EXECUTIVE FUNCTION AND LANGUAGE COMPREHENSION IN TRAUMATIC BRAIN INJURY

By

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To my boys: Dan, Isaac, and Jonah

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This study examined how cognitive components, such as attention and executive function, related to reading in traumatic brain injury (TBI) survivors and healthy young adults. Although the cognitive impairments associated with TBI are well documented, the relationship between different aspects of language functioning and cognition have not been thoroughly described. In fact, the relationship between different aspects of language processing and cognition has not been well documented in general. A pilot study was conducted with a control group hoping to describe the relationship between cognitive control and ambiguity resolution, but the results did not show a robust link. However, word-by-word processing interacted with ambiguity processing, which made the use of non-ambiguous materials necessary for use in the main study. This exploratory study examined behavioral and electrophysiological measures associated with reading using non-ambiguous sentences. Five TBI survivors and twenty-six healthy young adults completed a battery that included offline cognitive tasks, computerized reading comprehension measures, and the Attention Network Task (ANT). A word-by-word reading task and the ANT were completed during EEG recording.

Unsurprisingly, whole sentences with anomalies were read at a slower rate than nonanomalous control sentences, and comprehension questions following anomalous sentences were responded to at a slower rate than nonanomalous control sentences. There was a different pattern of results for sentences presented word-by-word. RSVP sentences with semantic anomalies were judged incorrectly to be ‘good sentences’ at a poor accuracy rate in a subgroup of control participants and all of the TBI group. The TBI group was significantly less accurate on word-by-word sentence judgments, but not significantly slower, and they were not significantly less accurate on whole sentence comprehension, whole sentence reading time or RT as a group. There were several correlations between sentence measures and executive function, memory and vocabulary measures on the combined group data. There was not a robust N400, which is discussed in light of the poor RSVP semantic anomaly judgment accuracy and the type of stimuli used. There was, however, a measurable P600 response with group differences in amplitude and latency. As expected, there was also variability within the TBI group.

This study confirmed that executive function, processing speed, working memory and vocabulary are related to sentence comprehension. Further, depression and immediate anxiety symptoms may affect sentence reading time and comprehension. The pattern of results also suggests that word-by-word processing is perhaps shallow overall due to the poor identification of semantic errors, which is consistent with the pilot study findings of shallow processing.

Despite our small group of TBI participants and despite few significant group differences in cognition, we still found that the TBI group performed significantly worse on sentence processing measures. A larger study will be needed to take a more in depth look at cognitive processing and sentence processing. ERP measurements provide a promising avenue of exploring the variability within the TBI population on language measures and their relationship to behavioral performance. The relationships observed across the control and TBI groups have implications for many populations besides TBI, such as ADHD, Parkinson’s and schizophrenia.

CHAPTER 1
GENERAL INTRODUCTION

Summary and Relevance

Reading comprehension is a complex skill that is known to require working memory (Myachykov, Tomlin, & Posner, 2005; Shaywitz et al., 2001; Ylvisaker, Szekeres, & Feeney, 2001) as well as language specific processing. However, the relative contributions of other cognitive processes, such as attention and executive function, are largely unknown. Because cognitive abilities can dissociate, there is a critical need to understand how different aspects of cognition contribute to reading. One way to investigate the relative contribution of attention and executive function to reading would be to use a population with acknowledged deficits in both attention and executive function, such as individuals with traumatic brain injury (TBI). As a step in this direction, the current study addresses the question of whether attention and executive function contribute to sentence comprehension during reading in readers with and without TBI. Second, this study addresses the question of whether any reading comprehension problems in TBI reflect an underlying language processing impairment, by taking advantage of the temporal specificity of event-related potentials (ERPs) and the sensitivity of the N400 and P600 ERP components to language (Duncan et al., 2009; Hagoort & Brown, 2000)

Over five million people are living with traumatic brain injury (TBI) related disability in the United States with an additional 80,000 people becoming disabled due to TBI each year (N.H.I. Foundation, 2006; Thurman, 1999). According to the N.H.I. Foundation, cognitive impairments, such as executive function, attention, memory, and language, are primary contributors to disability in this population. Although cognitive problems have been well-studied in TBI (Brooks, Fos, Greve, & Hammond, 1999; Chan, 2000, 2005; Chan, Hoosain, Lee, Fan, & Fong, 2003; Cicerone, 1996; Perlstein, Larson, Dotson, & Kelly, 2006; Pero, Incoccia, Caracciolo, Zoccolotti, & Formisano, 2006; Whyte, Polansky, Fleming, Coslett, & Cavallucci, 1995), there are few investigations of reading processes (Ferstl, Guthke & von Cramon, 2002; Schmitter-Edgecombe & Bales, 2005; Ylvisaker et al., 2001).

The scarcity of studies is surprising given that attention and executive functioning are necessary for reading (Myachykov et al., 2005; Shaywitz et al., 2001; Ylvisaker et al., 2001), and that these abilities are often impaired in TBI (Bittner & Crowe, 2006, 2007; Body & Parker, 2005; Brooks et al., 1999; Chan, 2000, 2005; Chan et al., 2003; Chobor & Schweiger, 1998; Cicerone, 1996; Leblanc, de Guise, Feyz, & Lamourreux, 2006; Moran & Gillon, 2004; Moran, Nippold, & Gillon, 2006; Perlstein et al., 2006; Pero et al., 2006; Turkstra, 1998; Whelan & Murdoch, 2006; Whyte et al., 1995). Impaired reading can impact a variety of instrumental activities of daily living, as well as the ability to be successfully reintegrated into the workplace or school (Leblanc et al., 2006; Ylvisaker et al., 2001). Thus, there is a critical need to understand how attention and executive function impairments contribute to reading in TBI as well as whether there are additional solely linguistic impairments impacting reading performance.

The introductory chapters that follow present first, a review of the literature addressing language and cognition in TBI survivors in order to show that there are documented deficits but the deficits have not been thoroughly researched. A short section describing the relationship between language deficits and cognitive deficits in

TBI survivors is also included. Second, the ERP components that are being studied are described.

A pilot study is then presented that compared rapid serial visual presentation (RSVP: word-by-word presentation) of sentences and whole sentence presentation along with a battery of cognitive tasks. RSVP is typically used in ERP studies of sentence processing because the word-by-word presentation makes it possible to time lock the EEG signal to each word in the sentence. However, RSVP is thought to tax cognition, particularly working memory, because a reader does not have the entire sentence available at once as is typical during reading. Problems associated with presentation type might be exacerbated in a population like TBI with known cognitive deficits. The pilot study was conducted to determine if the different methods of stimulus presentation type had different effects on reading comprehension and if these differences were related to individual differences in cognition in a group of healthy non-neurologically impaired undergraduates. The pilot study used ambiguous sentences because resolving ambiguity requires the suppression of an initial interpretation and the activation of the correct interpretation. This suspected pattern of suppression and activation suggests a relationship to executive function, which is often impaired in TBI. Ambiguous sentences were the original stimuli that were to be used with the main study. However, because RSVP seemed to worsen performance on ambiguous sentence comprehension disproportionally when compared with non-ambiguous sentence comprehension, the main dissertation study did not include ambiguity. Because of the differences found in this pilot study, sentence comprehension in TBI was assessed using both whole sentence presentation and RSVP, with only the latter method used during the ERP experiment. The dissertation study, which is presented following the pilot study, addresses the specific aims described below.

Specific Aims

My long-term research goal is to investigate the contribution of executive function components on aspects of language use using TBI as a model population. A secondary goal is to delineate the range of impairments of language use across modalities in TBI, with the intent of providing experimental data to support evidence-based practice in speech-language pathology. The specific objective of the proposed research is to define the relationship between sentence comprehension, attention and executive function in individuals with TBI. The central hypothesis is that both attention and executive function are related to reading but that there is an additional linguistic processing speed or linguistic integration component that also may be impaired that is indexed by the N400 for semantic processing and the P600 for syntactic processing. To address this hypothesis, I tested individuals with and without TBI on a battery of neuropsychological tasks and sentence comprehension tasks done with and without electroencephalography (EEG) recording in order to pursue the following specific aims.

Aim 1a

Determine whether sentence reading time and comprehension are impaired in TBI survivors relative to matched controls. The working hypothesis is that sentence reading will be slowed and comprehension impaired in TBI survivors. It is also predicted that performance will be variable within the impaired group.

Aim 1b

Determine whether cognitive impairments of specific components of attention, working memory or executive function predict comprehension performance in TBI survivors. The working hypothesis is that different types and severities of cognitive impairment will relate to measures of reading. For example, impairment of executive function may be related to performance on syntactically anomalous sentences, and impairment of working memory may better related to performance across all sentence types.

Aim 2

Determine whether typical electrophysiological markers of sentence processing (e.g. N400, P600) differ in mean amplitude and latency between the group of participants with TBI and the group of control participants. The working hypothesis is that sentence processing metrics will differ between groups. Due to the heterogeneous nature of brain injury from TBI, impairment levels for cognition and language may differ between participants even when severity levels as measured by length of loss of consciousness and coma scores may be similar. Amplitude differences are expected between groups. It is also predicted that the standard EEG components associated with language processing will be delayed in TBI survivors relative to healthy controls.

CHAPTER 2
LANGUAGE PROCESSING AND COGNTION AFTER TRAUMATIC BRAIN INJURY

Overview

Communication impairment in survivors of traumatic brain injury (TBI) profoundly influences their successful return to social, vocational, family and educational settings. Coworkers and supervisors of TBI survivors have frequently cited poor communication as a major impediment to workplace success (Leblanc et al., 2006; Ylvisaker et al., 2001). Despite the public health relevance, however, treatment of poor communication following a TBI has not been closely examined through research, and treatment outcomes are often poor (Ylvisaker et al., 2001). There have been very few treatment studies overall, and the few theoretically based treatments have not been shown to result in generalization or significantly improved long-term functioning (Cannizzaro & Coelho, 2002; Coelho, Grela, Corso, Gamble, & Feinn, 2005; Ylvisaker et al., 2001). The paucity of treatment studies is probably due to the general lack of research in this area. The research literature, which mostly addresses discourse level impairments, is a confusing mix of observational case studies and groups with a wide range of possible deficits. The wide range of deficits is typical of this heterogeneous population. It is difficult to determine if there is a shared underlying language deficit common across these studies, especially because they have mostly made conclusions about comparisons between a highly heterogeneous TBI group and a control group or single case studies. Group studies are important, but the diversity of injury etiology, severity, and post-onset time at the time of study are important to take into account. Comprehensive, efficient and relevant assessments and treatments are therefore difficult to develop. The relationship between language and cognition has also not been well described in TBI survivors despite the prevailing notion that cognitive deficits are the most likely cause of communication impairments (Hinchliffe, Murdoch & Chenery, 1998; McDonald, Togher & Code, 1999). After describing the basic epidemiology and clinical language characteristics of TBI, this chapter will review the available research describing the oral and written language of TBI survivors and how it may relate to cognition.

Epidemiology

Over five million people are living with TBI related disability in the United States. An additional 1.5 million people sustain a TBI each year with 50,000 deaths and 80,000 people becoming disabled annually (N.H.I. Foundation, 2006; Thurman, 1999). These figures do not include the more than 10% of wounded soldiers returning with TBI from current U.S. military engagements (Fischer, 2007). Hospitalization rate for TBI is highest among males, 15-24 years of age and over age 65 (Thurman, 1999). In 2000, the medical costs and indirect costs related to lost productivity were estimated to be $60 billion (N.H.I. Foundation, 2006). Impaired executive function, attention, memory, and language, are primary contributors to disability in this population with a high amount of variation from person to person due to the heterogeneous nature of TBI (N.H.I. Foundation, 2006).

The term “TBI” encompasses a wide range of causes of damage, lesion sites and types, as well as many levels of severity. TBIs include any brain injury caused by trauma other than disease or substance abuse. These injuries can be either open or closed head injuries. Open, or penetrating, head injuries occur when a foreign object, including a bullet or skull fragment, enters the brain tissue. Closed, or blunt, head injuries most often occur when the head encounters rapid acceleration and deceleration, such as during a motor vehicle accident or fall. Closed head injuries are the most common type of head injury and result in diffuse, multi-focal brain injury. Deficits can be widespread and are very different from the more focal lesions resulting from penetrating injury or cerebrovascular accident. Closed head injuries are the focus of this study, and the term TBI used here will refer to closed head injuries unless otherwise specified.

Concussion is by far the most common type of head injury comprising at least 75% of head injuries (Marsh & Smith, 1995; Wiebe, Comstock & Nance, 2011). It often involves a transient loss of consciousness and, instead of focal neurological deficits, symptoms include a wide array of physical and cognitive complaints. Headaches, fatigue, dizziness, sensitivity to noise, inability to concentrate and poor memory are just a few of the typical post-concussive symptoms. Language impairments have also been documented in a small number of studies (Marsh & Smith, 1995). Though these initial post-concussive symptoms typically resolve within a few months, subtle cognitive dysfunction may persist and emerge only under conditions of stress or further injury (Marsh & Smith, 1995; Wiebe et al., 2011). There is not a commonly used clinical scale for describing concussion severity due to the heterogeneous nature of the injuries, symptoms and recovery (Wiebe et al., 2011). People who have had a concussion may not always notice mild symptoms after the initial 6 month recovery period due to coping mechanisms that are not fully understood (Marsh & Smith, 1995). Moreover, it is not well understood how to determine when it is safe for a person who has sustained a concussion to return to normal activities, including activities requiring cognitive 'exercise' (Wiebe et al., 2011). Returning to previous activities, including school, work, and especially sports prematurely raises the risk for persistent post-concussive symptoms, future concussion, and in rare cases, death.

The extent and severity of neural damage following TBI is not always adequately identified through CT or MRI scans, because a large proportion of the overall damage is often at the level of individual neurons. Contusions and focal areas of bleeding can be seen in a scan, but diffuse axonal injury is common and not always associated with bleeding. Without overt bleeding, the damage is much more difficult to capture with clinical diagnostic imaging. Therefore, coma indices and post-traumatic amnesia (PTA) duration are often used to describe severity, because they have been shown to accurately predict the course of recovery from impairments (Chapman, 1997). There are certain brain regions thought to be more vulnerable to TBI. Memory impairments are the most common following head injury, because the hippocampal neuronal cells are particularly susceptible to oxygen deprivation (Prince, 1983), and because the frontal and temporal lobes are susceptible to structural injury. Specifically, the bony protrusions in the frontal brain case, especially the sphenoid bone, can cause tearing and scraping of the brain during injury and following injury if there is significant swelling (Bigler, 2001).

The frontal lobes are involved in many complex cognitive tasks, including language processing (Friedland & Miller, 1998; Hinchliffe et al., 1998; Whelan & Murdoch, 2006). The impairments due to diffuse brain damage are difficult or impossible to predict because diffuse damage is difficult to capture with brain imaging. Without imaging, it is difficult to predict the affected brain regions. Therefore, comprehensive neuropsychological assessment is one of the tools used to identify areas of impairment in TBI survivors even in the absence of clear findings via brain imaging. Language assessment during neuropsychological evaluation is typically only cursory. In fact, a full language evaluation by a speech-language pathologist is relatively rare and limited by the scarcity of available language assessment tools. Therefore, improving understanding of cognitive and language impairments and how they relate has the potential to greatly improve the rehabilitative care of TBI survivors.

Clinical Characterization of Communication in TBI

The American Speech-Language-Hearing Association (2005) specifically recognizes ‘cognitive-communication impairment’ as the primary communication impairment in TBI. Because aphasia is considered to be impairment specific to linguistic processing, the language impairments in TBI are usually non-aphasic in nature (McDonald et al., 2000). Indeed, any communication impairments are usually considered secondary to cognitive impairments (Hinchliffe et al., 1998). Difficulty with complex comprehension or connected speech following a TBI is often attributed to processing speed, executive function, or another cognitive deficit unless it occurs following damage to a known language area or in the absence of tested cognitive deficits. Test batteries for language in adults, most of which have been designed to assess aphasia, do not adequately identify the more complex, sometimes subtle communication problems observed in TBI survivors (McDonald et al., 2000). The development of standardized tests to identify communication impairments in TBI is limited by an incomplete understanding of both the range of possible impairments and the extent to which communication impairments stem from language- specific deficits or are secondary cognitive deficits. Despite an expectation of communication problems following TBI, assessment of language in TBI must often be improvised by clinicians due to a lack of available resources. The Academy of Neurologic Communication

Disorders and Sciences (ANCDS) has published guidelines for TBI assessment (Coelho, Ylvisaker & Turkstra, 2005; Turkstra, Ylvisaker, Coelho, Kennedy, Sohlberg, Avery, et al., 2005), but the majority of tests examine cognitive and neuropsychological status, rather than language use. Further, the majority of these tests have not been developed or standardized for use with TBI patients. The ANCDS recommendations for testing basically state to use tests cautiously and in conjunction with a variety nonstandardized measures such as functional reading comprehension, conversation pragmatic awareness, and especially discourse analysis. Nonstandardized measures are typically a part of a dynamic clinical assessment given by any speech-language pathologist, but the complexity and time intensive measures needed to provide a complete picture for the impairments following TBI make them unlikely to be regularly or consistently administered.

Oral language production and comprehension have both been observed to be impaired in TBI survivors (Hinchliffe et al., 1998). Hinchliffe and colleagues found statistically significant differences between TBI survivors and control participants on most subtests and specific items from a large battery of standardized language tests, but performance by TBI survivors was not always below clinical cutoffs for identifying impairment. In a clinical setting, whether performance on these standardized measures merits speech rehabilitation depends on the clinician's discretion and possibly on whether insurance coverage is contingent on performance on normed tests. Further, as mentioned in the ANCDS guidelines (Turkstra et al., 2005), performance on the recommended measures has not been shown to have functional significance. In particular, they do not fully address the complex problems with reading, conversation, and discourse which, though central to everyday functioning, are not routinely identified in standardized tests.

Written language has also been found to be impaired in TBI (Hinchliffe et al., 1998), though it is usually a secondary concern in the face of more immediately disabling oral language impairments. However, complex reading comprehension may be a particular challenge for TBI survivors hoping to return to school or work. As discussed, there are few available tests that identify complex reading impairments in adults and even fewer that are intended for use with TBI. The development of clinical assessments and treatments for language in TBI has been limited by a lack of knowledge about the variety of language deficits observed in TBI; consequently, initial research should aim at delineating the range of language deficits and severity range of these deficits in this population, so that appropriate assessments and treatments can then be developed.

Language Research in TBI

There is a growing body of research into the language characteristics of TBI survivors. The bulk of research to date has attempted to describe the impaired discourse production and comprehension, particularly involving communication pragmatics, because these deficits are most commonly noticed by both clinicians and others who interact with them. However, research on other aspects of language is extremely limited, including the interaction between cognitive impairments and language, the focus of this study. Below is a review of the research characterizing oral and written language use in studies of TBI survivors as well as studies that have explicitly addressed relationships between cognitive and linguist functions in this population.

Oral Language

Oral language production. Verbal fluency and anomia are the two most commonly reported oral language production impairments following TBI in the research literature (Butler-Hinz, Caplan & Waters, 1990; Goldstein et al., 1994; Gruen, Frankle & Schwartz, 1990; Hinchliffe et al., 1998; Levin, Grossman, Sarwar & Meyers, 1981) possible due to the frequency and ease of testing them. Fluency tasks involve the rapid generation of words within one minute beginning with a particular letter (e.g., ‘F’) or within a specific semantic category (e.g., ‘animals’). TBI survivors often produce fewer words within the specified category, and it is not uncommon in clinical settings to find that they switch letters or semantic categories very early in the task (e.g., begin with the ‘F’ words and then switch to ‘L’ words) or ask repeatedly for task instructions. Verbal fluency is typically used to measure processing speed and word associate generation (e.g., Controlled Oral Word Association Test, Benton, Sivan, Hamsher, Varney & Spreen, 1994; Gruen et al., 1990), and it has been found to correlate with some language measures such as sentence interpretation (see Hinchliffe et al., 1998). However, it does by no means constitute a thorough or adequate assessment of language processing.

Anomia refers to the inability to retrieve and produce words. It is not unique to TBI, and it has been a focus of research in stroke survivors for decades (Chapey, 2001). Although anomia is the most commonly reported language impairment following TBI (Butler-Hinz et al., 1990; Goldstein et al., 1994; Gruen et al., 1990; Hinchliffe et al., 1998; Levin et al., 1981), it has not been a particular focus for research in this group. Anomia is often accompanied by secondary behaviors such as paraphasias and circumlocutions. Paraphasias include phonological or phonemic substitutions (e.g., ‘pold’ for ‘cold’), verbal substitutions (e.g., ‘hot’ for ‘cold’; ‘lamp’ for ‘cold’), and neologistic substitutions (e.g., ‘til’ for ‘cold’). Most paraphasias are considered maladaptive and are usually noticeable by communication partners. Circumlocution involves speaking around, defining or otherwise describing a difficult-to-retrieve word. For example, if a patient is attempting to say the word, ‘mail,’ they might say, ‘It comes every day but Sunday. You need a stamp.’ It is usually considered an adaptive behavior and is often encouraged in therapy. It is also often used by non-brain injured adults as a normal word retrieval strategy and is, therefore, not always noticed by communication partners unless the circumlocutions are inappropriate.

