holm, L., ... & Pépin, M. (2004). Prognosis for mild traumatic brain injury: results of the WHO collaborating centre task force on mild traumatic brain injury. *Journal of Rehabilitation Medicine*, *36*(0), 84-105.

Cherney, L. R., Coelho, C. A., & Shadden, B. B. (1998). *Analyzing discourse in communicatively impaired adults*. Aspen Pub.

Coelho, C. A. (2007). Management of discourse deficits following traumatic brain injury: Progress, caveats, and needs. *Seminars in Speech and Language*, *28*(2), 122-135.

Coelho, C., Liles, B., & Duffy, R. (1995). Impairments of discourse abilities and executive functions in traumatically brain-injured adults. *Brain Injury, 9*(5), 471-477.

Coelho, C., Ylvisaker, M., & Turkstra, L. (2005). Nonstandardized assessment approaches for individuals with traumatic brain injuries. *Seminars in Speech and Language, 26*(4), 223-241.

Delpy, D. T., & Cope, M. (1997). Quantification in tissue near–infrared spectroscopy. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *352*(1354), 649-659.

Ferstl, E. C., Neumann, J., Bogler, C., & von Cramon, D. Y. (2008). The extended language network: a meta-analysis of neuroimaging studies on text comprehension. *Human Brain Mapping*, *29*(5), 581-593.

Finkelstein, E. A., Corso, P. S., & Miller, T. R. (2006). *Incidence and economic burden of injuries in the United States*. Oxford University Press.

Fleming, V.B., & Harris, J.L. (2008). Complex discourse production in mild cognitive impairment: Detecting subtle changes. *Aphasiology, 22*(7-8), 729-740.

fNIRS Imager & COBI Studio Manual (2013). *fNIR Imager*. fNIR Devices L.L.C., Camino Goleta, CA. Copy in possession of Cannizzaro Lab.

Galetto, V., Andreetta, S., Zettin, M., & Marini, A. (2013). Patterns of impairment of narrative language in mild traumatic brain injury. *Journal of Neurolinguistics*, *26*(6), 649-661.

Galski, T., Tompkins, C., & Johnston, M. V. (1998). Competence in discourse as a measure of social integration and quality of life in persons with traumatic brain injury. *Brain injury*, *12*(9), 769-782.

Glosser, G., & Deser, T. (1991). Patterns of discourse production among neurological patients with fluent language disorders. *Brain and Language*, *40*(1), 67-88.

Hull, R., Bortfeld, H., & Koons, S. (2009). Near-infrared spectroscopy and cortical responses to speech production. *The Open Neuroimaging Journal*, *3*(1).

Kemeny, S., Ye, F. Q., Birn, R., & Braun, A. R. (2005). Comparison of continuous overt speech fMRI using BOLD and arterial spin labeling. *Human Brain Mapping*, *24*(3), 173-183.

Kiran, S., Harris, J.L., & Marquardt, T.P. (2005). *Communication Wellness Check-ups: Age-related changes in communication.* San Diego, CA: ASHA National Convention.

Kleinschmidt, A., Obrig, H., Requardt, M., Merboldt, K. D., Dirnagl, U., Villringer, A., & Frahm, J. (1996). Simultaneous recording of cerebral blood oxygenation changes during human brain activation by magnetic resonance imaging and near-infrared spectroscopy. *Journal of Cerebral Blood Flow & Metabolism*, *16*(5), 817-826.

Kolb, B., & Whishaw, I. (2011). What causes emotional and motivated behavior? In *An Introduction to Brain and Behavior* (4th ed., pp. 419-421). New York City, New York: Worth.

Labov, W. (1972). The transformation of experience in narrative syntax. In *Language in the Inner City: Studies in the Black English Vernacular* (pp. 354-355). Philadelphia, Pennsylvania: University of Pennsylvania Press.

Mar, R. A. (2004). The neuropsychology of narrative: Story comprehension, story production and their interrelation. *Neuropsychologia*, *42*(10), 1414-1434.

Marsh, N. V., & Knight, R. G. (1991). Relationship between cognitive deficits and social skill after head injury. *Neuropsychology*, *5*(2), 107.

Mason, R. A., & Just, M. A. (2006). Neuroimaging contributions to the understanding of discourse processes. *Handbook of Psycholinguistics*, *799*.