Circumlocutions may lead to or underlie discourse level impairments (Friedland & Miller, 1998). For example, in a case study, Friedland and Miller (1998) found that circumlocutions often led to involved sudden shifts into a new topic which resulted in the communication partner having difficulty following the topic. However, this association between conversational breakdown and word retrieval was only noticed after extensive conversational analysis. Discourse impairments are difficult to predict from more basic formal testing focusing on phonology, naming or syntax, even when these processes are impaired. Conversational impairments, such as covert topic shifting and self repairs, could be directly related to impairments of different aspects of language.

Discourse in TBI survivors has received relatively more attention in the research literature than other aspects of language, because it is often the most noticeable and debilitating communication impairment. Thus, detailed discourse analysis is considered to be a useful tool for developing treatment plans for TBI survivors (Coelho, Liles & Duffy, 1991b; Coelho, Ylvisaker et al., 2005; Turkstra et al., 2005). Discourse impairments in conversation and various types of monologues have been observed, including: disorganization, incomplete story episodes, tangential language, disinhibition and socially inappropriate language (e.g., Biddle, McCabe, & Bliss, 1996; Body & Parker, 2005; Coelho, 2007; Coelho et al., 1991b; Coelho, Grela et al., 2005; Leblanc et al, 2006; Snow, Douglas, & Ponsford, 1999). Other analyses have shown that TBI patients produce the same quantity of discourse as controls, but the quality of the discourse is typically worse due to false starts, fillers and repetitions (Biddle et al., 1996). Additionally, Coelho, Grela and colleagues (2005) reported that their participants with TBI produced fewer propositions per T-unit (an independent clause with all associated subordinate clauses). That is, they produced less information and required more words to do it. These discourse problems in TBI survivors often put a significant burden on their listening partners.

Children and adolescents face many of the same language production difficulties as adults following TBI, such as anomia and impaired fluency (Chapman, 1997), although the severity of these may vary depending on their level of language development prior to injury. In personal narratives, children with brain injury provided less information overall, including central ideas, with less organizational structure over the course of the story than age matched, non-brain injured children (Chapman, 1997). Impairments may show up later in development as well when increasing levels of complexity are required for communicating in social or educational settings (Biddle et al., 1996).

Unfortunately, in the published literature on discourse production in TBI, there has been little overlap in methods of data collection, participant inclusion criteria or analysis methods between studies of discourse making it difficult to directly compare studies. Discourse elicitation methods have included conversation (Body & Parker, 2005), story retelling from picture sets (Coelho, Grela et al., 2005), story generation from a single picture (Coelho, Grela et al., 2005), and conversational mapping (Biddle et al., 1996) among others. Moreover, few studies have included a comparison or control group to help gauge the relative degree of impairment (Hinchliffe et al., 1998). Also, many reports of language or discourse functioning following TBI have been case studies (e.g., Body & Parker, 2005). The latter problem is particularly serious in this population due to the extreme heterogeneity of impairment seen across individuals.

Despite the disparate methods used to elicit discourse, and the different procedures used for discourse analysis, it is generally agreed that discourse level impairments can persist for years after an initial injury (Coelho, 2007). Based on this assumption, many of the studies looking at discourse have included patients with a wide range of post-onset times. For example, Biddle and colleagues (1996) limited testing to individuals with a post-onset time of 1 year or under, whereas Coelho, Grela and colleagues (2005) included individuals who spanned a range of 1-99 months post-injury. This range is surprising considering that it is typical in the aphasia literature to wait until at least 1 year for inclusion in research studies because of the often rapid “spontaneous” recovery of language during the first year post-onset of injury. If the goal of the study is to characterize the population, or determine what deficits are most likely to impact quality of life for TBI survivors, testing should be done after an initial, relatively standard recovery period. Further, the acceptance of discourse analysis as a widely used clinical tool is currently unlikely, because formal discourse analysis is more time consuming, complex and less reliable than testing of lower level language skills such as sentence comprehension or picture naming which do not require lengthy transcriptions and specialized language analysis skills. Clinicians are therefore less likely to attempt a formal analysis of discourse, even if they do include in their diagnostic reports their impressions of the adequacy of the discourse based on their conversation with a TBI survivor.

In contrast to discourse, little is known about impairments affecting more basic aspects of language following TBI. In a search of the literature, only one study was found that formally tested language production of a group of TBI survivors beyond naming ability. Hinchliffe and colleagues (1998) tested 25 closed-head injury patients that were between 2 and 9.75 months post-onset of injury, and these patients were compared to 23 control participants. All participants were tested on a norm-referenced, large battery of 10 language and at least 12 cognitive measures across 2-4 sessions. TBI patients were significantly worse than control participants on word naming from the Boston Naming Test (Kaplan, Goodglass & Weintraub, 1983) and the Western Aphasia Battery (Kertesz, 1982), and Oral Expression from the Test of Language Competence (Wiig & Secord, 1989). Notably, the Oral Expression subtest required participants to produce statements or questions that would be appropriate to an individual pictured in a certain social situation, supporting other reports in the literature of impairments in the pragmatics of language in TBI patients (Channon & Watts, 2003; Davis, 2007; McDonald, 1993). In contrast, the repetition of words and sentences was not significantly different from control participants. These were the only oral production measures that were analyzed in Hinchliffe and colleagues' study. These limited results suggest that some aspects of language production may be impaired in individuals with TBI and deserves further study.

In summary, oral production of language is actually the most widely studied aspect of language in survivors of TBI. Most of the work has focused on discourse production, which has been found to be impaired in several dimensions. Lower level language production impairment of sentences and single words have also been documented (Hinchliffe et al., 1998), but they have not been thoroughly studied. While the range of discourse difficulties are usually attributed to cognitive deficits, as will be discussed in a later section, discourse problems may also stem from language deficits. Friedland and Miller (1996) attributed discourse level problems to naming difficulties in a single patient. Much more work is needed to improve assessment and treatment of language production in TBI survivors.

Oral language comprehension. Less research has focused on oral language comprehension (Coelho, Grela et al., 2005; Hinchliffe et al., 1998; Moran & Gillon, 2004; Turkstra, 1998; Turkstra & Holland, 1998) than production deficits in TBI. Occasionally, it has been argued that syntactic comprehension is generally preserved in TBI survivors (Angeleri, Bosco, Zettin, Sacco, Collie & Bara, 2008; Coelho, 2002); however, a wide variety of comprehension impairments, mostly involving complex comprehension, have been documented in other studies (Coelho, Liles & Duffy, 1991a; Hinchliffe et al., 1998; Levin et al., 1981; Nicholas & Brookshire, 1995).

Hinchliffe et al. (1998) found that adults with TBI were consistently and significantly impaired on tests requiring complex comprehension but not on tests of simpler comprehension. Specifically, the comprehension subtest of the Western

Aphasia Battery (WAB; Kertesz, 1982) did not show significant differences between groups. The WAB includes sentences that are difficult in terms of length and the necessity of paying particular attention to function words (‘Put the pencil on top of the book and give it to me.’) and semantic content (‘Does paper burn in fire?’) but does not include complex ambiguity or other particularly difficult syntactic structures (for example, it does not include passives or relative clauses). In contrast, adults with TBI performed significantly worse on the token test (in which individuals rearrange colored shapes according to increasingly complex oral directions), ambiguous sentence comprehension (requiring recognition and interpretation of distinct meanings for each single sentence from the Test of Language Competence-Expanded; TLC-E; Wiig & Secord, 1989), and listening comprehension (requiring an inference to be made from two causally related events from the TLC-E). A number of other comprehension deficits were noted, but it was unclear whether or not those deficits were documented in the oral or written modality. These findings suggest that syntactic comprehension is impaired but only for more complex structures, at least for the relatively recently injured as were tested in Hinchliffe and colleague’s study (between 2 and 9 months post-onset).

Butler-Hinz and colleagues (1990) described syntactic processing as ‘vulnerable’ in a group of people with acquired head injury associated with a variety of lesion sites and etiologies. They looked at 17 closed-head injury, 16 stroke patients and 20 control participants to observe syntactic processing performance on 14 types of sentences with a range of complexity. Complexity was varied according to the number of verbs, number of thematic roles assigned by the argument structure, and canonicity of word order. Participants were required to manipulate toy objects to illustrate the meaning of sentences they heard. Complex syntactic processing appeared to be problematic for both brain injured groups based on poor accuracy of responses to sentences with noncanonical thematic role assignment, as comprehension of passives and cleft object was worse than actives. In addition, comprehension of sentences in which verbs assigned more than two thematic roles was impaired; for example, dative passives were comprehended worse than passive conjoined agent sentences. Also, comprehension of sentences containing two or more verbs, such as subject-subject relative sentences were impaired relative to active conjoined theme sentences. Only the number of nouns in a sentence did not appear to affect performance, suggesting that syntactic deficits may not be simply related to amount of semantic content. The stroke and TBI survivor groups did not differ from one another on these factors, and site of lesion did not appear to play an important role in comprehension performance.

The bulk of the research on comprehension impairments in TBI has been limited to discourse comprehension, especially figurative language comprehension in adolescents with TBI (Moran & Gillon, 2004; Turkstra, 1998; Turkstra & Holland, 1998). For example, processing of lexical ambiguity (i.e. words with more than one meaning such as, “letter”) has been observed to be impaired in both children (Dennis & Barnes, 1990) and adults with TBI (Chobor & Schweiger, 1998) in single words and in discourse. Other studies have demonstrated that certain patients have difficulty interpreting humor, irony, deceit and other metalinguistic uses of language (Angeleri et al., 2008; Hinchliffe et al, 1998). Certain discourse skills that rely on comprehension have been shown to be impaired as well. For example, drawing correct inferences from stories has been shown to be impaired (LeBlanc et al., 2006). Additionally, Chapman (1997) found that adolescents with TBI were poor at paraphrasing, summarizing and identifying the main point of a story. These types of discourse comprehension assessments rely on both comprehension and production skills, and deficits in these two skills may interact. That is, appropriate discourse production requires comprehension of discourse cues relating to situation and topic.

Based on the few studies that have directly addressed oral language comprehension, complex comprehension has been shown to be significantly impaired. In addition, Butler-Hinz and colleagues (1990) found that complex comprehension impairments seemed to be related to structural complexity and not simply sentence length. Metalinguistic comprehension, discourse comprehension and lexical ambiguity comprehension all also have been shown to be impaired.

Written Language

Written language production has received little attention in the literature on TBI survivors and language. Levin et al. (1981) noted that written language production impairments may be present following TBI, but to my knowledge, no research studies have documented or described it in TBI survivors. However, reading, has been directly addressed by a handful of studies. Reading is a particularly important skill that is often overlooked in this population possibly because it has not usually been a focus in traditional adult language rehabilitation. Moreover, adult language rehabilitation efforts have traditionally been associated with stroke survivors, and reading is not usually high on the list of therapeutic targets. For the typical young adult TBI survivor, however, reading impairment is more likely to interfere with an attempt to return to work or school. Reading is important to the quality of life of brain injury survivors, and it is also the focus of my study.

Reading requires the integration of multiple skills from language comprehension to visual processing. It is not surprising, then, that there is a general expectation of impaired reading along with anecdotal clinical evidence of frequent reading difficulty in TBI survivors. Hinchliffe and colleagues (1998) found reading comprehension to be impaired in TBI survivors when compared with control participants based on a single measure of reading comprehension from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983).

Frattali and colleagues (2007) examined the processing of written lexical ambiguity in a group of 25 patients with prefrontal cortex damage. Nineteen of the patients had a history of penetrating head injury, three of tumor resection, and three of stroke. Eleven of the participants had bilateral damage, six had right hemisphere damage, and eight had left hemisphere damage. Subgroups were based on the location of damage, not etiology, and were analyzed both together and separately. Sentences were presented in two phrases with a target word presented after the first phrase. For example, participants would see ‘Mary was scared to fly’ followed by ‘PLANE’ followed by ‘in the private jet’. When they saw the target word, participants were given up to 5000ms to decide whether that single word, presented mid-sentence, was related to the meaning of the sentence or not. The word immediately preceding the test word was a noun-verb homonym (e.g. ‘fly’) half of the time. The type of word was always indicated by either ‘the’ or ‘to’ for the noun or verb form respectively. One fourth of the test words were related to the correct interpretation (e.g. ‘plane’ for the verb, ‘fly’) and one fourth were related to the incorrect meaning (e.g. ‘plane’ for the noun, ‘fly’). The other half of the stimuli were unrelated to the target word, and the test words in the sentence were not homonymous. Two presentation timing conditions were also used: immediate and delayed. In the immediate condition, a formula allowed for a set presentation rate based on the number of characters and words in each phrase. In the delayed condition, a 1500ms constant was incorporated into stimulus onset time. Participants with prefrontal damage were less accurate in distinguishing between inappropriate and appropriate words. Surprisingly, however, when the sentence stimuli were presented at slower intervals, the control group showed increased interference and the group with prefrontal damage showed decreased interference. These results were based on a suppression ratio calculated by subtracting the mean RT to unrelated words from the mean RT to wrong-meaning words divided by the mean RT to unrelated words. That is, when compared to the prefrontal damage group, it took the control group longer to decide about words with the incorrect meaning than unrelated words in the delayed relative to the immediate condition.

Frattali and colleagues discussed their results in terms of control versus automatic processing in the prefrontal cortex. They suggested the results could be attributed to a loss of 'control aspects' of inhibition in the group with prefrontal damage (which included all participants with brain damage of any kind) or perhaps a 'hyper-response' to automatic processing of semantic relatedness. The finding that bilateral damage resulted in the worst performance when compared with left or right unilateral damage led Frattali and colleagues to propose that the left hemisphere is involved with lexical meaning selection while the right hemisphere is important for lexical ambiguity resolution. This study had several limitations, including the wide range of ages tested and the lack of a reported post-onset time for the brain injury. The control group was reported to not vary in age from the group with brain injury (mean was 52.76), but the range of ages for the controls was not reported. This is a significant drawback to the findings because the range in the group with brain injury was 38 to 68. Normal aging has been reported to result in changes to the prefrontal cortex and inhibitory responses in the literature (Hasher & Zacks, 1979). In this study, there were enough younger adults that age-based subgroups may have provided useful information. Their findings of language function are in line with the predominant theories of prefrontal cognitive function and therefore a valuable contribution to the sparse literature on language comprehension following TBI.

A paucity of research looking at written language is not unique to the TBI literature; it has also not been well described in the aphasia literature, with most studies presenting single cases. However, the expectations regarding language impairment in aphasia and TBI differ: following stroke, there is the expectation of language disability and therefore, stroke survivors are routinely evaluated by therapists. Following TBI, any apparent language impairment is often expected to resolve on its own, and therapy time is limited even during the acute stages. Written comprehension is an essential skill for people hoping to return to school and work after a head injury, which the small body of evidence suggests is impaired in TBI survivors. More research is needed to both prove the existence of and raise awareness of language deficits.

Language and Cognition in TBI

This section will describe the studies that have looked specifically at the relationship between language and cognition in TBI survivors. Although cognitive-communication deficits are the hallmark deficits of TBI, little research has been done to explicitly address the relationship between cognition and language use in this population. However, this is not surprising because while there is quite a lot of research looking at language and working memory in non-neurologically impaired adults (e.g., Just & Carpenter, 1992; Kemper & Sumner, 2001; MacDonald & Christiansen, 2002; Waters & Caplan, 1996), other aspects of cognition have only recently been addressed in relation to language more systematically. The relationship between cognition and language in normal adults will be addressed in the pilot study described in Chapter 4.

Coelho (2002) found modest correlations between the Wisconsin Card Sorting Test (WCST), a measure of executive function, and measures of discourse complexity in story narratives. No significant correlations were seen between any aspect of WCST performance and cohesion, an aspect of discourse organization based on the lexical and grammatical links that hold a text together. A separate study by Youse and Coelho (2005) looking at a large 55 person sample also only found modest correlations between scores from the Wechsler Memory Scale (WMS) and measures of discourse based on story generation and retelling. They measured the number of episodes (i.e. an initiating event, an action, and a direct consequence marking a goal), the number of complete ties out of total ties (i.e. a measure of cohesion in which the listener must find the meaning for the tie outside of the sentence), the number of T-units (i.e. an independent clause plus any associated subordinate clause) within an episode, and the number of words and subordinate clauses per T-unit. The WMS measures they used were digit span, logical memory, and associate learning. Digit span was only correlated with the number of subordinate clauses per T-unit in the generation task, and associate learning was correlated with the number of words and subordinate clauses per T-unit, the number of episodes, and the complete ties out of total ties in the retelling task.

Logical memory was not correlated with any of their measures. These results are surprising in that working memory and discourse deficits are a common concern following TBI, but their language and cognitive measures may not have been complex enough to show a relationship. Youse and Coelho discussed the need for a more complex working memory measure, such as the reading span, as well as a more varied set of discourse measurements. It is not clear whether or how they controlled for the wide variety of severities or ages in their sample. However, their results do suggest that there may be different relationships between different types of linguistic tasks and cognitive tasks following a TBI.

Links between working memory and discourse performance in adolescents with a history of TBI have also been observed. A series of studies by Moran and colleagues found that the working memory demands affected performance (Moran & Gillon, 2004, 2005; Moran, Nippold & Gillon, 2006). They pointed to the necessity of accounting for the storage demands of a task, which they found affected comprehension. Furthermore, when the storage demands were minimized, in the case of inference comprehension (Moran & Gillon, 2005), performance markedly improved. In some cases, comprehension was poor or reduced regardless of storage demands, but a demanding working memory component to the task weakened performance. Additionally, Channon and Watts (2003) found a relationship between the executive function of inhibition and the accuracy of judgment of the social appropriateness depicted in several short stories. The authors of these studies suggested that further research should take a wider variety of language and cognitive abilities into account.

A large battery of linguistic and neuropsychological tests was used in the study by Hinchliffe and colleagues (1998), discussed above, in order to address the relationships between many aspects of language and cognition. They found several promising relationships, though only correlational analyses were used. Working memory tasks were more closely associated with basic auditory comprehension (e.g. Token Test) than with processing more complex language (e.g. humor comprehension). They argued that this was because memory was associated with processing and storage and not conceptual integration. Lexical-semantic processing as tested by asking about synonyms, antonyms, definitions and semantic associates, however, was associated with attention. Because of the large number of tasks observed, their correlations must be interpreted with caution because of the possibility of uncontrolled or hidden variables and of Type I errors. The results of these few studies suggest that there may be a causal relationship between the cognitive deficits in TBI and language comprehension. However, there has been no replication of results to provide converging evidence for this hypothesis. Furthermore, the literature is so sparse that the specific cognitive processes involved have not been identified, nor have the affected linguistic processes been determined.

Limitations of Previous Research

A major limitation of many of the studies described is the time post injury observations were made. Studies were highly variable in when performance was observed with some as soon as 1 month post injury (Coelho, Grela et al., 2005) and others 7 years or more post injury (Yorkston, Jaffe, Polissar, Liao & Fey, 1997). Post injury variability was even present within the same study in many cases (e.g. 1-99 months in Coelho, Grela et al., 2005; 2-9.79 months in Hinchliffe et al. 1998). Initial observations within a very short amount of time following brain injury may be confounded by continued physical recovery of the brain. It is typical in the aphasia literature, for example, to observe performance no sooner than 6 months to a year following stroke, and it is not entirely clear why the same standards have not been observed in the literature regarding TBI and language. Aphasia research more often includes treatment studies which track improvement over time, and therefore, it is more necessary to limit the impact of the potential spontaneous recovery which happens during the first six to twelve months. It is an empirical question whether performance at a single point in time at the acute stage of recovery predicts long-term functioning of language following brain injury. Brain swelling and other physiological factors may obscure likely outcomes for any given patient. Controlling for time post-injury is therefore important.

The typical standard of post injury time in the reviewed studies of TBI is to wait until post-traumatic amnesia is no longer evident. However, this standard does not account for the impact of continued confusion and disorientation that can persist during the recovery period and longer for some TBI survivors. In fact, in some studies certain findings were explicitly argued to be based on possible confusion and disorientation (Coelho, Grela et al., 2005). In fact, Ellis and Peach (2009) intended to identify syntactic deficits in the acute confusional stage. At the very least, observations made at one month post injury are not comparable between subjects to observations made at one or more years. One aspect of language at least, discourse production, has been observed to be disrupted many years after initial injury (Coelho, 2007; Dennis & Barnes, 1990), but whether other deficits persist as well is unknown. Thus, there is a critical need for more research delineating the chronic language impairments affecting individuals with TBI.

Another non-trivial limitation in the TBI language impairment literature is that the vast majority of language research in TBI has addressed discourse level impairments. The nature of TBI is that brain damage and resulting deficits are likely to vary widely. One of the few studies discussed above that performed any significant testing of basic language functions (Hinchliffe et al., 1998) did find group differences on a number of basic language measures including: naming, oral expression, reading and listening comprehension, ambiguous sentence comprehension, and many others. Further, these language functions may affect discourse in both direct ways (e.g. failure to comprehend) and unexpected ways (e.g. compensatory strategies as noted by Friedland and Miller, 1996).

The limitations of the TBI literature are generally based on problems associated with the heterogeneity of the TBI population. Etiologies vary widely with people suffering head injuries from car accidents, falls, blunt assault trauma and other causes. Injury location varies widely, often in multiple locations and is not always readily assessable with a clinical MRI or CT scan. Diffuse injuries, for example, require extremely detailed scanning that is likely only able to pick up a fraction of the damage. Further, TBI survivors can be difficult to recruit if they are no longer in rehabilitation because a majority of TBI survivors have returned to work or school and simply may not have the time to donate to a study even with compensation. These factors and others are difficult to control but are probably part of cognitive and linguistic recovery in this population.

There are tremendous gaps in the research of language functioning following a TBI. Basic language functioning needs to be described in more detail with more basic information needed especially about language comprehension. Comprehension is arguably a more integral skill to returning to work and school, but it has received relatively less focus in the TBI literature. Reading comprehension is especially important in returning to school and has received even less attention in the literature than listening comprehension, although the psycholinguistic literature offers a range of established techniques particularly suited for assessing reading comprehension. Studies using modern techniques for examining language comprehension, especially reading comprehension, could inform a range of evidenced-based interventions for this population, once the linguistic deficits and their relationships with cognitive deficits are documented. The current study proposes to begin to fill the large gap in the TBI reading comprehension literature by exploring the nature of reading comprehension and cognition in this population using behavioral measures and EEG.

CHAPTER 3
EVENT-RELATED POTENTIALS AND LANGUAGE PROCESSING

One difficulty with examining language processing in a population such as traumatic brain injury (TBI) is that the behavioral assessments available may not capture the sometimes subtle language impairments that may be present due to concomitant cognitive impairments. Cognition is an integral component of complex language use; thus, the identification of language-specific processing, apart from cognition, is exceedingly difficult, even in populations without language impairments. Further, deficits specific to task performance (e.g., remembering which button means "No" or even understanding task requirements) may mask better language comprehension than is demonstrated by answers to comprehension or grammaticality questions.

Electroencephalography (EEG) has the potential to provide a source of data more sensitive to language processing due to its high temporal resolution and independence from task performance. Event-related potentials (ERPs) reflect changes in neural activity related to a specific internal or external stimulus or event as measured using EEG. Importantly, no response from the participant is necessary to determine whether processing is occurring. The primary components of interest for the purposes of describing language processing in TBI for this study are the N400 and P600, which are used as indices of semantic and syntactic processing respectively. The use of ERPs to describe language processing deficits has been established by aphasia research (e.g., Angrilli, Elbert, Cusumano, Stegagno & Rockstroh, 2003; Hagoort, Brown & Swaab, 1996; Swaab, Brown & Hagoort, 1997). It is accepted to use language related components to more fully describe the nature of the language deficits associated with aphasia, a group with known language problems (Dobel et al., 2001). The difference in this study is that it is hoped that ERPs may serve as a marker of language processing differences in a group with less obvious or accepted language impairments.

ERP Components

ERP components are features of an EEG that are averaged and time-locked to specific stimuli (Groppe, 2007). It is possible in some cases that a relationship between an ERP component and a predictable experimental stimulus is also related to a specific distributed neural network. It is largely assumed that the “functional” relationship between an ERP component and stimulus is based on a “physiological” relationship between a neural network and stimulus (as is assumed with all neuroimaging techniques), but this may not always be true (for a more thorough discussion, see Kutas and Dale, 1997). It is not a question of localization; the inverse problem makes localization particularly difficult with ERPs (see Fabiani, Gratton & Coles, 2000, among others). It is a question of whether any measureable component can truly reflect a single process at a given point in time. In this dissertation, the components to be measured are assumed to be functional. That is, observed components may reflect specific distributed networks of neural generators, but the components themselves will be defined functionally by their measureable polarity, latency and scalp distribution. In either case, the N400 and P600 components correspond to semantic and syntactic processing respectively, but their functional and physiological independence from other cognitive processes has been debated. The LAN is connected to early syntactic parsing and also to working memory. These components of interest will be described below.

N400: Semantic Processing

The N400 is an index of semantic processing difficulty and has a centro-parietal distribution that is slightly asymmetrical towards the right hemisphere (Duncan et al., 2009; Kutas & Iragui, 1998; Osterhout, McLaughlin & Bersick, 1997). It begins approximately 200-300ms after the target stimulus has been presented and peaks at around 400ms (Lau, Phillips & Poeppel, 2008). One of the most widely studied language related ERPs, it was first described as a response to semantically anomalous words within a written sentence (Kutas & Hillyard, 1980) but has since been found in response to word pairs, isolated words, strings of letters, and even faces or pictures (Debruille, Pineda & Renault, 1996; Kutas & Iragui, 1998). The N400 response to a word can be affected by many factors, including the predictability of the word in context (single word, sentence or discourse level context), word frequency, sentence position, and word repetition (Kutas & Iragui, 1998; Osterhout et al., 1997). These factors also influence one another. For example, although the N400 is often reduced in response to later occurring words within a sentence, increased semantic incongruity with context can reduce or eliminate sentence position effects (Osterhout et al., 1997).

Individual differences in processing strategies may influence the N400 response and may be particularly important to the current study which examines sentence processing in the heterogeneous population of TBI survivors. For example, a subset of normal participants has been found to have a large N400 response with an atypical frontal distribution to target words in ambiguous sentences, whereas most normal participants show a P600 instead (Osterhout et al., 1997). Osterhout and colleagues interpreted this as individual differences in how participants viewed the anomalies. They argued that some participants were ‘sensitive’ to the syntactic integration of an unexpected word and others were sensitive to the semantic integration of the word. The difference in sensitivity was also argued to relate to individual differences in working memory (WM) capacity. Osterhout and collegues suggested that participants with a higher WM capacity may be more sensitive to the syntactic aspects of anomalous words simply because they can hold more of the sentence active at one time. However, the abnormal 'N400' found by Osterhout and colleagues in this case had more of a frontal distribution than is typically seen in N400 responses. This different distribution suggests that the abnormal response may be similar to a different component, the left anterior negativities (LANs, described below) frequently reported in response to syntactic anomalies with particular relationship to WM (Fiebach, Schlesewsky & Friederici, 2001; Hahne & Friederici, 1999b). The N400 response to a syntactic event that typically elicits a P600, even taking into account the abnormal scalp distribution, suggests that the distinctiveness of semantic and syntactic levels of processing may not be as clear as frequently assumed.

The N400 has been looked at in a wide variety of populations with language impairments or differences (Duncan et al., 2009), including schizophrenia (Kuperberg, Sitnikova, Goff & Holcomb, 2006; Niznikiewicz, Mittal, Nestor & McCarley, 2010), Broca's and Wernicke's aphasia (Angrilli et al., 2003; Hagoort et al., 1996; Swaab et al., 1997), Alzheimer's disease (Schwartz, Kutas, Butters, Paulson & Salmon, 1996) and a wide variety of psychiatric disorders. In a study by Angrilli and colleagues (2003), the N400 was even used to provide evidence for neural reorganization of the language network during recovery from aphasia. To my knowledge, however, it has only been reported in a single case study of TBI, and it was only used as a tool to verify possible semantic comprehension in a patient who appeared to be in a vegetative state (Connolly, Mate-Kole & Joyce, 1999). It would therefore be beneficial to further develop an understanding of the range of possible N400 responses in TBI in order to be used more reliably in a clinical context.

The research looking at the N400 response in the aphasia literature has been useful in understanding the source of comprehension impairment. In a series of publications, Hagoort and colleagues (1996) and Swaab and colleagues (1997) described how N400 responses differ between good and bad ‘comprehenders’ in a group of people with aphasia. In both studies, rather than group participants by aphasia type (which included people with Broca’s and Wernicke’s classifications), they grouped them by how well they preformed on a comprehension test. In the earlier study Hagoort et al. (1996) found that good comprehenders in the group with aphasia had a similar N400 response to the control group for associative (e.g. bread-butter) and semantic (e.g. church-villa) word pairs that they heard. However, poor comprehenders had a reduced N400 to both pair types. In the later study, Swaab et al. (1997) found similar differences between good and poor comprehension groups on aurally-presented whole sentences. That is, poor comprehenders had a reduction and delay of the N400 effect while good comprehenders had a similar N400 response to the control group. In both studies, the researchers argued that their results suggested that poor comprehenders were not integrating lexical information into previous context, and, in the sentence study, that they were not integrating lexical information into a higher order semantic representation. In effect, the poor comprehenders may have been processing shallowly, in the sense that they were not fully integrating the words they were hearing into a semantic representation. Further, Hagoort and Swaab and colleagues argued that their results were language specific because they were not related to P300 effects that they also measured. The use of a relatively straightforward analysis to demonstrate impaired semantic integration in aphasia provides a promising standard for using the N400 to demonstrate the strength of semantic processing in TBI survivors.

P600: Syntactic Processing

A late occurring, positive component, the P600, is an ERP that has been associated with syntactic integration difficulty (Hagoort & Brown, 2000; Kaan et al., 2000) and is considered to index a relatively controlled, 'voluntary' process of language comprehension (Gunter & Friederici, 1999; Hahne & Friederici, 1999a). The P600 typically has a medial centro-parietal distribution, and it has a wide possible time window between 500 and 1000ms following the presentation of a target word. The P600 appears to be largest in amplitude to tasks involving comprehension of sentences with some sort of grammatical error (Gunter, Wagner, & Friederici, 2003; Munte, Matzke, & Johannes, 1997; Munte, Szentkuti, Wieringa, Matzke, & Johannes, 1997), and it is readily observable during complex and ambiguous sentence comprehension in healthy populations (Ainsworth-Darnell, Shulman, & Boland, 1998; Burkhardt, 2007; Featherston, Gross, Munte, & Clahsen, 2000; Hagoort, Brown, & Groothusen, 1993; Hagoort & Brown, 2000; Hahne & Friederici, 1999a; Kaan et al., 2000; Novick, Trueswell, January, & Thompson-Schill, 2004). A separate line of research has examined the P600 in relationship to WM and general rule-based processing in order to identify information processing differences in groups with known WM and cognitive deficits: schizophrenia (Kuperberg et al., 2006), obsessive-compulsive disorder (Papageorgiou & Rabavilas, 2003), and even multiple sclerosis (Papageorgiou et al., 2007). In the context of WM, the P600 is viewed as an index of more general rule-based processing (Papageorgiou et al., 2001). That is, the P600 may index any voluntary and synchronized process following the detection of a target.

The P600 is widely assumed to be at least specific to the integration of knowledge, because it can be observed in response to many types of stimuli (Burkhardt, 2007; Frisch, Kotz, von Cramon, & Friederici, 2003; Osterhout & Hagoort, 1999; Osterhout, McKinnon, Bersick, & Corey, 1996; Osterhout & Mobley, 1995). A limited number of studies have looked at the P600 in Broca's aphasia in order to measure integration (Wassenaar, Brown & Hagoort, 2004; Wassenaar & Hagoort, 2007). A study by Wassenaar and colleagues (2004) tested awareness of subject-verb agreement violations in patients with Broca's aphasia, elderly controls and patients with right hemisphere damage. The patients with Broca's aphasia did not show as strong of a P600 effect as the control group or the group with right hemisphere damage. Similarly to the N400 aphasia research discussed in the previous section, Wassenaar and colleagues found that a subgroup of poor comprehenders showed a significantly reduced P600 effect than the control group. They concluded that part of the effect could have been related to the fact that there was a clausal boundary between the subject and the verb, so the patients with Broca's aphasia were having difficulty maintaining the information about number across that boundary. The study by Wassenaar and Hagoort (2007) also found a reduced P600 effect in patients with Broca's aphasia in response to sentences that did not match a picture. However, the same patients with a reduced or absent P600 effect were above chance in identifying the mismatches. The behavioral responses, however, were much more delayed in the aphasic group than the control group and group with right hemisphere damage suggesting to the authors that the group with Broca's aphasia may have been relying on compensatory strategy to answer the questions since the accuracy was better than expected based on the P600. Wassenaar and Hagoort also proposed that the absence of a P600 could suggest shallow syntactic processing in that the patients with Broca's aphasia were not fully integrating the syntax or, in other words, were relying on a shallower semantic representation of the sentence or picture. They could have completed the task with a strategy that allowed them to identify the anomaly without having to fully process the sentence. Specifically, they suggested that the patients with Broca's aphasia were not always processing the agreement violations. Shallow processing in the sense of only partial integration of sentence information was also suggested by the research concerning the N400 in Broca's aphasia mentioned in the previous section. It is also worth noting that in both of the studies by Wassenaar and colleagues (2004; Wassenaar & Hagoort, 2007), the participants with Broca's aphasia did have a P300 response similar to the control group, which they used to conclude that the P600 effects were related specifically to language.

There is a history of debate regarding whether the P600 is specific to language, or whether it may simply reflect the engagement of attention necessary to identify an unexpected target, represented by another well studied EEG component, the P300 (Coulson, King, & Kutas, 1998a, 1998b). In order to address this debate, Frisch and colleagues (2003) tested a group of patients with aphasia that either did or did not have basal ganglia damage with two experiments. In the first experiment, participants listened to sentences with grammatically correct or incorrect verbs known to elicit a P600. In the second experiment, they used an auditory oddball task known to elicit a P300. In the oddball task, participants respond to target stimuli that occur irregularly and infrequently in a series of standard stimuli. They found that while both groups of patients demonstrated intact attention effects with a clearly observable P300, only the patients without basal ganglia damage had an observable P600. This difference indicates that the P300, representing attention, and the P600, representing syntactic processing or integration, can be dissociated. Frisch and colleagues, however, did not report any behavioral testing beyond two tests classifying aphasia types. The behavioral correlates of this dissociation and the neural generators of each remain unclear and are probably diverse.

Researchers who study the P300 hold that the component has a variety of sources that can vary based on modality (Johnson, 1993). As pointed out by Osterhout and Hagoort (1999), whether or not the P600 and P300 are generated by the same underlying physiological processes may not be the most important question. What is important is that the P600 can be elicited consistently and distinctly to language stimuli. What the Frisch et al. (2003) study later made clear, though, is that regardless of whether or not the P600 response is ‘just another P300’, they are dissociable. In their study, they were able to dissociate the auditory P600 is from an auditory based P300 response.

Another controversy surrounding the P600 is its relationship to agreement violations. The computation of agreement between sentence constituents (e.g. between the subject and the verb) is typically considered to be a syntactic process (Kuperberg, Kreher, Sitnikova, Caplan & Holcomb, 2007; Molinaro, Barber & Carreiras, 2011).

Agreement violations, then, would be expected to elicit a P600 and possibly a Left Anterior Negativity (LAN), which is a component described in the next section. However, grammatical agreement has many dimensions: number, animacy requirements, thematic role requirements, and others. In a recent review of 29 published studies, Molinaro and colleagues (2011) argued that different ERP components are related to different aspects of agreement processing. Specifically, they argued that the LAN is a response to expectancy violations, the early P600 is a response to sentence level syntactic integration, and an N400-like effect might be related to morphosyntactic markers that activate representations that are not just syntactic. That is, while agreement processing is intended to integrate the syntactic structure of the message and integrate this structure into a higher-level representation of the sentence, non-syntactic information, such as morphological markers, may also be used to achieve the same effect.

LAN: Early Syntactic Processing

The LAN is elicited by syntactic anomalies in the 300 to 500ms time window with an anterior distribution over the left hemisphere, which differentiates it from the N400 that has a more centro-parietal distribution (Fiebach et al., 2001; Hahne & Friederici, 1999b; Sabisch, Hahne, Glass, von Suchodoletz & Friederici, 2006). The LAN has not received the same level of attention as the N400 and P600, and therefore, the functional process represented by the component is not as thoroughly defined. In contrast to the voluntary syntactic processing attributed to the P600, the LAN has been attributed to first pass or automatic syntactic parsing (Hahne & Friederici, 1999b) and syntactic WM (Fiebach et al., 2001). Hahne and Friederici (1999b) further distinguish between an early left anterior negativity (ELAN) between 100 and 300 ms in response to phrase structure violations, and a slightly later LAN between 300 and 500 ms in response to agreement violations. The WM LAN, or the sustained LAN, has a similar scalp distribution and also begins at about 300 ms but does not return to baseline like the syntactic or focal LAN does (Fiebach, Schlesewsky & Friederici, 2002). The ELAN is not a focus of this study because it is a relatively difficult component to elicit and measure, possibly due to the fact that it is a more focal, short lived response rather than large, wide-spread, long-lasting response like the N400 and P600 (Pulvermüller, Shtyrov & Hauk, 2009). Because it is assumed to signal the deployment of syntactic WM, the sustained LAN component falling between 300 and 500 ms may be useful in examining language processing following TBI, a population with frequent WM deficits.

Osterhout and colleagues (1997) suggested that the LAN is only found in a certain subset of people and that it actually reflects *semantic* processing of syntactic stimuli. That is, they argued that it is the N400 despite its more frontal distribution. Osterhout and colleagues (1997) argued that the LAN may be elicited in response to syntactic stimuli only in a subset of the population that may have different WM abilities. As mentioned before, Osterhout et al. proposed that people with a higher WM capacity may be more sensitive to syntactic aspects of anomalous words, so people with a lower WM capacity may only show a semantic response to syntactically anomalous stimuli. Similarly, Fiebach and colleagues (2001) argued that the slow wave or sustained LAN was stronger in those with lower WM capacities. Therefore, regardless of whether it reflects semantic or syntactic processing, it seems agreed that the component will vary depending on verbal WM capacity,.

Another perspective is that the LAN is not found across studies because it is only found in response to stimuli or paradigms that violate morphological expectancy rather than simply automatic morphosyntactic processing (Molinaro et al., 2011). Unlike the semantic expectancy violations associated with the N400, the expectancy violations associated with the focal LAN are associated with the expected morphology. The current study is not attempting to explicitly test for the LAN, but it is an important component to be aware of in a population with known WM deficits, such as individuals with TBI. Particularly if the P600 is not readily observable in response to syntactic anomalies, it would be worth examining the data for an earlier syntactically elicited component like the LAN.

Dissertation Study

The interaction between cognition and language processing is beginning to receive more attention in the literature. Most of the research has been done in individuals without impairments. Examining the relationship between cognition and language in TBI survivors may provide a wide range of information about the relationship because of the highly variable level of impairments in the TBI population. This study examined two ERP components, the N400 and P600, in response to sentences with and without grammatical and semantic anomalies.

If TBI survivors are processing semantics similarly to adults without a history of TBI, the N400 should not be significantly different between groups in terms of latency, scalp distribution or area under the curve. If semantic anomalies are simply not identified as they occur, either consciously or unconsciously, the N400 may be missing in TBI survivors. Shallow integration of semantics is a possibility suggested by the aphasia research (Hagoort et al., 1996; Swaab et al., 1997) that would also lead to a reduced or absent N400. Another possibility is that while participants with TBI may eventually recognize a word as wrong, they may be initially more accepting of the misplaced word. In this case, the N400 response in TBI survivors may be delayed and have a less pronounced peak than in control participants.

If patients with TBI are processing syntax similarly to adults without TBI, the P600 should not be significantly different in people with TBI than in control participants in terms of latency, scalp distribution or area under the curve. If normal processing is not occurring and syntactic anomalies are not identified as they occur, or if syntax is only shallowly processed as suggested by the aphasia research (Wassenaar et al., 2004; Wassenaar & Hagoort, 2007), the P600 may be missing in people with TBI. A likely possibility is that comprehension will be more difficult and slower in TBI, but not absent, resulting in a delayed P600 with a longer latency and greater overall amplitude.

The focus here is to simply identify the presence or absence and group characteristics of these ERP components given the exploratory nature of this study. Confirming that there are electrophysiological differences in our sample will help to validate our findings on the language analyses. Previously published studies do not address how the relationships between language and cognitive processing are related to behavior and sentence comprehension. This study extends previous studies by employing both electrophysiological methods and behavioral methods to address the relationship between language processing and cognitive processing. Once the components are identified in this population, the heterogeneous nature of TBI survivors as a group will allow for the possibility of mapping relationships between specific aspects of sentence processing and cognition, which would not be possible in a more homogeneous population.

CHAPTER 4
SENTENCE COMPREHENSION DURING RAPID SERIAL VISUAL PRESENTATION: A PILOT STUDY

Overview

The dissertation study was planned to address sentence comprehension in traumatic brain injury (TBI) survivors, who frequently have cognitive deficits. However, we first completed a pilot study with healthy control participants to determine if our methods and stimuli were reasonable to use with an impaired group. In order to more directly parallel sentence comprehension and a particular cognitive ability, the original plan for the study was to look at ambiguity resolution and executive function. On the surface, they both require conscious suppression of a stimulus and activation of another stimulus. In the case of ambiguity resolution, the stimuli were presumed to be internal. That is, a reader would have to suppress an incorrect interpretation of an ambiguous sentence internally and then activate the correct interpretation. To test the correlation between ambiguity resolution and executive function, we planned to correlate a comprehension task of single ambiguous sentences and separate cognitive tasks. However, because of potential task performance impairments in the TBI group, electroencephalography (EEG) was planned in order to look more closely at sentence processing as it occurred rather than simply relying on behavioral data.