McCabe, A., Hillier, A., & Shapiro, C. (2013). Brief report: Structure of personal narratives of adults with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *43*(3), 733-738.

McDonald, S. (1993). Pragmatic language skills after closed head injury: Ability to meet the informational needs of the listener. *Brain and Language*, *44*(1), 28-46.

Mentis, M., & Prutting, C. A. (1987). Cohesion in the discourse of normal and head-injured adults. *Journal of Speech, Language, and Hearing Research*, *30*(1), 88-98.

Moro, S. B., Cutini, S., Ursini, M. L., Ferrari, M., & Quaresima, V. (2013). Prefrontal cortex activation during story encoding/retrieval: a multi-channel functional near-infrared spectroscopy study. *Frontiers in Human Neuroscience*, *7*(925), 24427131.

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., ... & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, *53*(4), 695-699.

National Center for Injury Prevention and Control. (2016). *Injury prevention and control: Traumatic brain injury and concussion*. Center for Disease Control. <http://www.cdc.gov/traumaticbraininjury/index.html>.

Nicholas, L.E., & Brookshire, R.H. (1993). A system for quantifying the informativeness and efficiency of the connected speech of adults with aphasia. *Journal of Speech and Hearing Research, 36*, 338-350.

Office of Communications and Public Liaison, National Institute of Neurological Disorders and Stroke (2015). *Traumatic brain injury: hope through research*. National Institute of Health.

Partiot, A., Grafman, J., Sadato, A. N., Wachs, J., & Hallett, M. (1995). Brain activation during the generation of nonemotional and emotional plans. *Neuroreport*, *6*, 1269-1272.

Peterson, C., & McCabe, A. (1983). *Developmental psycholinguistics: three ways of looking at a child's narrative*. New York City, New York: Plenum Press.

Plenger, P., Krishnan, K., Cloud, M., Bosworth, C., Qualls, D., & de la Plata, C. M. (2015). fNIRS-based investigation of the Stroop task after TBI. *Brain Imaging and Behavior*, 1-10.

Quaresima, V., Bisconti, S., & Ferrari, M. (2012). A brief review on the use of functional near-infrared spectroscopy (fNIRS) for language imaging studies in human newborns and adults. *Brain and Language*, *121*(2), 79-89.

Snow, P., Douglas, J., & Ponsford, J. (1997). Procedural discourse following traumatic brain injury. *Aphasiology, 11*(10), 947-967.

Snow, P., Douglas, J., & Ponsford, J. (1998). Conversational discourse abilities following severe traumatic brain injury: A follow up study. *Brain Injury*, *12*(11), 911-935.

Stein, N. L., & Glenn, C. G. (1979). An analysis of story comprehension in elementary school children. In R. O. Freedle (Ed.), *New Directions in Discourse Processing,* 53–120.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643.

Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., ... & Bates, E. (2005). Timed action and object naming. *Cortex*, *41*(1), 7-25.

Tak, S., (2011). NIRS-SPM: Statistical Parametric Mapping for Near Infrared Spectroscopy Users Guide. <http://bispl.weebly.com/nirs-spm.html#/>.

Trans Cranial Technologies. (2012). *Cortical functions: Reference*. Trans Cranial Technologies ldt. <http://www.trans-cranial.com/local/manuals/cortical_functions_ref_v1_0_pdf.pdf>.

Troiani, V., Fernández-Seara, M. A., Wang, Z., Detre, J. A., Ash, S., & Grossman, M. (2008). Narrative speech production: an fMRI study using continuous arterial spin labeling. *Neuroimage*, *40*(2), 932-939.

Tucker, F. M., & Hanlon, R. E. (1998). Effects of mild traumatic brain injury on narrative discourse production. *Brain Injury*, *12*(9), 783-792.

Wiig, E. H., Semel, E. M., & Secord, W. (2013a). *CELF 5: clinical evaluation of language fundamentals – test objectives and descriptions*. Pearson: Psychological Corporation.

Wiig, E. H., Semel, E. M., & Secord, W. (2013b). *CELF 5: clinical evaluation of language fundamentals – evidence of reliability*. Pearson: Psychological Corporation.

Ye, J. C., Tak, S., Jang, K. E., Jung, J., & Jang, J. (2009). NIRS-SPM: statistical parametric mapping for near-infrared spectroscopy. *Neuroimage*, *44*(2), 428-447.