When using data collection methods such as EEG, data must be time locked to stimulus presentation. Presentation of visual sentence stimuli for reading is therefore usually accomplished using a method called Rapid Visual Serial Presentation (RSVP), originally developed for behavioral testing. In RSVP, words are presented one at a time for a short period (e.g. word visible for 250ms, blank screen for 350ms). Conventional wisdom about using RSVP for examining sentence comprehension maintains that working memory (WM) probably affects sentence processing (Caplan & Waters, 1999; Miyake, Carpenter & Just, 1994; Waters & Caplan, 1996). WM is defined broadly here as the ability to actively store information and manipulate it according to the demands of the situation (e.g., Engle, Kane & Tuholski, 1999; Salthouse, 1991; Waters & Caplan, 2005). However, no studies to our knowledge have directly compared comprehension using RSVP and whole sentence presentation behaviorally and related these finding to WM.

RSVP was originally used as a way to behaviorally tax linguistic processing (Forster, 1970; Potter, Kroll & Harris, 1980). These early studies found that RSVP reading was affected by linguistic complexity and that recall for passages presented using RSVP was poor. While performance was attributed to WM demands, WM was not directly tested. Further, it is not clear if RSVP actually interfered with syntactic comprehension. This is problematic because RSVP is frequently used to test theoretical sentence processing questions without many or any cognitive tests (Lee & Newman, 2010) despite the expected relationship. Furthermore, RSVP is increasingly being used in studies to make claims about impaired sentence processing in groups of people that also typically have cognitive impairments (e.g. schizophrenia; Salisbury, O'Donnel, McCarley, Nestor & Shenton, 2000), including this dissertation study with TBI survivors. Thus, the effects of RSVP on sentence comprehension and the relationship between RSVP performance and cognitive abilities are critical questions for the field and one that was important to address if the method was going to be used with a group of TBI survivors. To address these questions using our planned stimuli set prior to using EEG, we compared reading comprehension following RSVP and whole sentence presentation, and tested whether reading comprehension in each related to WM or other cognitive factors in a group of healthy undergraduates. The following sections describe first, different theories of how ambiguity in a sentence is resolved, second, the relationship between cognition and ambiguous sentence processing in people without neurological impairment and finally, the relationship between RSVP and whole sentence processing.

Ambiguous Sentence Processing

A theory of incremental, syntax-first parsing would predict that the parser initially builds a syntactic structure based on the least complex interpretation of words as they are encountered (Frazier & Rayner, 1982; Kimball, 1973; Rayner, Carlson & Frazier, 1983; Rayner & Frazier, 1987). When the minimal attachment parser encounters a word that suggests a different parse, it then reanalyzes the entire sentence. The bottom half of Figure 1 shows the only correct parse for this sentence with red lines indicating what would be added during reanalysis: [[The florist][sent the invitation]][was nervous]. The principles of minimal attachment and late closure were developed within a modular framework (Frazier & Fodor, 1978). Therefore, non-syntactic information, such as plausibility and thematic information would not be presumed to influence parsing until a later interpretation stage. Syntax-first parsing is also sometimes called a two-stage model to reflect the incorporation of non-syntactic information during the second stage of processing.

The multiple constraints model was developed as an alternative to the two-stage model (Garnsey et al., 1997; MacDonald, Pearlmutter & Seidenberg, 1994). Rather than assuming readers approach each word in the same way syntactically, the multiple constraints model predicted that multiple sources of information may be used interactively throughout processing. Several sources of information become available incrementally as a sentence is processed, but, in the multiple constraints model, they are used immediately to guide predictions and processing rather than used during a second revision stage as in the two-stage model. For example, certain verbs are more frequently used with direct objects (e.g. *confirmed*) while others tend to be used with embedded clauses more often than direct objects (e.g. *figured*). When these biased verbs are used in sentences that go against their most frequent usage, they lead to the garden path effect. It has been found that ambiguous sentences such as (a) take longer to read and respond to than (b) presumably due to this difference in how each verb is typically encountered (Garnsey et al., 1997).

(a) The CIA confirmed the rumor should have been stopped sooner.

(b) The salesman figured the prices would be going up soon.

Other factors mentioned that influence or constrain initial interpretation include the frequency a verb occurs in a transitive or intransitive form and even visual or referential context (Altmann, 1998).

Both the minimal attachment and multiple constraints models were developed to account for a parser that disambiguates alternatives in order to allow the reader to develop the correct interpretation. However, Ferreira (2003) pointed out that despite this underlying purpose, very few studies of sentence comprehension directly addressed comprehension. Following earlier research suggesting that readers do at least some sort of initial gist-like interpretation that may not be corrected when faced with complex or ambiguous structure (e.g. Late Assignment of Syntax Theory; Townsend & Bever as cited in Ferreira, 2003), Ferreira (2003) and Christianson and colleagues (2001) found that people do not always correct an initially incorrect parse. They seemed to be only interpreting even non-ambiguous sentences (Ferreira, 2003) at a shallow or “good enough” level of processing.

A shallow interpretation is not just limited to syntactic representation, and it has been observed in relationship to lexical ambiguity and even word-level errors (Frazier & Rayner, 1990; Frisson & Pickering, 1999). Sanford, Sanford, Molle and Emmott (2006) found that simply using italicization, one of many linguistic attention capturing devices, increased depth of processing. Depth of processing may vary from study to study because it can apparently be affected by a wide variety of linguistic components (Sanford et al., 2006) and because it could be related to how much effort a reader is putting forth (Ferreira & Bailey, 2004). Processing depth is likely to vary between individuals and even dynamically across the course of a task within a single individual (Gimino, 2002; Iqbal, Zheng & Bailey, 2004). Accounting for when and how processing depth varies could partially explain some of the variability in ambiguous sentences processing.

Cognition and Ambiguous Sentence Comprehension

Individual variability in language comprehension could potentially be due to a wide variety of linguistic and non-linguistic factors, including cognitive factors such as WM and executive function (EF). The relationship between WM and sentence processing has been explored extensively (e.g., Just & Carpenter, 1992; Kemper & Sumner, 2001; MacDonald & Christiansen, 2002; Waters & Caplan, 1996), but it was not until fairly recently that studies have begun to examine the role of other cognitive constructs using non-linguistic comparison tasks (Grossman, Lee, Morris, Stern & Hurtig, 2002; January, Trueswell & Thompson-Schill, 2009; Nappa, January, Gleitman &

Trueswell, 2004; Novais-Santos, Gee, Shah, Troiani, Work & Grossman, 2007; Novick, Trueswell, January & Thompson-Schill, 2004; Novick, Trueswell & Thompson-Schill, 2005; Ye & Zhou, 2008). EF in particular, defined generally as intentional or voluntarily controlled neural processes, may explain a large portion of individual variability in performance and variability between studies of ambiguity resolution tasks.

WM and Ambiguity

The most notable non-linguistic explanation of variability has been in the literature on working memory and language comprehension. Just and Carpenter (1992) identified two phenomena that are not easily incorporated into a theory of language processing without some extra-linguistic source of variation. First, when Just and Carpenter (1992) split their participants into two groups based on WM capacity, as measured by reading span, the higher capacity group seemed to use prior disambiguating information to avoid being led down the garden path. People with lower WM capacity did not avoid ambiguity. A second observation by Just and Carpenter was that individuals with a high span actually did worse than low span individuals in certain cases because those with a high span seemed to be maintaining more possible syntactic representations during processing. When the simplest parse did end up being the correct one, high span individuals were actually slower because they were maintaining alternative parses in parallel, in working memory, while low span individuals were not, Just and Carpenter (1992) argued. Syntactic processing appeared, therefore, to be positively or negatively affected by WM capacity, depending on the eventual parse and capacity of the individual.

MacDonald and Christiansen (2002) took issue with capacity being the individual difference causing the effects in Just and Carpenter's (1992) account. MacDonald and

Christiansen instead argued for regularity and individual experience being the contributing factors. Rather than processing exceeding capacity, they claimed that complex sentences were simply more irregular and therefore, some readers had the advantage of greater experience in reading them. The high span participants identified by Just and Carpenter were really just more experienced readers in MacDonald and Christiansen's view. Regularity and individual experience are therefore two more possible sources of variability.

The sources of individual variability in sentence processing described by Just and Carpenter (1992) and MacDonald and Christiansen (2002) are largely passive resource constraints. One of the resource constraints described by MacDonald and Christiansen (2002), experience, is arguably a more active source of differences than regularity or capacity, but it is not likely to vary considerably within one session (although, Wells, Christiansen, Race, Acheson & MacDonald, 2009 found that four 30- to 60-min training sessions were enough to influence how well non-canonical word order was processed). Overall, experience may be influenced by volition, but experience itself is not a direct, immediate source of controlled or volitional variability.

EF and Ambiguity

A source of volitional based variability in language comprehension may be EF. EF is a loosely defined term that has been criticized as being too vague or at least difficult to define (Burgess, 1997) and is sometimes used in exchange with at least two other terms usually used equivalently: supervisory attention (Baddeley, 1986; Miyake, Friedman, Emerson, Witzki & Howerter, 2000; Collette & Van der Linden, 2002) and the central executive (Baddeley, 1986). EF from a neuropsychological perspective generally refers to neural systems in the brain that are responsible for 'higher-order' cognitive processes, such as voluntary planning or effortful control, goal selection, goal maintenance, cognitive flexibility, inhibition of inappropriate actions and many others (Fernandez-Duque & Posner, 2001; Spreen & Strauss, 1998). EFs are often considered to be control processes for lower level functions and some consider EFs only to be necessary in the case of situations that are novel or requiring adaptation (Miyake et al., 2000; Stuss & Alexander, 2000). Lezak (1982) emphasized that EFs should be separated from cognitive functions, which were defined as quantifiable knowledge, skills and "intellectual equipment" (p. 283). According to Lezak, EFs refer to how and whether a person carries out a behavior or acts towards a goal. Some researchers consider EF to be equivalent to the central executive of working memory and therefore a part of working memory following Baddeley (1986) while others consider EF to encompass working memory, attention and inhibition (e.g. Miyake et al., 2000; Salthouse, Atkinson & Berish, 2003).

EF is a not a unitary construct (Stuss & Alexander, 2000; Alvarez & Emory, 2006) and therefore, it is necessary to look at the subcomponents of EF to relate to the processing of ambiguous sentences. EF components differ from source to source, but they are usually assumed to be located largely in the prefrontal cortex (PFC; Miller & Cohen, 2001). The right hemisphere, basal ganglia, and thalamus are also sometimes thought to be involved with EFs (Lezak, 1982), but most of the research focus has been on the PFC. There is some evidence to suggest that the usual equating of the PFC with EFs is incorrect because there have been cases reported of people with frontal lesions and no EF deficits and of people with EF deficits and no frontal damage (Alvarez &

Emory, 2006). However, EF deficits are difficult to identify due to the multi-factorial nature of EF and the tasks used to test it (Stuss & Alexander, 2000). Therefore, the lack of documented EF deficits in patients with frontal lesions may be due to the lack of a complete enough set of testing materials to identify deficits across the range of EF abilities or in an underlying mechanism.

There has been little consensus about whether there is a unifying mechanism of EF. The common concept that EF simply refers to controlled rather than automatic processes is not specific enough given the wide range of possible levels of control (Stuss & Alexander, 2000). Some researchers do not consider EF to be a unitary construct (Stuss & Alexander, 2000), but others have suggested the possibility that either inhibition (Miyake et al., 2000; Zacks & Hasher, 1994) or sensory biasing, in the form of cognitive control (Miller & Cohen, 2001), may be what is partially the source of the wide variety of EF variables. Miyake et al. (2000) analyzed the factors underlying a set of tasks thought to test shifting, updating and inhibition and found that the three factors were distinguishable but still substantially correlated. They argued that the correlation was explained by an underlying basic inhibitory or working memory component. EF may therefore be multi-factorial but also have partially shared processing. Only a few of the subcomponents of EF have been looked at directly in relation to language processing: planning, shifting and conflict resolution, and inhibition. These three are discussed below.

EF subcomponents: Planning

Planning is one of the few EF components to be considered in relation to language (Grossman et al., 2002; Nappa et al., 2004; Novais-Santos et al., 2007). Planning may be recruited separately along with working memory resources by ‘core’ sentence processing when needed (Novais-Santos et al., 2007). In fact, Novais-Santos and colleagues commented that while a parallel approach to ambiguity resolution may seem to require a perhaps unrealistic amount of working memory, the serial approach assumes a much larger contribution from planning and decision-making as it only follows the most probable parse. Novais-Santos and colleagues do not seem to directly address the possibility of a multiple constraints that would not necessarily put the same strain on working memory (Garnsey et al., 1997), though their point about a possible trade off between working memory and planning is a valid one. They found evidence for "strategic on-line planning" (p.361) and a generally widespread network for sentence processing using ambiguity resolution of reduced relative clauses. Their conclusion about planning was based on increased activation in the dorsolateral prefrontal cortex (dlPFC), previously observed to be recruited for EF tasks like the Stroop (e.g. MacDonald et al., 2000), when the verb was biased towards either a direct object or sentence complement structure and ended up being used with the opposite structure. Previous work has also suggested that the dlPFC may be involved with working memory, however (e.g. Cohen et al., 1997), and so the conclusions are not definitive. Further, they did not include non-linguistic tasks in their fMRI study so there was no direct way to compare activation increases across tasks within participants.

In a behavioral study, Grossman and colleagues (2002) measured EF using a short battery of tasks (including animal naming fluency, Stroop, digit span forward and backward, and Trails B) and sentence comprehension using a word detection procedure that they claimed assessed sensitivity to grammatical agreements as well as a more traditional subject and object-gap comprehension task. They found correlations between their measures of EF and sentence comprehension, though values were not given. They interpreted their results as implying that “working memory, inhibition, planning, and information processing speed” (p. 612) could be the true source of comprehension impairments in PD. Specifically relating to planning, they found a difference in performance on Trails B, which they considered a measure of planning, between two groups of Parkinson’s patients. The groups were based on a discriminant analysis that found a certain percentage of patients performed similarly to control participants and another that performed considerably worse on sentence comprehension measures. The group that did more poorly on Trails B, based on a t-test between groups, was also the group that did more poorly on sentence comprehension measures. Grossman and colleagues did include a wide range of tasks, but without correlation values or a factor analysis, it is unclear how each of the observed EF constructs may be related specifically to the sentence comprehension measures, especially in an older population that has been argued to show dedifferentiation between abilities (Baltes, Cornelius, Spiro, Nesselroade & Willis, 1980).

A further study by Nappa and colleagues (2004) addressed priming more indirectly as it related to selective attention in speech production. They directed visual attention to scene objects subtly using a 500ms fixation point or subliminally using a 60-80ms cue following fixation. They found that the object that corresponded to the fixation point or subliminal cue location was much more often mentioned first in a sentence than other scene objects. This finding suggests that attention can affect the planning of the word order of a message.

Though planning does seem to be related to linguistic processing in some way based on these studies, and certainly must be in the more general sense of message planning, it is far from clear what role the traditional notion of executive planning may play in sentence processing. Strategically planning comprehension has been made an argument against massively parallel processing (Novais-Santos et al., 2007), but the evidence given here is only preliminary. The fMRI study by Novais-Santos and colleagues (2007) based their argument for planning on increased activation in the dlPFC, an area also argued to be used during working memory (Cohen et al., 1997). The earlier behavioral study by Grossman and colleagues (2002) did not clearly address which aspects of planning were involved as it related to their measures related to their linguistic measures or findings. The more specific study by Nappa and colleagues (2004) only suggested that attention may influence linguistic planning, not how or when planning itself may be carried out. The studies are suggestive, but only address planning in a peripheral way.

EF subcomponents: Shifting and conflict resolution

Planning is followed by actually carrying out activities (Lezak, 1982), which includes, among many other things, the ability to shift between behaviors and sequences. It has been widely studied in the cognitive literature, but unlike planning, shifting has taken on a wide variety of designations (see Figure 2). While many of the terms are often used interchangeably, they are also sometimes used to refer to performance during certain kinds of task or in certain contexts. Set shifting, for example, may refer specifically to when one set or rule is no longer desirable and another is, as in the WCST (Berg, 1948), while flexibility may refer to repeated switching or the ability to take on new viewpoints in novel contexts (Miyake et al., 2000). Confusingly, flexibility is also sometimes defined to literally refer to shifting (Hill, 2004).

Shifting in its simplest sense of shifting from one set to another has traditionally been thought to require inhibition of previous items and activation of new items (Alvarez & Emory, 2006; Collette & Van der Linden, 2002; Stuss & Alexander, 2000). Others, however, think it may be the ability to do something new despite interference, negative priming and distraction (Miyake et al., 2000). The fact that tasks of shifting such as the WCST do not always correlate with inhibitory tasks suggests that shifting is a discrete function. This notion is further supported by the findings of a dissociation between shifting and 'simple' inhibition in autistic children (Ozonoff & Strayer, 1997).

Set shifting seems particularly well suited to explain ambiguity resolution as, on the surface, both seem to require the suppression of an initial incorrect parse and the shifting to the correct parse. Some researchers have found evidence that we do not fully suppress the initial incorrect parse (Christianson et al., 2001), but this does not necessarily go against the definition of set shifting as doing something despite interference (Miyake et al., 2000). In garden path sentences and comprehension tasks that require more overt control for correct parsing, however, conflict resolution may be a more appropriate term.

Conflict resolution has been defined as part of a system that monitors for levels of conflict and then passes that information to control centers in order for control processes to respond appropriately (Botvinick, Braver, Barch, Carter & Cohen, 2001). The resolution portion of conflict resolution is in the active seeking of an alternative interpretation or response to the incorrect one (Luo, Niki & Philips, 2004). In studies looking at when people have “Aha!” moments, conflict resolution is necessary in order to break mental impasse (Luo et al., 2004). Set shifting by itself is not enough to do so. The conflict resolution system is necessary for the control system to determine just how much control to exert because it is not always correctly estimated prior to a task. The WCST, for example, does not always engage conflict resolution to a large extent because the possible rules are quickly learned and it is simply necessary to switch between them.

A recent review provided by Novick et al. (2005) described the relationship between syntactic parsing and cognitive control with a particular focus on cognitive control in the face of conflict between internal representations. They were concerned with defining the role of the left inferior frontal gyrus (LIFG) and the link between syntactic and non-syntactic theories regarding its function. The LIFG has been long thought to be involved with some level of syntactic processing or syntactic working memory based on observations of people with Broca’s aphasia. However, lesion studies have found that when damage is limited to LIFG, language deficits are minimal while conflict resolution performance is consistently impaired (Dronkers, Wilkins, Van Valin, Redfern & Jaeger, 2004). Novick et al. (1995) predicted that the LIFG is not involved simply with processing all ambiguous sentences but only those sentences that specifically have multiple conflicting possible parses. They provided a simple explanation of how they predicted cognitive control to interact with syntactic parsing:

> Upon encountering disambiguating information … the parser has to relax its initial commitment to the analysis that was strongly pursued up to that point … because the newly discovered information is incompatible with

> that solution. Then, once this analysis has been suppressed, the parser revises its syntactic characterization of the input to be in accordance with *all* the available evidence, including less reliable linguistic and nonlinguistic patterns (e.g., referential context). This allows the system to settle into a different analysis that better respects the sentence- and situation-relevant information. (p. 270)

The relationship between cognitive control, ambiguity resolution and Broca's area was examined using fMRI by January and colleagues (2009). They examined activity localization for an ambiguous sentence task and a Stroop task within each participant. The sentence task consisted of participants passively viewing scenes while listening to sentences that had a prepositional phrase that could either modify the object or refer to an instrument to carry out the suggested action in the sentence. Participants were instructed to imagine carrying out the actions they heard on the objects in the scene they were viewing. Despite the passive nature of the task, they found that as ambiguity conflict increased *and* as Stroop conflict increased, activity in Broca's area increased. Their results support the idea of a general cognitive control mechanism being used during syntactic ambiguity resolution.

Individual variability in cognitive control relating to syntactic ambiguity resolution was also supported behaviorally by Novick and colleagues (2004). They asked participants to listen to ambiguous 'put' sentences such as, 'Put the frog on the napkin into the box' or disambiguated versions while looking at scenes. A non-syntactic delayed verification task (see Table 1) was used to measure cognitive control. They found that their measures of ambiguity resolution correlated with individual variation on the delayed verification task and attributed the relationship to a possible shared resource in the frontal system responsible for cognitive control, as was supported by the more recent study by January and colleagues (2009).

Ye and Zhou (2008) offered further support that cognitive control was necessary to ambiguity resolution. They were interested in determining whether the P600 was related specifically to the stage in processing when EF and language interact or rather whether it was related to thematic role reassignment. In order to address their questions, Ye and Zhou compared conflicts of plausibility and syntax in simple active and passive sentences. They also compared ERPs between participants grouped by control ability, as measured by performance on the Stroop task. The plausibility of the sentences was manipulated such that the thematic role reassignment view would predict no P600 as there was no animacy violations while the cognitive control view would predict a P600 in all cases. They found a P600 in all cases, supporting the cognitive control view. They also found evidence that the P600 may vary based on individual cognitive control abilities. For the low control group, they found a single sustained positivity for implausible sentences when compared to plausible sentences. For the high control group, however, they found different responses to plausibility depending on whether the sentences were active or passive. Active implausible sentences elicited an anterior negativity, while passive sentences elicited a sustained positivity. They related the anterior negativity seen during active implausible sentences to the anterior negativity observed in other conflict type tasks such as Stroop tasks suggesting that higher control participants were actively suppressing alternative parses.