<u>Appendix A – Tables</u>

Table 1

Participant	Age	Sex	Education	English	TBI	Disability	Medical	MoCA Score
1	21	F	1 to 3	Yes	No	No	No	29
2	22	F	1 to 3	Yes	No	No	No	24
3	18	F	1 to 3	Yes	No	No	No	28
4	21	F	1 to 3	Yes	No	No	No	29
5	21	F	1 to 3	Yes	No	No	No	30
6	22	F	4	Yes	No	No	No	30
7	19	F	1 to 3	Yes	No	No	No	29
8	21	M	1 to 3	Yes	No	No	No	27
9	21	F	1 to 3	Yes	No	No	No	28
10	20	F	1 to 3	Yes	No	No	No	30
11	21	F	1 to 3	Yes	No	No	No	30

Table 1 presents all of the demographic data on the cohort of subjects who participated in the study. The 'Education' column has the unit of years of college. The 'Enlgish' column is in regard to whether or not English is the primary language of the participant. 'TBI' is in regard to whether or not they have ever experienced a TBI. The column entitled 'Disability' reports any speech, language, or learning disability. The 'Medical' column is specifically regarding a history of neurologic impairment or psychiatric disorder. MoCA = Montreal Cognitive Assessment.

Table 2

	Discourse							
	Procedural			Narrative				Conversational
				Personal			Fictional	
Participant	NYC	ATM	Pooled	Injury	Vacation	Pooled	Runaway	Conversation
1	L			B		L	L	
2								
3								
4	B		L	B		L		
5	L			L				L
6		L		L				
7	L	B	L	B		L	B	L
8	R		R	R		R		
9	R	R	R	R			R	R
10	L				R	R		B
11	B	R	B	B	R	B	B	B
Total n (%)	8 (73%)	4 (36%)	5 (45%)	8 (73%)	2 (18%)	6 (55%)	4 (36%)	5 (45%)
Left	4	1	2	2	0	3	1	2
Right	2	2	2	2	2	2	1	1
Bilateral	2	1	1	4	0	1	2	2

Table 2 shows the significant activation observed for each task. Organized by genre of discourse for each individual. NYC = "Trip to New York" task. ATM = withdrawing money from an ATM task. Pooled (under the procedural heading) = NYC+ATM. Injury = personal narrative regarding injury. Vacation = personal narrative regarding vacation. Pooled (under personal narrative heading) = Injury+Vacation. Runaway = fictional narrative about Norman Rockwell painting. L = left hemisphere activation. R = right hemisphere activation. B = bilateral activation. Blank cells indicate no significant activation.

Table 3

	Discourse							
	Procedural			Narrative				Conversational
				Personal			Fictional	
Participant	**NYC**	**ATM**	**Pooled**	**Injury**	**Vacation**	**Pooled**	**Runaway**	**Conversation**
1	L			B		B	L	
2		R					B	
3	R	L	B	B				B
4	B		B	B		L		L
5	B	B	B	B	B	L		L
6				L				
7		B	B	B		B	B	B
8	L		L	B		B	L	R
9		L	B	B		B	B	L
10	B				R	R		B
11	B	B	B	B	B	B	B	B
Total n (%)	7 (64%)	6 (55%)	7 (64%)	9 (82%)	3 (27%)	8 (73%)	6 (55%)	8 (73%)
Left	2	2	1	1	0	2	2	3
Right	1	1	0	0	1	1	0	1
Bilateral	4	3	6	8	2	5	4	4

Table 3 shows the significant activation observed for each task when the simple productive recitation task was subtracted. Organized by genre of discourse for each individual. NYC = "Trip to New York" task. ATM = withdrawing money from an ATM task. Pooled (under the procedural heading) = NYC+ATM. Injury = personal narrative regarding injury. Vacation = personal narrative regarding vacation. Pooled (under personal narrative heading) = Injury+Vacation. Runaway = fictional narrative about Norman Rockwell painting. L = left hemisphere activation. R = right hemisphere activation. B = bilateral activation. Blank cells indicate no significant activation.

Appendix 2 – Figures

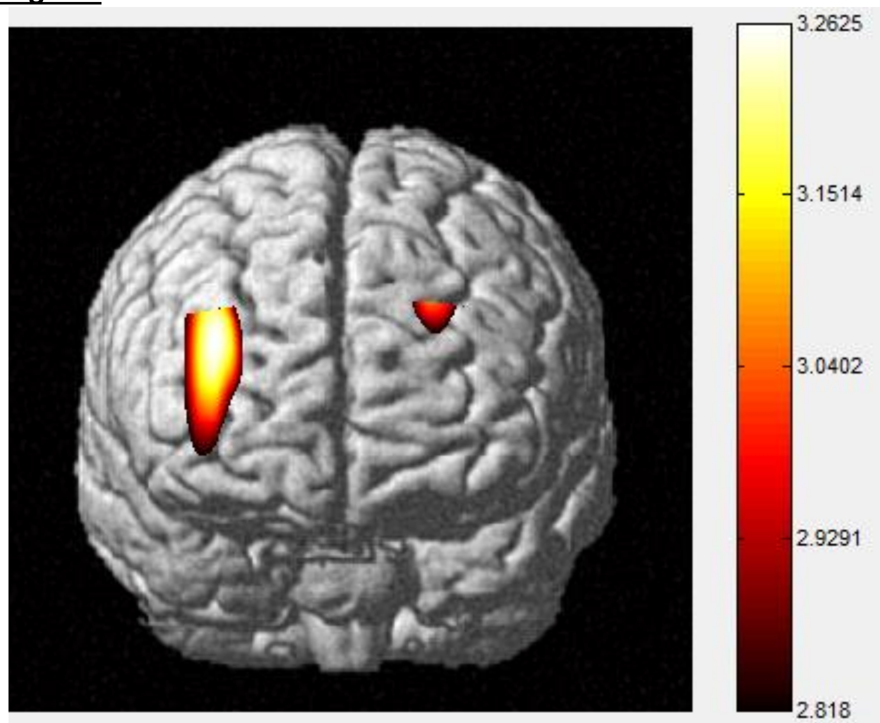

Figure 1: Cortical activation during group analysis of the “Trip to New York” task with no baseline tasks subtracted. P<0.05. Color map represents the scale of activation using t-statistics as a unit.

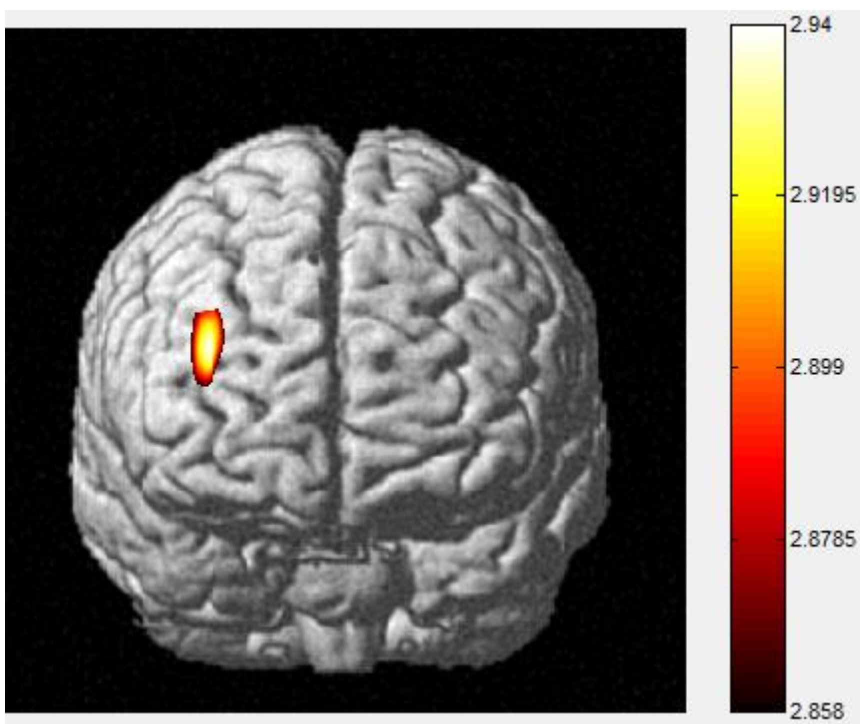

Figure 2: Cortical activation during group analysis of the combined procedural tasks (i.e., “Trip to New York” and ATM) with no baseline tasks subtracted. P<0.05. Color map represents the scale of activation using t-statistics as a unit.