Ye and Zhou's (2008) results indicated that high and low ability participants may disambiguate sentences differently. Ye and Zhou interpreted their findings as suggesting that those with lower control abilities may not suppress alternative parses as well as those with higher abilities. The group difference brings to mind previous findings by Just and Carpenter (1992) that high and low span groups performed differently on ambiguity resolution tasks. Just and Carpenter found the seemingly incongruous result that higher span participants seemed to actually have more difficulty, based on gaze durations, than lower span participants on certain sentences because they may be holding on to more possible alternative parsed. However, Ye and Zhou's findings suggested that higher control abilities allow readers to suppress too many alternative parses and they did not find any group difference patterns related to performance on the reading span task as they did for the Stroop task. On the surface, it seems as though working memory and cognitive control abilities could be related. It would therefore be worthwhile to determine first, if higher control performance was related to higher working memory performance, and second, if longer gaze durations as were seen in relation to higher working memory performance were related to higher control abilities or not. The relationship between working memory and cognitive control could be directly related to some overall EF ability, or they could dissociate such that those with higher working memory abilities could have lower cognitive control abilities or vice versa. One possibility is that cognitive control is made easier when fewer alternative parses are able to be maintained in working memory, for example.

EF subcomponents: Inhibition

Inhibition may be separable from set shifting and conflict resolution (Miyake et al., 2000; Salthouse et al., 2003) and it is used in a variety of ways. Four most immediately types of inhibition relevant to sentence processing may be resistance to interference, cognitive inhibition, inhibition of prepotent responses and negative priming. Resistance to interference prevents information that is irrelevant to the current focus from entering working memory, and it is distinguished from cognitive inhibition which inhibits or 'expels' information that is already in working memory, though they may be controlled similarly neurologically (Wilson & Kipp, 1998). Interference can be measured by decreased efficiency when there are multiple available sources of information that must be ignored or resisted. This is thought to be a passive process, but it is still thought to be related to the frontal lobes. Items that have been cognitively inhibited can be detected through recognition memory, though not through direct recall, unlike items that have been resisted which will not be recognizable. The difference is that actively inhibited items have been encoded in working memory, even if the active inhibition was not overtly recognized.

Unintentional inhibition occurs when items have been automatically entered into working memory because of their association with relevant information (Harnishfeger, 1995). However, it is suppressed prior to overt awareness. It is a distinction made to emphasize a possible difference between active, overt or conscious suppression and unconscious suppression, but it may not be easily measured. Wilson and Kipp (1998) pointed out that unintentional inhibition may be the type of inhibition used when the irrelevant meanings of polysemous words are suppressed.

Inhibition of prepotent responses and negative priming are related. Inhibition of a prepotent response is the inhibition of a positive response to a target that is incorrect or undesired but has been recently the correct target (Jonides, Smith, Marshuetz, Koeppe

& Reuter-Lorenz, 1998). That is, the given target requires a ‘no’, but it recently required a ‘yes’ response. Negative priming is considered to be related to inhibition, but is better understood as the positive response to a target that was recently a distractor. That is, in the reverse of the inhibition of a prepotent response, a negatively primed target requires a ‘yes’, but it recently required a ‘no’ response.

RSVP and Whole Sentence Presentation

A recent study by Lee and Newman (2010) directly compared the effects of RSVP and whole sentence presentation on brain activation using fMRI in an attempt to account for variation in the complexity effect found in neuroimaging studies. They specifically examined whether activation related to linguistic complexity in BA 44, the posterior superior and middle temporal gyri (i.e. Broca’s and Wernicke’s areas), and the hippocampus was modulated by presentation type. These researchers contrasted activation for conjoined active and object relative sentences using RSVP and whole sentence presentation. They measured accuracy and response times to verification of probe sentences that described an event from the target sentence. Accuracy varied significantly between complexity conditions and presentation conditions, but a significant interaction revealed that there was a larger effect of complexity in the RSVP condition. Response times to probe sentences only showed a main effect of syntactic complexity with whole and RSVP sentences being slower in the more complex condition.

Lee and Newman (2010) concluded that RSVP prevented readers from showing processing benefits in the simpler sentences, because the serial order processing required by RSVP interfered with either syntactically relevant word order processing or deeper encoding of syntactic and semantic relationships. This conclusion was based on the observation that syntactic complexity effects were only observed in BA 44 during whole sentence presentation. Interestingly, hippocampal activation was much larger during whole sentence presentation than during RSVP as well. This suggested that participants were only processing information shallowly during RSVP, leading to impaired memory consolidation and poor binding of lexical items into an ‘integrated memory’ representation, especially in the case of sentences with complex syntactic structure. This memory representation was hypothesized to be necessary for computing the semantic meaning of a sentence, based on the syntactic structure. Unfortunately, Lee and Newman (2010) did not include behavioral cognitive measures. Moreover, their methodology included a 6 second delay between the target and probe sentence, in order to get a clear hemodynamic response to only the target sentence in question, which may have increased WM demands and influenced activation patterns. Further, participants responded with separate hands for true (right finger) and false (left finger) sentences. Therefore, their behavioral and neuroimaging results from probe sentences must be interpreted cautiously.

Waters and Caplan (1996) also explored the notion that RSVP might tap working memory resources using sentences with sentential complements, reduced relatives, or embedded clauses, all with and without garden path versions. However, their study did not explicitly address the questions of interest here. Specifically, Waters and Caplan compared RSVP and whole sentence processing only in older adults (50-80 years old). They also did not explicitly test sentence comprehension, but instead used sentence acceptability judgments. Furthermore, the same sentences were used for RSVP and whole sentence conditions, though they were given on separate days. Their methods also varied somewhat from the norm. In the RSVP condition, they presented words successively for 250ms without a typical blank screen between each word (e.g. Hagoort & Brown, 2000; Osterhout & Holcomb, 1992), which may cause problems of attentional blink, discussed below. Additionally, the screen went blank after the last word of the sentence until the acceptability judgment response was given. Whole sentences, in contrast, were left on the screen until the acceptability judgment was given. The authors acknowledged that these differences in presentation and response type between conditions made a direct comparison of RTs between RSVP and whole sentence presentations impossible. On the other hand, Waters and Caplan did examine the effects of working memory by splitting their group into three smaller groups based on reading span performance, which was the only cognitive measure reported. Low WM-span participants were significantly worse at deciding the acceptability of sentences with sentential complement structures. Additionally, the RSVP condition was more difficult than the whole-sentence condition overall (i.e., lower accuracy on the acceptability judgments). They argued that differences were likely due to the increased memory load and novelty of the RSVP task, but that there was no differential effect of RSVP on garden-path structures and no differential effects of WM on processing. Therefore, while Waters and Caplan did find RSVP was more difficult overall, they also found that this difficulty was not exaggerated when the sentence used required more processing, which was quite unexpected.

Why might RSVP of sentences be so difficult? RSVP is also used in cognitive research to study temporal properties of information processing, such as target detection and attentional blink (e.g., Broadbent & Broadbent, 1987). In attentional blink studies, stimuli are briefly presented for identification with no time lag between stimuli, and the faster the targets are presented, the more poorly they are recognized. Attentional blink research has found that when participants are visually attending to items presented sequentially, correctly identifying one stimulus causes poorer identification for subsequent stimuli occurring within the next 200-500ms (Broadbent & Broadbent, 1987). The attentional blink effect is attributed to having to eliminate previous items from attention while simultaneously introducing new items, leaving resources limited for higher level processes, such as activation of the meaning of the stimulus word. Thus, the method used by Waters and Caplan (1996), with no lag between sentence words, was more like an attentional blink experiment, than like other sentence processing tasks using RSVP (e.g., Hagoort & Brown, 2000; Kaan et al., 2000; Osterhout & Holcomb, 1992).

Pilot Study Predictions

We hypothesized that, compared to whole sentence presentation, RSVP presentation would place an added cognitive burden on readers because they received the words one-at-a-time, and combined them online in memory, as they appeared. Thus, we predicted that comprehension of sentences would suffer when sentences were presented via RSVP. Furthermore, we also predicted that sentence comprehension accuracy and response times would be related to a variety of cognitive tests tapping working memory and executive function. We were particularly interested in the relationship between ambiguous sentence comprehension and executive function and expected that there would be one, based on previous research (Novick, Trueswell & Thompson-Schill, 2005). In order to directly compare whole sentence presentation and RSVP, sentences were presented for the same amount of time in each condition.

Accuracy and response times were collected to comprehension questions that were presented following every sentence in both conditions.

Pilot Study Methods

This study examined the relationship between ambiguous and unambiguous language comprehension using RSVP and whole sentence presentation methods. Sentence comprehension was compared to WM and executive function in neurologically healthy young adult participants. All participants completed a short neuropsychological battery and two sentence comprehension tasks in one two-hour visit.

Pilot Study Participants

Twenty-three healthy undergraduate students from the University of Florida participated. Participants reported no history of acquired brain disorders, attention deficit hyperactivity disorder, developmental learning or reading disability, uncorrected visual impairment, or impaired mobility of the right hand or finger. The participants with brain injury did not receive compensation. All undergraduate volunteers received course credit for their participation.

Pilot Study Neuropsychological Screening

The participants completed commonly used neuropsychological measures. Digit Span-Forward (DSF) (Wechsler, 1997), and Digit Span-Backward (DSB) tests were used to test WM. The Shipley Vocabulary test (Shipley, 1940), and the North American Adult Reading Test (NART; Nelson, 1982) were used to test vocabulary. Trails A and B (Reitan, 1958), and Stroop colors and color words (Stroop, 1935) were used to test executive functions. These commonly used tasks are not described here for the sake of brevity.

A less commonly used working memory task, the Operation Span (O-Span; Conway et al., 2005) was also completed as a complex WM measure. The O-Span task has many variations; the version we used required participants to solve simple mathematical problems and to recall letters (Engle, 2005; Unsworth, Heitz, Schrock & Engle, 2005). This version of the O-Span consisted of showing a series of letters (between 2 and 5 letters long) presented individually on the computer screen for later recall. Prior to the presentation of each letter, participants viewed a simple mathematical operation and responded either 'true' or 'false' to the answer presented on the screen. Finally, a screen was displayed asking the participant to rank the letters in the order they were presented by clicking on them on the computer screen in the correct order. If accuracy on the mathematical operations was less than 85% overall, the recall scores would not have been used for that participant. No participants failed to meet this criterion. This accuracy score was shown to the participant throughout the test. Scores on the cognitive tasks are shown in Table 4-1.

Pilot Study Sentence Comprehension Tasks

Pilot study materials

Half the sentences in each sentence comprehension were ambiguous and the other half were unambiguous. All sentences were between 9 and 11 words long. All sentence stimuli were patterned on the sentences used in Christianson, Hollingworth, Halliwell and Ferreira (2001) to evaluate whether people completed a partial reanalysis of a garden path sentence when ambiguity was encountered in a sentence. The ambiguous sentences were a type of garden-path sentence that led the participant to make an incorrect initial interpretation that needed to be revised, as shown in Table 4-2. Comprehension questions were presented following each sentence. The questions were also similar to those developed by Christianson et al. (2001), which were designed to determine whether or not the sentence was interpreted correctly, even with ambiguity. Half of the questions required a ‘yes’ response and all questions were targeted at the direct object of the first verb in order to test whether the reader correctly resolved the ambiguity. Sentences were divided into two lists of 60 items in order to counterbalance the response type between participants. Accuracy and RTs for comprehension questions were recorded and analyzed. The sentences were presented randomly for each participant using E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Fillers were not used in this pilot study.

Task 1: Whole sentence comprehension

In the Whole Sentence presentation condition, participants read 60 complete sentences and answered a comprehension question about each. Each trial comprised six events. Participants first saw a 1000ms blank screen with a centered fixation point. Sentences were presented in their entirety on a computer screen, using a light colored font on a dark colored background, about a half inch above the fixation point. The sentence remained on the screen for 5000ms. The timing of the sentences reflects a normal reading rate for sentences containing 9-11 words (Hagoort & Brown, 2000). Following sentence presentation, a blank screen with a centered fixation point was presented for 500ms. Next, a yes/no comprehension question appeared slightly below the centered fixation point. After the participant responded using the mouse buttons, a 300ms blank screen appeared. Following that was the message “Press the Yes button for the next sentence.” When the participant pressed the mouse button, a new trial appeared.

Task 2: RSVP sentence comprehension

The sequence of events in RSVP presentation was similar to Whole Sentence presentation with the exception of the method of sentence presentation. During RSVP, total presentation time for each sentence was identical to the timing used in the Whole Sentence Comprehension task (i.e., 5 seconds per sentence), except presentation of sentences was RSVP. Each word was presented slightly above the centered fixation point in a light colored font with a dark colored background on a computer screen. Words were each presented for 300ms followed by a blank screen for 200ms (Kaan et al., 2000). The timing and presentation rate reflect a normal reading rate for young adults (Hagoort & Brown, 2000).

Results

Table 4-3 shows the means and standard deviations for the accuracy and RTs for the sentence comprehension tasks. There was a main effect of ambiguity on accuracy using repeated measures ANOVA, $F(1,22)=6.26$, $p=.020$. Responses to comprehension questions were less accurate after ambiguous sentences than unambiguous sentences, regardless of presentation type. There was also a main effect of sentence presentation type, $F(1,22)=10.46$, $p=.004$. Responses to comprehension questions were less accurate after RSVP than whole sentence presentation. The interaction between ambiguity and presentation type did not reach significance, $F(1,22)=3.740$, $p=.066$, which was likely due to low power.

The repeated measures ANOVA results for RTs for correct responses only found again a main effect of ambiguity, $F(1,22)=8.45$, $p=.008$, with responses to comprehension questions after ambiguous sentences taking longer than those following unambiguous sentences. The main effect of sentence presentation type was not significant, *F(*1,22)=1.658, *p*=.211, but the interaction between ambiguity and presentation type was, *F(*1,22)=8.936, *p*=.007. Unambiguous sentence comprehension responses did not differ between sentence presentation types, *t*(44)=1.156, *p*=.254, but comprehension responses were significantly slower when ambiguous sentences were presented using RSVP than when they were presented as a whole sentence, *t*(44)=2.472, *p*=.017.

Table 4-4 shows the correlations between the sentence comprehension measures and performance on cognitive tasks. Comprehension accuracy of ambiguous (but not unambiguous) sentences in the Whole Sentence condition correlated with one WM and one executive function measure (TrailsB). In contrast, comprehension accuracy in the RSVP condition correlated only with WM measures. Vocabulary scores predicted RTs but not accuracy in both sentence presentation conditions. RTs for comprehension in the Whole Sentence condition with both sentence types correlated with the executive function tasks (Trails B and Stroop), but only RTs to unambiguous sentences in RSVP correlated with executive function.

Pilot Study Discussion and Conclusion

Accuracy was found to vary significantly between ambiguity conditions and presentation conditions, but there was also a marginal interaction suggesting that there might be a significant effect of complexity in the RSVP condition with higher power. RTs also showed a significant main effect of ambiguity and a significant interaction between presentation method and ambiguity. These results are consistent with our prediction in some but not all regards. As predicted, responses to comprehension questions following RSVP were less accurate overall than those following Whole Sentence presentation. However, RSVP only significantly affected RTs to questions following ambiguous sentences in which responses were slowed significantly compared to Whole Sentence presentation. These findings suggest that RSVP exacerbated the effects of local ambiguity on comprehension as also suggested by Lee and Newman (2010). Disambiguating information (that is, the next word) is not immediately available during RSVP unlike during whole sentence presentation. Therefore, understanding sentences presented in RSVP required reliance on WM storage and integration later in the sentence, whereas this information was available much more rapidly during whole sentence presentation.

Regarding the second research question that accuracy and RTs would relate to WM and executive function measures, our prediction was not fully supported. Complex WM correlated with accuracy and RTs in RSVP performance, but only with ambiguous sentences RTs. In contrast, timed executive function measures (Trails, Stroop) correlated strongly with whole sentence comprehension RTs regardless of ambiguity. Correlations between RSVP comprehension RTs and executive function measures were limited and only significant for questions following unambiguous sentences. Given that our intention was to test whether people actually fully reanalyze ambiguous sentences, our findings suggest that many do not fully reanalyze a significant portion of them, especially during RSVP, despite all participants reporting that the task was subjectively easy. Retaining the unintended meaning of the ambiguous sentence may also contribute to reduced accuracy and increased RTs. Furthermore, it is likely that people with poor WM are less likely to fully reanalyze or fully integrate the correct meaning of these sentences. This is consistent with previous research finding that people with lower WM span process ambiguity, and possibly incoming language in general, differently than those with a higher WM span (Swets, Desmet, Hambrick, & Ferreira, 2007). Our expectation of a strong relationship between ambiguity comprehension and EF performance, particularly during RSVP, was not validated.

These findings clearly illustrate that comprehension of sentences presented using RSVP differs from whole sentence presentation. Comprehension was both less accurate and more sensitive to ambiguity in the RSVP condition. Furthermore, the patterns of correlations with cognitive measures differed for the two presentation methods. We expected comprehension of ambiguous sentences to relate strongly to executive function tasks that required inhibitory control, because it is assumed that ambiguity resolution requires inhibition of the initial incorrect interpretation. However, the Stroop task only correlated with sentence comprehension for RTs in the Whole Sentence condition. Therefore, while the current battery of cognitive tasks showed that comprehension in the Whole Sentence condition was highly related to both WM and executive function measures, it was inadequate to explain the pattern of results in RSVP. This finding suggests that there was one or more untested cognitive factor that contributed to comprehension performance in RSVP.

Neuroimaging data supports the notion that an untested cognitive factor may be involved with RSVP comprehension. The effects of syntactic complexity and associated memory processing, as observed via fMRI by Lee and Newman (2010), suggested that there were much larger effects during the processing of probes following complex sentences than during target sentences. They concluded that people may have been reprocessing the target sentence as well as the probe, generating larger brain responses. However, this larger effect was attenuated or absent in the RSVP condition, depending on the brain region, suggesting to Lee and Newman that people may only be processing RSVP sentences shallowly and responding to probe questions using word order information rather than with a deeper understanding of the meaning. This explanation is consistent with our findings of lower accuracy and slower response times to comprehension questions about ambiguous sentences in RSVP relative to Whole Sentence presentation, while there was no difference between RSVP and Whole Sentence conditions for unambiguous sentences.

These results are also consistent with findings that attentional blink effects can be exaggerated by the complexity of the processing required by stimuli (Van der Burg, Brederoo, Nieuwenstein, Theeuwes & Olivers, 2010). Attentional blink processes suggest that attentional processes may limit comprehension of RSVP sentences, even with a blank screen between stimuli. The blank screen was presented for 200ms; thus, each subsequent word would appear at least partially within the 200-500ms window for attentional blink.

A number of limitations were present in this pilot study. First, our cognitive task battery was somewhat limited, as mentioned, and this has been addressed in ongoing studies. Second, RTs were collected for comprehension probe questions which were presented following the target sentence, as in the Lee and Newman (2010) study. Therefore, our RTs reflected a secondary measure of processing time. However, this is a general problem with RSVP studies that typically present stimuli with fixed timing. We also used a fixed timing of 5 seconds for whole sentences to make the tasks as similar as possible for comparison. Participants reported that the whole sentences seemed to stay on the screen for a very long time. Current studies are underway that allow for measurement of individual variability in reading times.

This study provides an important look into how RSVP sentence reading may differ from whole sentence reading. RSVP is widely used in sentence processing research. Accuracy, processing time, and cognitive demands all differ between these presentation methods, and these differences would likely be exacerbated in a cognitively impaired population. Therefore, before examining ambiguous sentences using RSVP, our current study took a step back to use only unambiguous sentences with grammatical errors to elicit the P600.

Table 4-1. Scores on Cognitive Tasks

	Mean	*SD*	N
NART (max 50)	35.30	6.07	23
Shipley (max 40)	32.48	3.78	23
DSF (max 16)	8.30	1.55	23
DSB (max 14)	6.39	1.73	23
O-Span (# correct)	40.42	20.55	19[2]
Trails A (seconds)	69.52	15.49	21[3]
Trails B (seconds)	83.00	21.51	20[3]
Stroop interference score[1]	26.88	9.08	17[4]

[1]Number of X's read in 45 seconds – number of colors named when word and color are incongruent. [2]3 participants were below the accuracy cutoff score and therefore did not complete the task. [3]Participant errors in completing the task were not corrected by the task administrator and the time could therefore not be used. [4]The task administrator did not record the number of X's read in 45 seconds for the first several of the participants that she tested independently instead recording the total time to read the list.