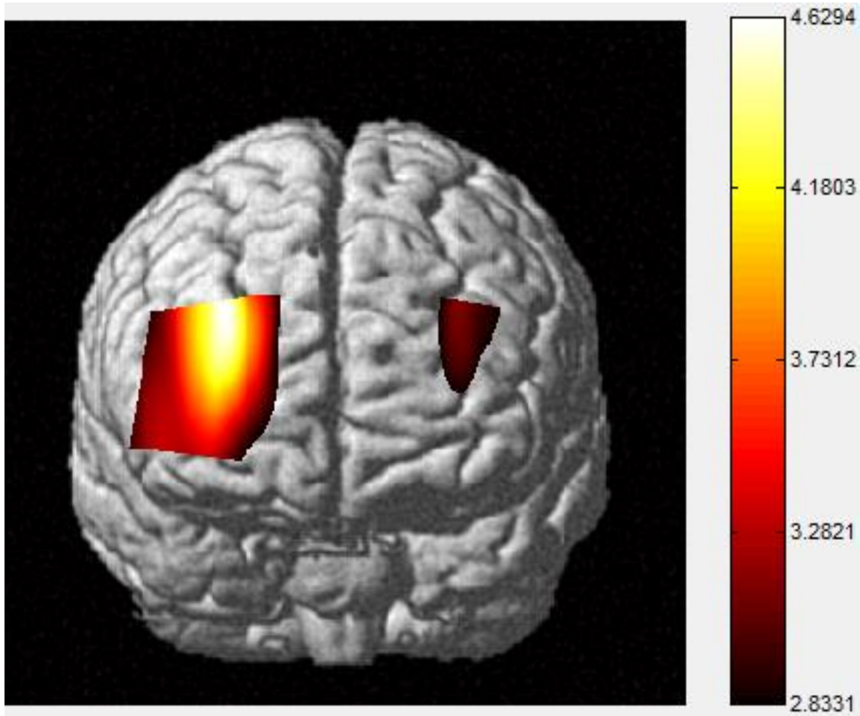

Figure 3: Cortical activation during group analysis of the Injury task with no baseline subtracted. P<0.05. Color map represents the scale of activation using t-statistics as a unit.

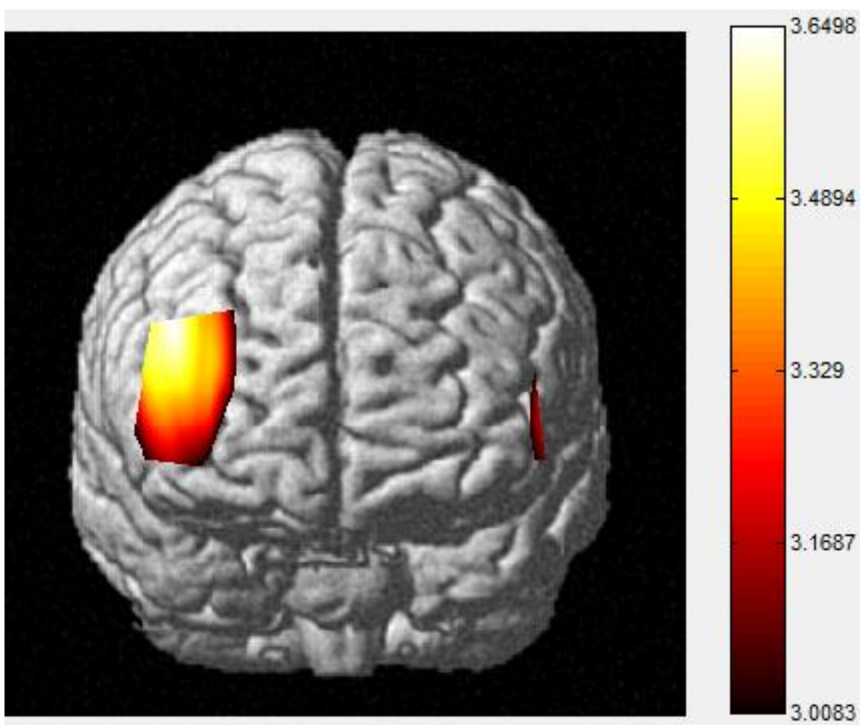

Figure 4: Cortical activation during group analysis of the Injury task with the recitation baseline subtracted. P<0.05. Color map represents the scale of activation using t-statistics as a unit.