Table 4-2. Sentence Types and Examples

Sentence Types	Examples
Ambiguous	While the man hunts the rabbit runs into the woods.
Unambiguous	While the man hunts, the rabbit runs into the woods.
Comprehension Question	*Did the man hunt the rabbit?*

Table 4-3. Scores on Experimental Sentence Tasks

		Accuracy		RT (ms)	
Presentation	Sentence Type	Mean	*SD*	Mean	*SD*
Whole Sentence	Unambiguous	0.89	0.12	2261	802
	Ambiguous	0.87	0.12	2150	828
RSVP	Unambiguous	0.89	0.09	2532	788
	Ambiguous	0.80	0.13	2864	1111

Table 4-4. Correlations between sentence comprehension performance and cognitive measures

			NART	Shipley	DSF	DSB	O-Span	Trails A	Trails B	Stroop
Accuracy	Whole	Unambiguous	0.031	0.030	0.107	0.297	0.355	-0.075	-0.423	-0.357
		Ambiguous	0.229	0.277	0.290	0.409	.515*	-0.399	-0.580**	-0.279
	RSVP	Unambiguous	0.319	0.089	0.199	0.234	.479*	0.112	-0.335	-0.466
		Ambiguous	0.129	0.095	0.111	.424*	0.353	-0.243	-0.356	-0.284
RTs	Whole	Unambiguous	-0.499*	-.578**	-0.344	-0.272	-0.310	0.281	.624**	.605*
		Ambiguous	-0.352	-.521*	-0.224	-0.219	-0.227	0.388	.663**	.601*
	RSVP	Unambiguous	-0.241	-.572**	-0.127	-0.199	-0.069	0.215	.570**	0.254
		Ambiguous	-0.357	-0.279	-0.466	-0.284	.605*	.601*	0.254	0.115

**p*<.05, ***p*<.01

CHAPTER 5
RESEARCH DESIGN AND METHODS

Overview

This study examined the relationship between language comprehension, executive function and attention in patients with mild-moderate-severe (M/M/S) traumatic brain injury (TBI) and in neurologically healthy control participants. All participants completed a short neuropsychological battery, the Attention Network Task (ANT) and two sentence comprehension tasks in one three-hour visit. One of the sentence comprehension tasks and the ANT were completed while undergoing EEG recording.

Participants

Five M/M/S TBI patients participated in the study. Table 5-1 shows more details for each participant with a history of brain injury. Three of these were undergraduates at the University of Florida. One was an undergraduate at Santa Fe Community College. One was a member of the surrounding community. Four additional TBI patients were recruited for participation in the study from an existing database of previous volunteers and undergraduates from the University of Florida. These four did not meet study criteria due to a history of dyslexia, attention deficit hyperactivity disorder (ADHD) or learning disability. An additional 85 to 100 recruiting calls were placed to members of an existing database of previous volunteers with TBI, but approximately 60 of those were no longer available. The remained declined to participate.

Twenty-six neurologically healthy control participants were also recruited from the Linguistics-Speech, Language, and Hearing Sciences (LIN-SLHS) database and the local community. The participants with brain injury did not receive compensation. All undergraduate volunteers received course credit for their participation. Participants with

TBI were at least six months post-injury and no longer exhibiting post-traumatic amnesia. TBI severity was determined using loss of consciousness duration, post-traumatic amnesia duration, and the lowest post-resuscitation Glasgow Coma Scale (Teasdale & Jennett, 1974) score as reported in medical records, when available.

Any participants with a history of other acquired brain disorders (e.g. seizure disorder, stroke), ADHD, developmental learning or reading disability, or mobility impairment of the right hand or finger were excluded from the study. Participants with uncorrected visual impairments were also excluded. All possible measures were taken to avoid recruiting participants who did not fit study criteria including details in the advertisements, phone call interview, and email confirmation of information. Data from five of the healthy control volunteers were excluded from all analyses. One sustained a concussion between the screening interview and the testing date, one reported having had a seizure disorder as a child after testing started, two tested as having probable chronic depression and anxiety disorders, and testing was not completed with one participant because the computer did not record the EEG properly. Therefore, only the data from 21 control participants were used in the analyses. Table 5-2 shows the demographic information for each group. There were no significant differences between groups on any of the demographic variables using the Mann-Whitney test (p>.05).

Cognitive Testing

Tasks looking at a variety of cognitive constructs were included in a brief neuropsychological battery. Digit Span Forward and Backward (DSF and DSB from the WAIS-III; Wechsler, 1997) were used to test working memory. Shipley Vocabulary (Shipley, 1940) and the North American Adult Reading Test (Nelson, 1982) were used to test vocabulary. The Stroop test (Golden, 1978) were used to test response inhibition and conflict resolution. The Wisconsin Card Sorting Task (Heaton, Chelune, Talley, Kay & Curtiss, 1993) were used to test abstract problem-solving, executive control and set shifting. The Trail Making Test A and B (Trails; Reitan & Wolfson, 1995) were used to test cognitive flexibility and set shifting. The Digit Symbol task (Wechsler, 1997) was used to test processing speed and complex sustained attention. The Controlled Oral Word Association (COWA; Benton & Hamsher, 1989) was used to test verbal fluency. The Beck Depression Inventory (BDI; Beck, 1996) and the State Trait Anxiety Inventory (STAI; Speilberger, Gorusch, Lushene, Vagg, & Jacobs, 1983) were used to screen for depression and anxiety symptoms. Table 5-3 shows the tasks from the neuropsychological battery and the constructs they are intended to test.

Attention Network Task

The ANT was administered to obtain measures of executive attention, orienting attention and alerting attention. Stimuli were presented via E-Prime (Schneider et al., 2002) using programming freely available for research use (Fan, 2002). First, a fixation cross was visible for a duration that varied between 400 and 1600ms. A warning cue was then presented for 100ms as one of four possible cuing conditions: no-cue, center-cue, double-cue and spatial-cue. The target stimuli consisted of rows of five visually presented horizontal black lines, with arrowheads pointing leftward or rightward, against a white background. The target was a leftward or rightward arrowhead at the center and was flanked on either side by two arrows in the same direction (congruent condition), or in the opposite direction (incongruent condition), or by lines (neutral condition). The target remained on the screen until the participant made a response, but not for longer than 1700ms. Participants were asked to identify the direction of the centered target arrow by pressing the left button for the left direction and the right button for the right direction. After the target stimulus disappeared, the fixation cross remained alone on the screen for a period that varied based on the duration of the fixation and RT to the target (3500ms – duration of pre-stimulus fixation – RT). The fixation cross was visible throughout each trial, and participants were asked to focus on the fixation cross throughout the experiment. Different types of attention were assessed by comparing the various conditions. For example, the alerting response was calculated by subtracting the double-cue from the no-cue condition, the orienting response by subtracting the spatial-cue condition from the central-cue condition, and the executive condition by subtracting the congruent flanker from the incongruent flanker condition.

Experimental Sentence Comprehension Tasks

Summary

There were two computerized sentence tasks: a grammaticality judgment task was completed during EEG recording with word-by-word presentation (rapid serial visual presentation: RSVP), and a comprehension question task was completed without EEG recording with whole-sentence presentation.

Both RSVP and whole-sentence tasks were necessary to determine whether sentence comprehension was affected following TBI. RSVP presentation may alter sentence comprehension performance, as demonstrated in our pilot study, because it may be more cognitively taxing. The RSVP task, therefore, was only designed to give limited information about comprehension, and was more intended to provide data about language processing via electrophysiological recording.

Materials

Each of the sentence comprehension tasks used sentences of the types described in Table 5-4. Sentences were based on those used by Osterhout and Nicol (1999). 225 experimental sentences and 225 filler sentences were developed. 150 of each were be used during EEG recording and 75 without EEG recording. The entire set of sentence stimuli is shown in the Appendix.

Each experimental sentence was developed with three possible target verbs as shown in Table 5-4: semantically anomalous, syntactically anomalous and non-anomalous target. Semantic anomalies appeared grammatically appropriate to the sentence but violated selection restrictions. That is, were not paired appropriately with the sentence agent (e.g. ‘the alibi would prevent’ vs. ‘the alibi would consider’). Syntactic anomalies always involved a present participle form of the verb following a modal verb (e.g. ‘the alibi would preventing’). The critical words were matched for frequency (using Kucera & Francis, 1967) and letter length.

Each filler sentence was developed from 1 verb and 2 nouns that were not used in the experimental sentences and that had a frequency in the same average range as those used in the experimental sentences (using Kucera & Francis, 1967). The sentences were all based on the same structure as the example shown in Table 5-4.

Three lists were then made so that no single participant saw a sentence more than once. Each sentence was between 10 and 15 words long (mean=11.5). Each participant saw 50 of each type of sentence with RSVP during EEG recording and 25 of each type of sentence with whole sentence presentation without EEG recording. Presentation of sentences was counterbalanced across participants.

All sentences were presented to participants in random order using E-Prime (Schneider et al., 2002), followed by task questions. Comprehension questions were designed to determine whether the participant interpreted the sentence correctly. Half of the comprehension questions are correctly answered with a ‘yes’. Goodness judgments were elicited when participants saw ‘???’ indicating that they were to press the left button if the sentence just presented was ‘good’ and the right button if it was not. All of the syntactically anomalous sentences were grammatically incorrect (50 total) and two-thirds of the fillers were grammatically incorrect (100 total) so that half of the grammaticality judgments required a ‘yes’ response.

Filler sentences were included in order to avoid learning effects and were developed to be simple active sentences matched in length to the experimental sentences.

Sentence Task 1: Whole Sentence Comprehension

Participants answered a comprehension question following each of 150 total sentences (shown in Table 5-4). Each trial consisted of six events. After a 1000ms blank screen with a centered fixation point, sentences were presented in their entirety above center on a computer screen in a light colored font with a dark background. Sentences were shown for a minimum of 2000ms. After 2000ms, the participant could press any button to continue to the comprehension question. The comprehension question appeared slightly below the center of the screen and required a ‘yes or no’ response using either the left (‘yes’) or right (‘no’) mouse buttons. Following the participant’s response, the message “Press a button for the next sentence” appeared. A new trial began when the participant pressed a button. Accuracy and reaction time (RT) were collected from the comprehension questions for further analysis. This portion of the experiment took approximately 30 minutes.

Sentence Task 2: RSVP Sentence Comprehension with EEG

A second comprehension task was similar to Task 1 except that stimuli were presented word-by-word (using rapid serial visual presentation, or RSVP). It employed 300 novel sentences of the type in Table 5-4 and was administered during EEG recording. After a 1000ms fixation, each word was presented in a light font on a dark background at a variable rate depending on the number of letters in each word using the following equation: (249.9*[16*number of letters of word])-10ms. Each word was followed by 350ms of blank screen. The words were centered on the screen and surrounded by a 2 pixel thick border that was 25% of the size of the screen. A prompt, '???', then appeared in the center of the screen until the participant responded 'yes' that it was grammatical with the left mouse button or 'no' that it was ungrammatical with the right mouse button. Following a response, 'Press any button to continue' appeared below the center point. Three 15-second minimum breaks occurred every 75 sentences. This portion of the experiment took approximately 90 minutes. Figure 5-1 shows an example of the timing of sentence presentation for each sentence task.

Participants were encouraged to focus on comprehending the whole sentence, and each sentence was followed by a comprehension question, half with 'yes' answers. Participants were also instructed to 'stay as relaxed as possible, especially the jaw, face, and eyes'. We explained that muscle movements would make it hard to see the brain waves and that if they needed to blink or yawn, to wait until during the 'press to continue' screen. Accuracy and RT were collected from the grammaticality responses for further analysis.

EEG Procedures

EEG Recording

EEG was recorded from 64 scalp sites, using a geodesical sensor net (see Fig 5-2) and Electrical Geodesics, Inc. (EGI; Eugene, Oregon) amplifier system (20,000 gain, nominal bandpass = .10 -100 Hz). Electrode placements enabled recording vertical and horizontal eye movements reflecting electro-oculographic (EOG) activity. EEG was referenced to Cz and digitized continuously at 250 Hz with a 16-bit analog-to-digital converter. A right posterior electrode approximately two inches behind the right mastoid served as common ground. Electrode impedance was maintained below 70kΩ**.** EEG application took approximately 15-30 minutes depending on how difficult impedances were to reduce.

EEG was processed offline using NetStation Waveform Tools. A 30 Hz lowpass finite impulse reponse (FIR) filter was used with a passband gain of 99.0% (-0.1 dB), a stopband gain of 1% (-40.0 dB), and a roll off of 0.29 Hz. Individual files were segmented into 1700ms windows around each target verb (200ms pre-target; 1500ms post-target) for sentence data. Segments were marked as bad if there were more than 10 bad channels, eye blinks, or eye movements. The bad channel threshold was max-min>100.00 μV over the entire segment with a moving average of 20ms. The eye blink threshold was max-min >100.0 μV with a window size of 1000ms and a moving average of 20 samples. The eye movement threshold was max-min>55.0 μV with a window size of 1700ms for sentence data and a moving average of 20 samples. Bad channels were replaced with data interpolated from the remaining channels. The blink slope threshold (μV /ms) was 14.0. Eye channels were then flattened because they could not be used to extract data as they had already been used to correct for eye movements. Individual, segment averages were calculated from all the segments that were not rejected for each segment category (i.e. syntactic anomaly, semantic anomaly, nonanomalous control). Source files were handled separately and subjects were not averaged together at this stage. The data was digitally re-referenced to an average mastoid reference. Channels marked bad during the artifact correct stage were excluded from the reference. The baseline interval was established as the 200ms preceding each target stimulus. That is, the average of all the samples within the baseline interval was subtracted from every sample in the segment establishing a new zero-voltage value. Files were combined and segments averaged for each group.

EEG Analysis

Individual participant event-related potentials (ERPs) were extracted and averaged together in discrete temporal windows that coincided with the onset of each target stimulus. ERP averages were then calculated for each participant separately for nonanomalous control, semantically anomalous and syntactically anomalous stimuli. Waveforms were visually inspected to confirm the time windows and general waveform shape. Mean amplitude and peak latency were then calculated for each individual during a specified time window. Time windows used for the ERP components examined were as follows: N400: 300-500ms and P600: 500-900ms. These time windows were determined based on expected latencies for the components and on visual inspection of the grand averaged waveforms.

ERP mean amplitudes and latencies were examined with 2-Group (control, TBI) x 3-Stimulus (nonanomalous, semantic anomaly, syntactic anomaly) x 3-Side (left, mid, right) x 2-Anterior/Posterior repeated measures analyses of variance (ANOVAs). Electrode regions were comprised of the following electrodes: left anterior (13, 15, 16, 20), left posterior (22, 24, 25, 28), mid anterior (3, 4, 8, 9, 58), mid posterior (29, 30, 34, 38, 42), right anterior (56, 57, 61, 62), and right posterior (46, 47, 50, 52).

Table 5-1. Participants with closed-head injury

Age	Sex	Months post injury	Etiology	Injury details	LOC[1]	PTA[2]	Initial GCS[3]
19	F	44	MVA[4]	CT scan revealed brainstem/mid-brain contusions and probable diffuse axonal injury; Left skull base fracture; Right frontal ventriculostomy; 1 month outpatient speech therapy	"uncertain" according to medical records	Yes	3-4 at scene; 7 at ER
24	M	132	Blow to the head with baseball bat at age 13	No hospitalization; Symptoms of concussion: LOC, nauseous, fatigued, dizzy	10-15 min	No	n/a
55	F	154	MVA	Seizures, EEG revealed diffuse abnormalities, CT revealed small right frontal contusion; Approx. 4 years of speech therapy	10 days	Yes	4
21	M	24	Fall	No hospitalization; symptoms of concussion: fatigue, vomiting, dizzy, light headed, confused for 1 day	<1 min	Yes	n/a
19	F	45	MVA	Left frontal craniotomy; 4 months outpatient rehab including speech therapy	5 days	Yes	Not reported

[1]LOC: Loss of consciousness; [2]PTA: Post traumatic amnesia; [3]GCS: Glasgow Coma Score; [4]MVA: Motor vehicle accident

Table 5-2. Demographic averages*

		Control	TBI
	Age	21.9	27.6
	Gender	5 M, 16 F	2 M, 3 F
	Dominant Hand	17 R, 3 L, 1 mixed	4 R, 0 L, 1 mixed
Years of Education	Participant	14.2	14.5
	Mother	15.9	16.5
	Father	16.6	14
Occupation code	Participant	11	7.2
	Mother	3	4
	Father	3.7	1.25
	High school GPA	3.6	3.4
	College GPA	3.4	3.5

***No significant differences between groups *p*>.05

Table 5-3. Neuropsychological battery

Tasks	Constructs Assessed
Digit Span-Forward (Weschler Memory Scale)	Working Memory
Digit Span-Backward (Weschler Memory Scale)	Working Memory
Shipley Vocabulary Test	Vocabulary
North American Adult Reading Test	Vocabulary, Estimated premorbid intelligence
Stroop Test	Response inhibition, Conflict resolution
Wisconsin Card Sorting Task (WCST)	Executive Control, Set shifting
Trail-Making Test	Set shifting , Visual tracking, Processing speed
Digit Symbol Task	Processing speed, attention
Controlled Oral Word Association (COWA)	Verbal fluency
Beck Depression Inventory (BDI)	Depression Screening
State Trait Anxiety Inventory (STAI)	Anxiety Screening

Table 5-4. Sample sentences[a] from both sentence tasks

Sentence Types	Samples	Comprehension 'Yes' Response	Questions[b] 'No Response
Anomalous Semantic 25 Task 1, 50 Task 2	This test of reasoning might **hate** to discriminate among students.	Will the test possibly hate to discriminate?	Will the test definitely hate to discriminate?
Syntactic 25 Task 1, 50 Task 2	This test of reasoning might **failing** to discriminate among students.	Will the test possibly fail to discriminate?	Will the test definitely fail to discriminate?
Non-anomalous Control 25 Task 1, 50 Task 2	This test of reasoning might **fail** to discriminate among students.	Will the test possibly fail to discriminate?	Will the test definitely fail to discriminate?
Filler 75 Task 1, 150 Task 2	The cow walked through pasture to eat the green grass near the fence.	Did the cow walk through the pasture?	Did the cow run through the pasture?

[a]The words in bold in each sentence represent the target words used in the analysis of ERPs. There are 75 experimental and 75 filler sentences in Task 1 (150 total), and there are 150 experimental and 150 filler sentences in Task 2 (300 total).
[b]Comprehension questions are only used with the Whole Sentence Comprehension Task.

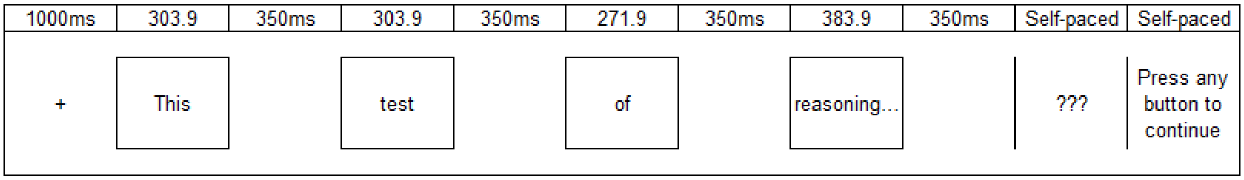


Figure 5-1. RSVP sentence presentation timing example. Word durations were determined by the number of letters in the word using the equation: (249.9*[16*number of letters of word])-10ms.

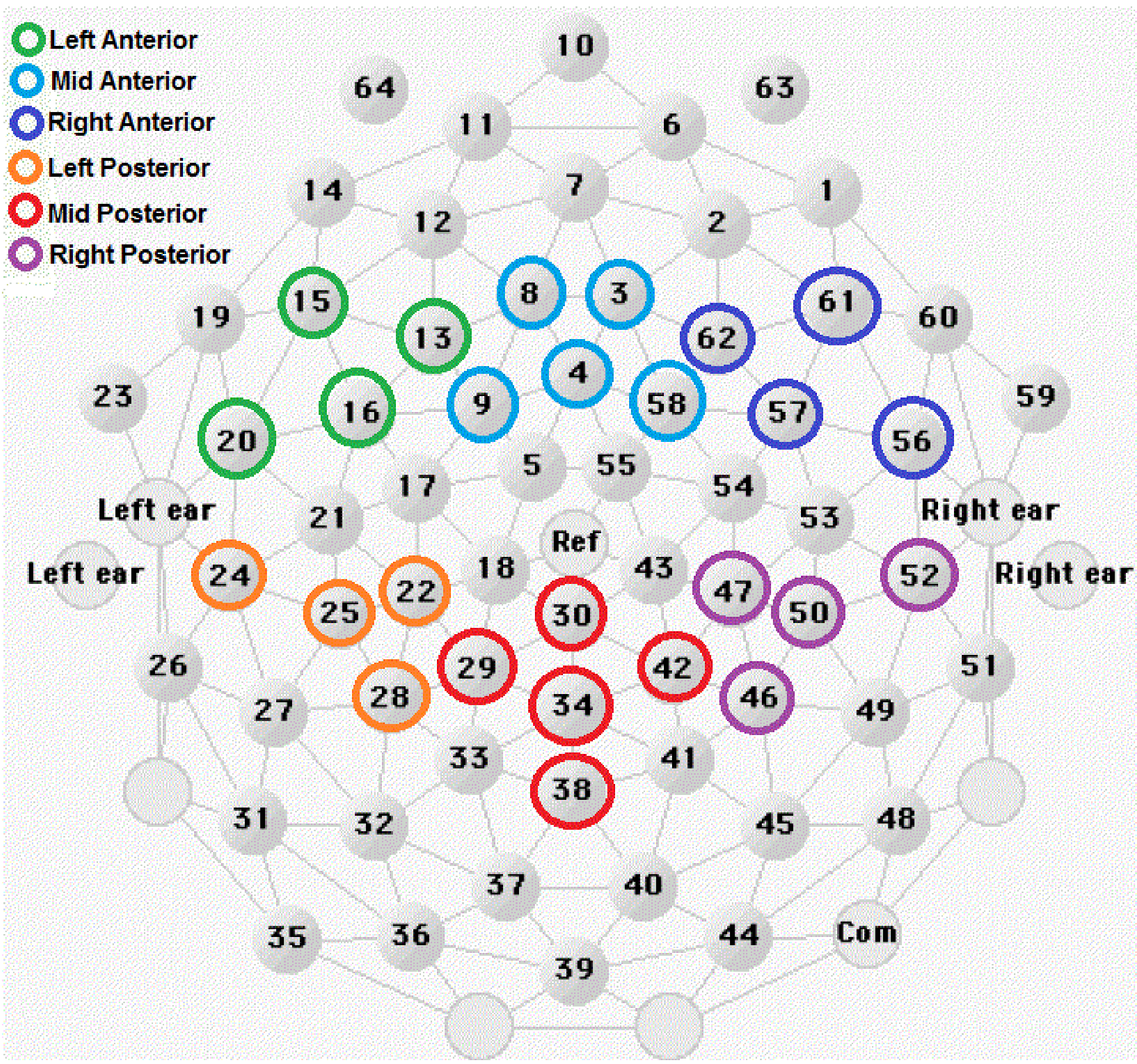


Figure 5-2. Montage used for EEG analyses, showing the 64-channel arrangement of the geodesic sensor net (EGI; Eugene, Oregon). The 6 regions of interest used in sentence analyses are highlighted.

CHAPTER 6
RESULTS

Overview

The data from 21 adults without traumatic brain injury (TBI) and 5 adults with TBI were analyzed. Behavioral measure results will be reported first followed by electrophysiological results.

Anxiety and Depression Screening

There were no statistical differences (based on independent samples t-tests) between groups on the anxiety and depression screening tools. Table 6-1 shows the scores for each group.

Neuropsychological Battery

There were significant group differences only on the digit span backwards (DSB) task (p<.05) and the digit symbol task (p<.05) using the Mann-Whitney non-parametric test. There were no other significant group differences on the cognitive tasks (p>.05). Table 6-2 shows scores for each group on all of the tasks from the neuropsychological battery. The Wisconsin Card Sorting Task (WCST) is shown separately in Table 6-3.

There were no significant differences between groups on any of the WCST measures. Table 6-3 shows six of the raw WCST scores for each group. Further, there were five control participants that performed poorly on the task as can be seen in the scatterplot in Figure 6-1. These five participants made incorrect responses at a rate of between 30% and 60%, and only 25% to 60% of their answers indicated that had an understanding of the sorting task.

ANT

Alerting, orienting and attentional control scores were calculated based on recommendations from Fan and colleagues (2002). The alerting score was calculated by subtracting the mean RT of the double-cue from the mean RT of the no-cue conditions. The orienting score was calculated by subtracting the mean RT of the spatial cue from the mean RT of the center cue conditions. The attentional control (or conflict) score was calculated by subtracting the mean RT of all congruent flanking conditions from the mean RT of incongruent flanking conditions. There were no significant differences on any of the calculated scores between groups using the Mann-Whitney non-parametric test ($p>.05$). Table 6-4 shows the scores for the different conditions of the ANT task for each group.

Whole Sentence Comprehension

Accuracy and RTs to comprehension questions following whole sentences were analyzed in separate repeated measures analyses of variances (ANOVAs) using Greenhouse-Geisser corrections. Any RTs under 200ms were rejected as were the RTs of any inaccurate responses. Table 6-5 shows the means for whole sentence comprehension measures for each group.

There were no significant effects of anomaly type, $F(1.57,26.68)=1.38$, $p=.265$, or group, $F(1,17)=.006$,$p=.394$, on accuracy. However, there was a significant main effect of anomaly type, $F(1.16,19.64)=5.90$, $p=.021$, but not group, $F(1,17)=.801$, $p=.383$, on RTs. The interaction between anomaly type and group was close but not significant using the Greenhouse-Geisser correction, $F(1.16,19.64)=3.880$, $p=.058$. The non-corrected data was significant ($p=.030$), but the correction was needed because sphericity could not be assumed (Mauchly's W=.269, Approx. Chi-Square=21.006, *p*<.001). Post hoc pairwise comparisons of RT using Bonferroni adjustments revealed that participants were significantly slower to respond to comprehension questions about semantically anomalous sentences than to nonanomalous control sentence RTs ($p<.001$) and slower to syntactically anomalous than nonanomalous control sentence RTs ($p=.025$). The difference between semantically and syntactically anomalous sentence RTs was not significant ($p=.734$).

There was a significant main effect of anomaly type on sentence reading time, $F(1.92,24.94)=9.32$, $p=.001$. There was not a significant main effect of group, $F(1,13)=.663$, $p=.430$, or a significant interaction between anomaly type and group, $F(1.92,24.94)=1.12$, $p=.339$. Post hoc pairwise comparisons using Bonferroni correction revealed no significant differences between syntactically and semantically anomalous sentence reading times combined across groups ($p>.05$), but syntactically anomalous sentences were read at a significantly slower rate than nonanomalous control sentences ($p=.014$) and semantically anomalous sentences were read at a significantly slower rate than nonanomalous control sentences ($p=.006$).

RSVP Sentence Judgment

Accuracy and RTs were analyzed in separate repeated measures ANOVAs. Accurate responses only were used in calculating RTs. The 200ms criteria used in the whole sentence analysis was not used because the decision about the goodness of the sentence could have been made before the prompt appeared. Table 6-6 shows the means for the RSVP sentence judgment measures for each group.

There was a significant main effect of anomaly type on accuracy, $F(1.04,24.95)=36.47$, $p<.001$. Nonanomalous and syntactic anomaly accuracy did not significantly differ ($p=.530$), but participants were significantly less accurate on semantic anomalies (both $p<.001$). There was also a significant main effect of group, $F(1,24)=6.078, p=.021$, on accuracy of RSVP sentence goodness judgments with the TBI group being significantly less accurate ($p=.021$). The interaction between anomaly type and group approached but did not reach significance using the Greenhouse-Geisser correction, $F(1.04,24.95)=3.68$, $p=.065$. The non-corrected F value was significant ($p=.033$), but the correction was used because sphericity could not be assumed (Mauchly's W=.076, Approx. Chi-Square=59.181, $p<.001$). As can be seen in Table 6-6, the TBI group was disproportionally less accurate than the control group on RSVP semantic anomalies, though the interaction did not reach significance. The control group's accuracy on RSVP semantic anomalies was not significantly different from chance based on a one-sample *t*-test (mean=.59, $t=1.15$, $p=.264$), but the TBI group's accuracy was significantly below chance (mean=.22, $t=-4.53$, $p<.01$).

There was a significant main effect of anomaly type, $F(1.13,27.01)=12.50$, $p=.001$, on RTs to goodness judgments of sentences presented RSVP. RTs to semantic anomalies were significantly slower than to syntactic anomalies ($p=.003$) and to nonanomalous controls ($p=.019$). RTs to syntactic anomalies were significantly faster than to nonanomalous controls ($p=.001$). There was no significant effect of group, $F(1,24)=.616$, $p=.440$, or significant interaction between anomaly type and group, $F(1.13,27.01)=.457$, $p=.527$.

Correlations among Sentence Measures

Bivariate Pearson's correlations were calculated for sentence and cognitive task data for the control group. As mentioned, there were significant effects of group on sentence data, but for the TBI group, there was only one significant correlation among sentence measures, between whole sentence accuracy on semantic anomalies and RSVP accuracy on nonanomalous control sentences (r=.976, p<.01).

Correlations among sentence measures for the control group is shown in table 6-7. Semantically anomalous RSVP sentence judgment accuracy correlated with all whole sentence RTs and reading times (rs between -.450 and -.728, p<.05) and with whole sentence comprehension accuracy for only semantic anomalies (r=.421, p<.05). Further, RSVP sentence judgment accuracy for nonanomalous controls correlated with all whole-sentence accuracy, RTs and reading times (rs between -.452 and -.760, p<.05). However, none of the RSVP sentence judgment accuracy on syntactic anomalies correlated with any of the whole sentence measures.

RSVP sentence judgment RTs correlated only slightly less regularly with the whole sentence task accuracy, RT and reading time measures, as shown in Table 6-7. RSVP semantic anomaly and nonanomalous control RTs correlated with whole syntactic anomalous sentence comprehension accuracy (r=-.422, p<.05; r=-.698, p<.05). All RSVP sentence judgment RTs correlated with all whole sentence comprehension RTs (rs between .414 and .696, p<.05) except between RSVP semantic anomaly judgment RT and whole syntactic comprehension RT (r=.391, p>.05). All RSVP judgment RTs correlated with all whole sentence self-paced reading times as well (rs between .458 and .747, p<.05).

Correlations between Sentence Measures and Neuropsychological Measures

Bivariate Pearson's correlations were calculated for sentence and cognitive task data using combined groups. The data for the groups was combined because there were only significant differences between groups on the DSB and the accuracy of RSVP sentence judgments. WCST is not shown because there were no significant correlations between any of the WCST measures and the sentence measures (all $p > .05$) despite removal of the five outlying control cases. FAS fluency, Animal fluency, and the Stroop interference score correlations are also not shown because they did not significantly correlate with any of the sentence measures (all $p > .05$).

As shown in Table 6-8, there were several significant correlations between accuracy of sentence comprehension and cognitive scores. In the whole-sentence presentation task, comprehension of semantically anomalous sentences correlated with the Digit Symbol task ($r = -.540$, $p < .05$), a measure of processing speed. In addition, comprehension of syntactically anomalous sentences correlated with the Digit Symbol task ($r = -.425$, $p < .05$) and the Trails Difference score ($r = -.473$, $p < .05$), a measure of set shifting or cognitive control. Within the RSVP presentation task, sentence goodness judgments nonanomalous sentences correlated with the BDI ($r = -.421$, $p < .05$), NART ($r = -.398$, $p < .05$), DSF ($r = .457$, $p < .05$), DSB ($r = .546$, $p < .01$) and Digit Symbols tasks ($r = -.471$, $p < .05$). In contrast, RSVP sentence goodness judgments for semantically anomalous sentences correlated only with the DSB ($r = .489$, $p < .05$), a measure of working memory, while judgments of syntactically anomalous sentences correlated with the Shipley Vocabulary task ($r = .503$, $p < .01$).

A scatterplot for semantically anomalous sentence judgment accuracy versus DSB performance is shown in Figure 6-2. A bimodal distribution of performance was revealed based on judgment accuracy performance. One group that was accurate at a mean of .8 or above and another that was .4 or below. All of the participants with TBI performed in the lower performing group.

Regarding whole sentence comprehension task RTs, RTs for semantically anomalous sentences correlated with DSF (r=-.520, p<.05) and DSB (r=-.498, p<.05); people with greater memory spans responded faster. Similarly, RTs for nonanomalous sentences also correlated with DSF (r=-.508, p<.05). RSVP sentence judgment times for syntactically anomalous sentences correlated significantly with the BDI (r=.598, p<.01), STAI-State (r=.455, p<.05) and NART (r=.511, p<.01) and for nonanomalous sentences and the Digit Symbols task (r=.392, p<.05). There were no significant correlations between RSVP judgment times for semantically anomalous sentences and any cognitive measures (p>.05).

For whole sentence self-paced reading times, there were significant correlations between the BDI and semantically (r=.641, p<.05), syntactically (r=.766, p<.05) and nonanomalous (r=.560, p<.05) sentences; people with a higher number of self reported depression symptoms took longer to read the sentences. Reading time for syntactically anomalous sentences was also significantly correlated with STAI-Trait score (r=.492, p<.05). There were also significant correlations between syntactically anomalous and nonanomalous control sentence reading times and DSF (r=-.550 and -.545, p<.05) and between reading time and the DSB (rs between -.468 and -.669, p<.05). Reading times for semantically anomalous and nonanomalous controls were significantly correlated with the Trails difference score (r=.410 and .448, p<.05). Table 6-8 shows the results of the correlational analysis.

There were also significant correlations between whole sentence comprehension accuracy for syntactically anomalous sentences and the Orienting score from the ANT (r=-.529, p<.05) and between RSVP sentence comprehension accuracy for syntactically anomalous sentences and the Control score from the ANT (r=.458, p<.05). These scores are not included in Table 6-8.

Event-Related Potential (ERP) Data

Nonanomalous stimuli waveforms contained an average of 32 (*SD* 15.2) trials, semantic anomaly stimuli waveforms contained an average of 37 (*SD* 17.3) trials, and syntactic anomaly stimuli waveforms contained an average of 28 (*SD* 19.1) trials. A 2-Group x 3-Stimulus ANOVA did not reveal any significant group or stimuli differences in the number of trials per waveform. Target word locked ERP waveforms averaged across participants from the sentence task are shown in Figures 6-3 and 6-4.

Visual inspection of the grand averaged waveforms confirmed the specified time windows for the N400 and P600 components. Visual inspection also revealed a difference in polarity between the control and TBI groups for certain regions of interest. It is most noticeable in the Left Posterior region between groups with the syntactic anomaly response having a large positive effect in the control group, but a shorter negative going response in the TBI group. Mean ERP amplitude and latency data are shown in Tables 6-7 through 6-10.

The left posterior negative polarity observed for the syntactic anomalies in the grand averaged TBI waveform in the 500-900ms window held true across the individual waveforms for participant number 602, 604 and 605, but participants 601 and 603 showed the more expected pattern of more positive going waveforms for that time window. There was no obvious qualitative association to any differences in TBI severity or behavioral scores.

N400 Component

Separate 2-Group x 3-Stimulus x 3-Side (Left, Mid, Right) x 2-Anterior/Posterior repeated measures ANOVAs using Huynh-Feldt corrections of N400 amplitude and latency revealed only a single significant effect, as shown in Table 6-13. There was a significant 3-way interaction between side, anterior/posterior and group effect on amplitude $F(2.726,68.155)=3.63, p=.034, \eta^2=.13$. Anterior and posterior electrodes were similar for left and mid electrode regions in the control group, but the amplitude was higher for the right posterior electrode than for the right anterior electrode. In contrast, the TBI group had higher amplitudes at left- and right-anterior than posterior regions, and mid-anterior and posterior regions were similar. The significant interaction is not depicted in a figure because the range of means was extremely limited (between -4.16E-17 and 5.26E-18). The mean amplitudes and latencies for the N400 measures are shown in Tables 6-9 and 6-10. Figures 6-5 and 6-6 show the mean amplitude and latency data for the N400 graphically.

P600 Component

A 2-Group x 3-Stimulus x 3-Side (Left, Mid, Right) x 2-Anterior/Posterior repeated measures ANOVA for P600 mean amplitudes, summarized in Table 6-14, revealed no significant main effects of Group, Stimulus, Side or Anterior/Posterior. However, there were several significant interactions. Stimulus interacted significantly with Side, $F(4,100)=2.58$, $p=.04$, $\eta^2=.09$, but there was also a 3-way interaction between Stimulus, Side and Group, $F(4,100)=3.07$, $p=.02$, $\eta^2=.11$: the control group showed larger amplitudes to syntactically anomalous targets across all three sides whereas the TBI group showed lower amplitudes for syntactically anomalous targets only for left regions and for semantically anomalous targets only for right regions, as shown in Figure 6-9.

The control group also showed smaller amplitudes for mid regions for nonanomalous and semantically anomalous targets than for the left or right regions. Anterior regions showed a linear trend decreasing amplitude from nonanomalous to semantic to syntactic anomalies, but posterior regions showed a quadratic trend with syntactic anomalies having larger amplitude than semantically anomalous and nonanomalous sentences. This led to a significant interaction between Stimuli and Anterior/Posterior, $F(4,100)=10.99$, $p<.01$, $\eta^2=.31$, and is illustrated in Figure 6-10. Finally, there was a significant interaction between Group, Side and Anterior/Posterior, $F(1.981,49.525)=3.97$, $p=.03$, $\eta^2=.14$, such that anterior sites generally showed the highest amplitudes on the right side in the control group and in the mid region in the TBI group, and the posterior sites showed the highest amplitudes in the left region in both groups, as shown in Figure 6-11. Table 6-11 and Figure 6-5 summarize the mean P600 amplitudes.

A 2-Group x 3-Stimulus x 3-Side (Left, Mid, Right) x 2-Anterior/Posterior repeated measures ANOVA for P600 mean latencies, as summarized in Table 6-14, revealed a significant main effect of Group, $F(1,25)=4.09$, $p=.05$, $\eta^2=.14$, with the TBI group having a later peak latency and a main effect of Side, $F(1.35,33.64)=7.21$, $p=.01$, $\eta^2=.22$, such that the mid and right side regions had a later peak latency than the left side. The TBI group's latency was about the same across all three sides, but the control group had a later peak latency on the mid and right side than on the left side, reflected by an interaction that did not quite reach significance between Group and Side, $F(1.35,33.64)=3.57$, $p=.06$, $\eta^2=.13$, that can be seen in Figure 6-12. Nonanomalous stimuli had a later latency across anterior than posterior regions while syntactic anomalies showed the opposite effect, which is reflected in a significant interaction between Stimuli and Anterior/Posterior, $F(1.89,47.18)=6.63$, $p<.01$, $\eta^2=.21$, as shown in Figure 6-13. Table 6-12 and Figure 6-8 summarize the peak P600 latencies.

Table 6-1. Anxiety and Depression Screening Mean Scores by Group.

	Control Group				TBI Group			
	Mean	Range	*SD*	N	Mean	Range	*SD*	N
BDI	4.33	0-14[1]	3.44	21	4.40	2-10	3.21	5
STAI-State	27.38	21-41	5.59	21	24.00	23-26	1.23	5
STAI-Trait	33.00	22-41	4.83	21	30.40	26-33	2.70	5

[1]We referred three participants to counseling services for depression screening scores over 9.

Table 6-2. Neuropsychological Battery Mean Scores by Group.

	Control Group			TBI Group		
	Mean	*SD*	N	Mean	*SD*	N
NART errors (max 40)	15.86	4.49	21	18.80	3.56	5
Shipley Vocabulary Test (max 40)	33.24	3.46	21	33.00	4.848	5
DSF (max 16)	11.67	2.24	21	11.60	1.342	5
DSB (max 14)*	8.81*	2.48	21	6.00*	1.23	5
FAS Fluency (COWA)	42.48	7.90	21	43.20	7.50	5
Animals Fluency (COWA)	23.10	5.97	21	23.60	4.39	5
Trails difference time (seconds)	25.22	9.57	21	27.62	9.73	5
Stroop interference score[1]	20.05	7.42	21	19.20	12.657	5
Digit Symbol score (seconds)*	118.75*	18.33	21	154.57*	31.32	5

*****$p<.05$; [1]Number of X's read in 45 seconds – number of colors named when word and color are incongruent.

Table 6-3. Wisconsin Card Sorting Task Mean Scores by Group.

	Control Group			TBI Group		
	Mean	*SD*	N	Mean	*SD*	N
Errors (% of total responses)	22.36	16.16	21	14.57	.99	5
Perseverative responses (% of total responses)	12.59	10.48	21	7.67	2.68	5
Responses that demonstrated correct conceptualization of the task (% of total responses)	74.62	21.64	21	83.08	2.42	5
Categories completed (max 6)	5.33	1.43	21	6.00	.00	5
Number of failures to maintain set	.62	.87	21	.60	.89	5
Learning to learn score[1]	-5.33	10.25	21	-1.49	1.12	5

[1]Average change in percent errors from 1 category to the next is meant to demonstrate average change in conceptual efficiency. A more positive score indicates improved efficiency.

Table 6-4. ANT Mean Scores by Group.

	Control Group			TBI Group		
	Mean	*SD*	N	Mean	*SD*	N
Alerting	45.22	33.61	20	62.59	27.20	5
Orienting	113.32	40.61	20	129.95	52.46	5
Control	47.14	25.33	20	68.61	49.06	5

Table 6-5. Whole Sentence Comprehension Mean Scores by Group.

		Control Group			TBI Group		
		Mean	*SD*	N	Mean	*SD*	N
Accuracy	Overall	.94	.05	21	.92	.08	5
	Semantic Anomalies	.93	.07	21	.90	.10	5
	Syntactic Anomalies	.93	.06	21	.90	.09	5
	Nonanomalous	.95	.04	21	.94	.08	5
RT to Questions (ms)*	Overall	2061	701	21	2376	727	5
	Semantic Anomalies	2164	694	21	2462	494	5
	Syntactic Anomalies	2152	837	21	2792	1171	5
	Nonanomalous	2083	647	21	2130	476	5
Self Paced Reading Time (ms)*	Overall	4263	1726	21	4961	1145	5
	Semantic Anomalies	4615	1970	21	5218	1175	5
	Syntactic Anomalies	4650	1875	21	5180	1533	5
	Nonanomalous	3763	1449	21	4774	1116	5

*p<.05 for main effects using repeated measures ANOVA

Table 6-6. RSVP Sentence Judgment Mean Scores by Group.