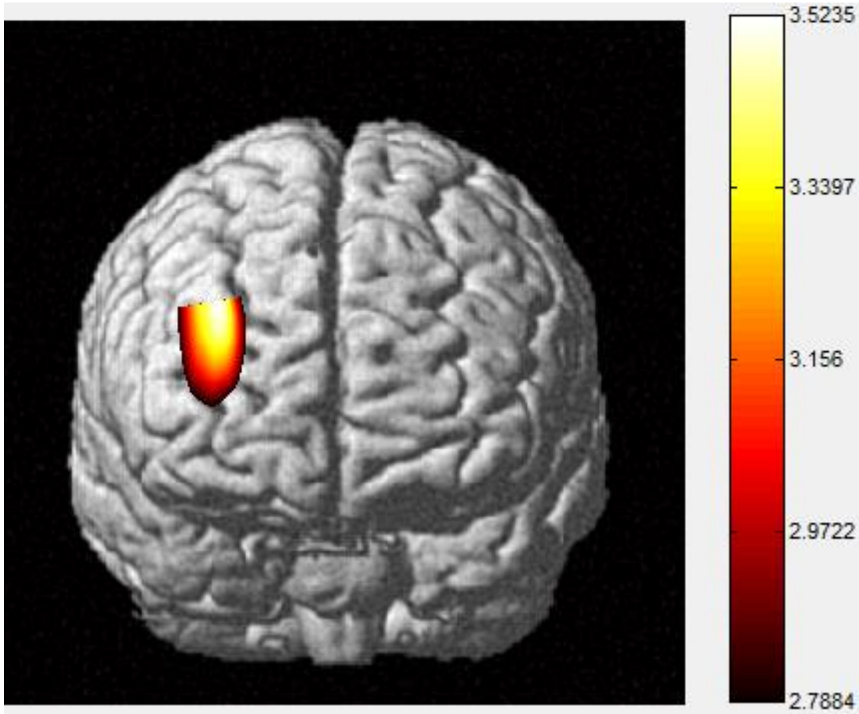

Figure 5: Group activation during the group analysis of the combined personal narrative tasks (i.e., Injury and Vacation) with the no baseline tasks subtracted. P<0.05. Color map represents the scale of activation using t-statistics as a unit.

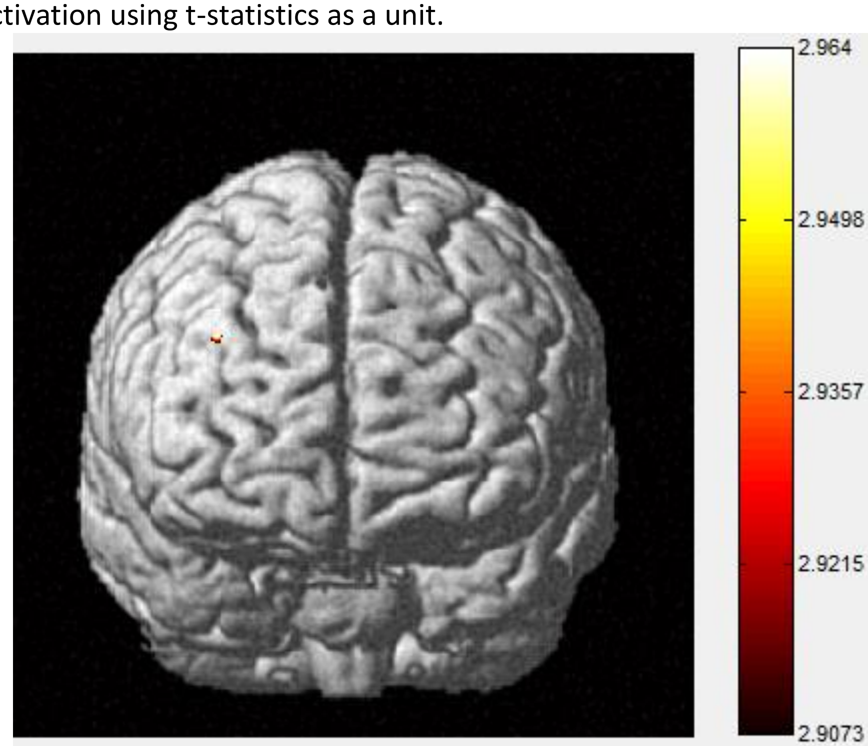

Figure 6: Cortical activation during the group analysis of the conversational discourse task with no baselines subtracted. P<0.05. Color map represents the scale of activation using t-statistics as a unit.