		Control Group			TBI Group		
		Mean	*SD*	N	Mean	*SD*	N
Accuracy*	Overall	.83	.28	21	.68	.35	5
	Experimental Semantic Anomalies	.59	.37	21	.22	.14	5
	Syntactic Anomalies	.94	.06	21	.90	.12	5
	Nonanomalous Controls	.97	.04	21	.92	.05	5
RT to Sentence Judgment*	Overall	792.82	632.75	21	974.74	582.92	5
	Semantic Anomalies	1143.16	928.73	21	1397.98	677.62	5
	Syntactic Anomalies	542.42	214.95	21	564.71	218.84	5
	Nonanomalous Controls	692.88	356.70	21	961.51	498.07	5

*p<.05 for main effects using repeated measures ANOVAs

Table 6-7. Correlations between RSVP Sentence Judgment, Whole Sentence Comprehension Performance and Self-Paced Reading Time for Control Participants

		RSVP Accuracy			RSVP RTs		
		Semantic	Syntactic	Nonanom	Semantic	Syntactic	Nonanom
Whole Sentence Accuracy	Semantic	0.421*	0.395	0.795**	0.087	-0.291	-0.231
	Syntactic	-0.018	0.227	0.452*	-0.422*	-0.404	-0.698**
	Nonanom	0.053	0.22	0.485*	-0.087	-0.235	-0.294
Whole Sentence Comprehension Question RTs	Semantic	-.566*	0.097	-0.605*	0.557*	0.414*	0.681**
	Syntactic	-.728**	0.179	-0.695**	0.391	0.449*	0.606*
	Nonanom	-.657*	0.186	-0.760**	0.657*	0.688**	0.696**
Whole Sentence Reading Time	Semantic	-.535*	-0.147	-0.685**	0.576*	0.670**	0.611*
	Syntactic	-.450*	-0.257	-0.750**	0.594*	0.747**	0.667**
	Nonanom	-.540*	-0.253	-0.757**	0.458*	0.551*	0.550*
RSVP Accuracy	Semantic	1	-0.15	0.743**	-0.203	-0.209	-0.233
	Syntactic	-0.15	1	0.541*	0.061	-0.405	-0.078
	Nonanom	0.743**	0.541*	1	-0.233	-0.514*	-0.460*
RSVP Judgment RTs	Semantic	-0.203	0.061	-0.233	1	0.692**	0.948**
	Syntactic	-0.209	-0.405	-0.514*	0.692**	1	0.785**
	Nonanom	-0.233	-0.078	-0.460*	0.948**	0.785**	1

*p<.05, *p<.01

Table 6-8. Correlations between Sentence Performance and Neuropsychological Battery Performance

		BDI	STAI-State	STAI-Trait	Shipley	NART Errors	DSF	DSB	Digit Symbol	Trails difference
Whole Sentence Accuracy	Semantic	-0.217	0.106	-0.113	0.295	-0.175	0.207	0.358	-.540*	-0.247
	Syntactic	-0.351	-0.027	-0.093	0.107	-0.06	0.079	0.309	-.425*	-.473*
	Nonanom	-0.332	0.112	-0.193	0.052	0.231	0.18	0.233	-0.232	0.068
Whole Sentence Comprehension Question RTs	Semantic	0.343	-0.046	0.339	-0.045	0.197	-.520*	-.498*	0.304	0.371
	Syntactic	0.288	-0.056	0.189	0.059	0.3	-0.24	-0.342	0.306	0.242
	Nonanom	0.404	0.086	0.342	-0.069	0.28	-.508*	-0.381	0.159	0.351
Whole Sentence Reading Time	Semantic	.641*	0.038	0.373	-0.337	0.258	-0.501*	-.468*	0.129	.410*
	Syntactic	.766**	0.145	.492*	-0.363	0.314	-.550*	-.488*	0.185	0.386
	Nonanom	.560*	-0.08	0.292	-0.378	0.243	-.545*	-.669**	0.364	.448*
RSVP Accuracy	Semantic	-0.163	-0.034	0.212	-0.035	-0.123	0.123	.489*	-0.238	-0.213
	Syntactic	-0.221	0.014	-0.023	.503**	-0.323	0.077	0.199	-0.243	-0.377
	Nonanom	-.421*	-0.012	-0.079	0.288	-.398*	.457*	.546**	-.471*	-0.284
RSVP Judgment RTs	Semantic	0.248	0.3	0.206	0.168	0.049	-0.306	-0.317	0.121	0.049
	Syntactic	.598**	.455*	0.35	-0.277	.511**	-0.313	-0.184	0.038	0.161
	Nonanom	0.304	0.224	0.166	0.084	0.245	-0.262	-0.293	.392*	0.215

**p*<.05, **p*<.01

Table 6-9. Mean amplitudes (μV) for the N400 component (300-500ms window) for each stimulus type and region.

		Nonanomalous				Semantic Anomaly				Syntactic Anomaly			
Group	Region	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
N400 Control	Left Ant	0.51	2.70	-3.87	7.21	0.31	1.91	-4.97	2.76	0.41	2.80	-6.84	6.25
	Left Post	0.47	1.95	-3.14	6.81	0.13	1.58	-4.57	3.29	0.72	2.21	-2.75	7.79
	Mid Ant	-0.21	2.80	-5.30	7.25	-0.37	2.25	-7.07	4.17	0.11	3.48	-5.07	10.22
	Mid Post	-0.91	2.16	-3.49	6.77	-1.04	1.73	-5.60	2.97	-0.39	2.73	-3.80	6.65
	Right Ant	0.50	2.63	-3.01	6.97	0.52	2.13	-4.41	4.29	0.13	3.64	-5.42	9.30
	Right Post	-0.51	1.47	-3.09	2.45	-0.56	1.72	-4.69	3.53	-0.31	2.05	-3.96	4.81
N400 TBI	Left Ant	0.22	1.73	-2.58	1.95	-0.15	2.69	-4.10	2.91	-0.99	3.52	-5.92	3.44
	Left Post	0.57	1.51	-1.47	2.34	-0.39	1.15	-1.88	0.90	-0.11	1.22	-1.34	1.94
	Mid Ant	-0.04	2.27	-3.61	2.00	-1.18	4.28	-7.04	3.47	-0.81	2.81	-4.66	3.09
	Mid Post	0.45	1.29	-1.08	2.33	-0.29	1.24	-1.78	1.37	0.49	1.63	-1.64	2.20
	Right Ant	-0.31	1.43	-2.47	1.16	-1.46	3.36	-6.77	1.60	-0.70	2.16	-3.60	2.48
	Right Post	0.61	1.05	-0.57	1.82	-0.55	1.32	-2.18	0.78	0.96	1.16	-0.47	2.48

Table 6-10. Peak latencies (ms) for the N400 component (300-500ms window) for each stimulus type and region.

		Nonanomalous				Semantic Anomaly				Syntactic Anomaly			
Group	Region	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
N400 Control	Left Ant	417.68	67.35	300.00	496.00	397.50	68.19	301.00	493.00	370.41	43.52	306.00	455.00
	Left Post	403.73	57.43	319.00	493.00	378.23	50.25	304.00	490.00	383.45	28.77	333.00	434.00
	Mid Ant	404.29	54.95	317.60	496.00	412.73	65.09	301.60	496.00	389.64	47.81	304.80	495.20
	Mid Post	400.29	49.33	301.60	471.20	393.96	40.43	318.40	467.20	392.91	33.81	328.00	467.20
	Right Ant	395.27	59.87	300.00	494.00	416.55	54.83	300.00	496.00	393.36	41.37	305.00	451.00
	Right Post	404.00	42.01	317.00	484.00	409.77	34.55	358.00	459.00	409.23	37.55	339.00	491.00
N400 TBI	Left Ant	368.40	21.49	337.00	395.00	388.20	34.75	330.00	417.00	383.40	26.01	343.00	404.00
	Left Post	390.20	16.89	372.00	410.00	394.60	7.99	384.00	405.00	390.40	48.58	304.00	419.00
	Mid Ant	386.88	56.02	318.40	449.60	395.68	44.10	317.60	424.00	408.00	19.17	378.40	429.60
	Mid Post	413.12	42.16	360.80	455.20	419.52	24.93	395.20	459.20	375.68	24.59	350.40	408.00
	Right Ant	399.40	46.75	347.00	441.00	405.40	41.11	351.00	459.00	381.60	31.97	328.00	405.00
	Right Post	407.80	58.53	334.00	458.00	423.80	19.55	400.00	446.00	398.00	49.87	331.00	448.00

Table 6-11. Mean amplitudes (μV) for the P600 component (500-900ms window) for each stimulus type and region.

		Nonanomalous				Semantic Anomaly				Syntactic Anomaly			
Group	Region	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
P600 Control	Left Ant	0.78	2.45	-3.79	6.62	0.57	1.88	-3.07	3.91	0.62	3.25	-5.73	10.56
	Left Post	0.67	1.82	-2.56	6.41	0.50	1.40	-2.49	3.91	1.65	2.47	-1.67	10.82
	Mid Ant	0.54	2.19	-2.96	7.42	0.44	1.92	-3.77	3.43	0.86	3.59	-4.49	13.79
	Mid Post	0.03	1.97	-2.94	7.14	-0.09	1.58	-3.15	2.85	1.86	2.55	-1.34	10.51
	Right Ant	1.23	2.26	-2.10	7.33	1.23	1.89	-3.54	5.24	1.23	3.74	-5.79	13.22
	Right Post	0.12	1.45	-2.85	2.92	0.35	1.59	-2.71	3.75	0.98	2.09	-2.31	6.51
P600 TBI	Left Ant	1.64	2.15	-0.57	5.08	1.63	0.96	0.41	2.88	0.10	1.99	-2.28	2.65
	Left Post	1.03	1.01	-0.50	2.12	0.53	1.32	-1.43	2.05	1.04	1.29	-0.10	3.23
	Mid Ant	1.54	2.41	-2.14	4.53	1.33	1.38	-0.82	2.63	0.71	1.71	-0.81	3.65
	Mid Post	1.28	1.16	0.24	2.97	0.83	1.28	-1.15	2.13	2.37	2.27	-1.38	4.73
	Right Ant	1.26	2.09	-1.45	4.34	0.31	0.83	-0.46	1.36	0.76	1.22	-0.45	2.82
	Right Post	1.23	1.62	-0.46	3.66	0.23	1.00	-1.08	1.46	2.19	2.00	-1.02	3.99

Table 6-12. Peak latencies (ms) for the P600 component (500-900ms window) from the TBI group for each stimulus type and region.

		Nonanomalous				Semantic Anomaly				Syntactic Anomaly			
Group	Region	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
P600 Control	Left Ant	664.95	117.28	518.00	874.00	660.82	126.56	512.00	882.00	633.68	94.21	508.00	817.00
	Left Post	632.59	87.70	539.00	875.00	660.95	104.36	542.00	894.00	679.77	76.00	554.00	841.00
	Mid Ant	719.16	132.78	550.40	886.40	673.67	126.43	508.00	888.00	668.55	114.41	513.60	896.00
	Mid Post	736.69	127.13	536.80	896.00	703.96	126.31	505.60	889.60	788.65	55.00	695.20	885.60
	Right Ant	738.55	118.98	559.00	880.00	710.05	128.00	538.00	894.00	748.23	94.33	561.00	874.00
	Right Post	737.95	118.99	559.00	884.00	719.55	116.46	568.00	896.00	799.45	68.33	632.00	887.00
P600 TBI	Left Ant	858.80	21.65	835.00	894.00	753.00	139.05	591.00	886.00	697.00	124.46	546.00	882.00
	Left Post	737.60	67.88	664.00	835.00	765.60	96.19	619.00	884.00	730.00	93.09	620.00	856.00
	Mid Ant	825.76	92.52	664.80	896.00	784.00	123.22	587.20	874.40	749.92	162.41	564.00	889.60
	Mid Post	801.12	86.48	667.20	893.60	797.12	99.80	628.80	893.60	765.28	82.43	632.80	848.00
	Right Ant	823.40	96.59	654.00	888.00	785.80	142.80	542.00	887.00	733.60	115.52	586.00	842.00
	Right Post	742.80	145.98	508.00	882.00	765.60	158.29	502.00	891.00	757.00	140.81	508.00	843.00

Table 6-13. Summary of the 2-Group x 3-Stimulus x 3-Side x 2-Anterior/Posterior repeated measures ANOVAs performed on the N400 mean amplitude and latency data.

	Amplitude			Latency		
	F	*p*	η^2	F	*p*	η^2
Group	0.04	0.84	0.00	0.05	0.83	0.00
Stimulus	0.73	0.49	0.03	0.98	0.38	0.04
Side	2.26	0.12	0.08	2.18	0.14	0.08
AntPost	0.21	0.65	0.01	0.24	0.63	0.01
Group x Stim	0.40	0.67	0.02	0.24	0.79	0.01
Group x Side	1.49	0.24	0.06	0.11	0.90	0.00
Group x AntPost	3.34	0.08	0.12	0.61	0.44	0.02
Stimuli x Side	0.84	0.50	0.00	0.56	0.63	0.02
Stimuli x Side x Group	1.83	0.13	0.07	1.56	0.21	0.06
Stimuli x AntPost	1.10	0.34	0.04	0.13	0.83	0.01
Stimuli x AntPost x Group	0.09	0.91	0.00	1.43	0.25	0.05
Side x AntPost	0.01	0.99	0.00	0.92	0.41	0.04
Side x AntPost x Group	3.63	0.03*	0.13	0.20	0.82	0.01
Stimuli x Side x AntPost	0.57	0.69	0.02	1.43	0.23	0.05
Stimlui x Side x AntPost x Group	0.25	0.91	0.01	1.21	0.31	0.05

*Significant

Table 6-14. Summary of the 2-Group x 3-Stimulus x 3-Side x 2-Anterior/Posterior repeated measures ANOVAs performed on the P600 mean amplitude and latency data.

	Amplitude			Latency		
	F	*p*	η^2	F	*p*	η^2
Group	0.20	0.66	0.01	4.09	0.05*	0.14
Stimulus	0.71	0.50	0.03	0.57	0.35	0.02
Side	0.06	0.95	0.00	7.21	0.01*	0.22
AntPost	0.00	0.99	0.00	0.14	0.71	0.01
Group x Stim	0.36	0.70	0.01	1.59	0.22	0.06
Group X Side	0.97	0.39	0.04	3.57	0.06	0.13
Group x AntPost	0.32	0.58	0.01	0.14	0.71	0.01
Stimuli x Side	2.58	0.04*	0.09	1.03	0.39	0.04
Stimuli x Side x Group	3.07	0.02*	0.11	0.71	0.57	0.03
Stimuli x AntPost	10.99	0.00*	0.31	6.63	0.00*	0.21
Stimuli x AntPost x Group	0.67	0.51	0.03	0.75	0.47	0.03
Side x AntPost	0.47	0.63	0.02	1.75	0.18	0.07
Side x AntPost x Group	3.97	0.03*	0.14	0.16	0.85	0.01
Stimuli x Side x AntPost	1.02	0.40	0.04	0.82	0.52	0.03
Stimlui x Side x AntPost x Group	0.07	0.99	0.00	1.17	0.33	0.05

*Significant

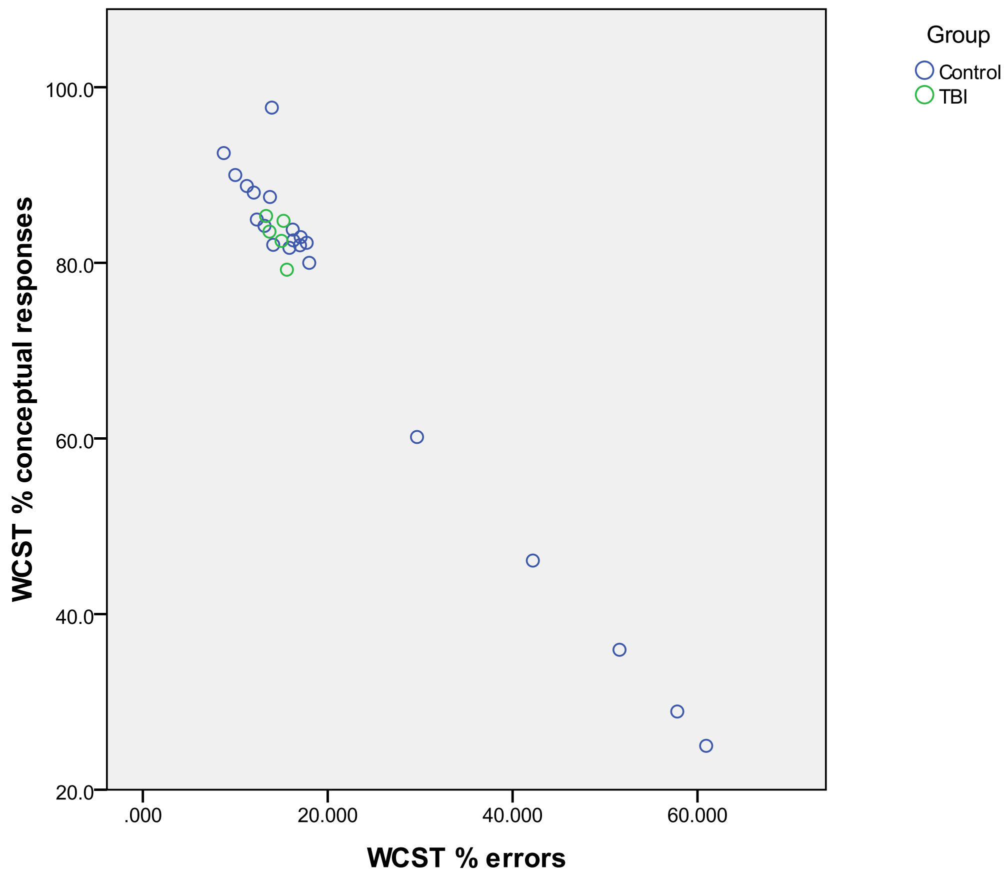


Figure 6-1. Scatterplot of error and conceptual response percentages on the WCST for control and TBI groups to demonstrate the large number of outliers in the control group.

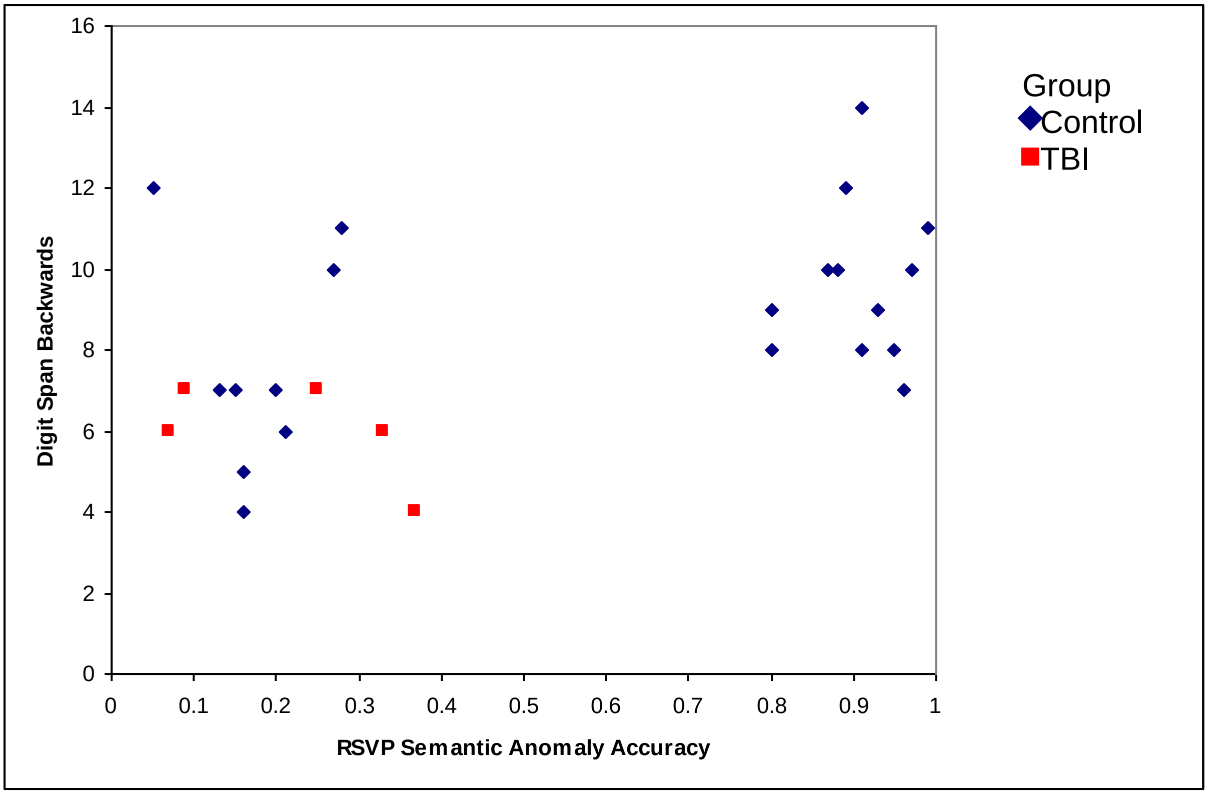


Figure 6-2. Scatterplot of RSVP Semantic Anomaly Accuracy and Digit Span Backwards performance for control and TBI groups to demonstrate the split in performance on RSVP Semantic Anomaly Accuracy.

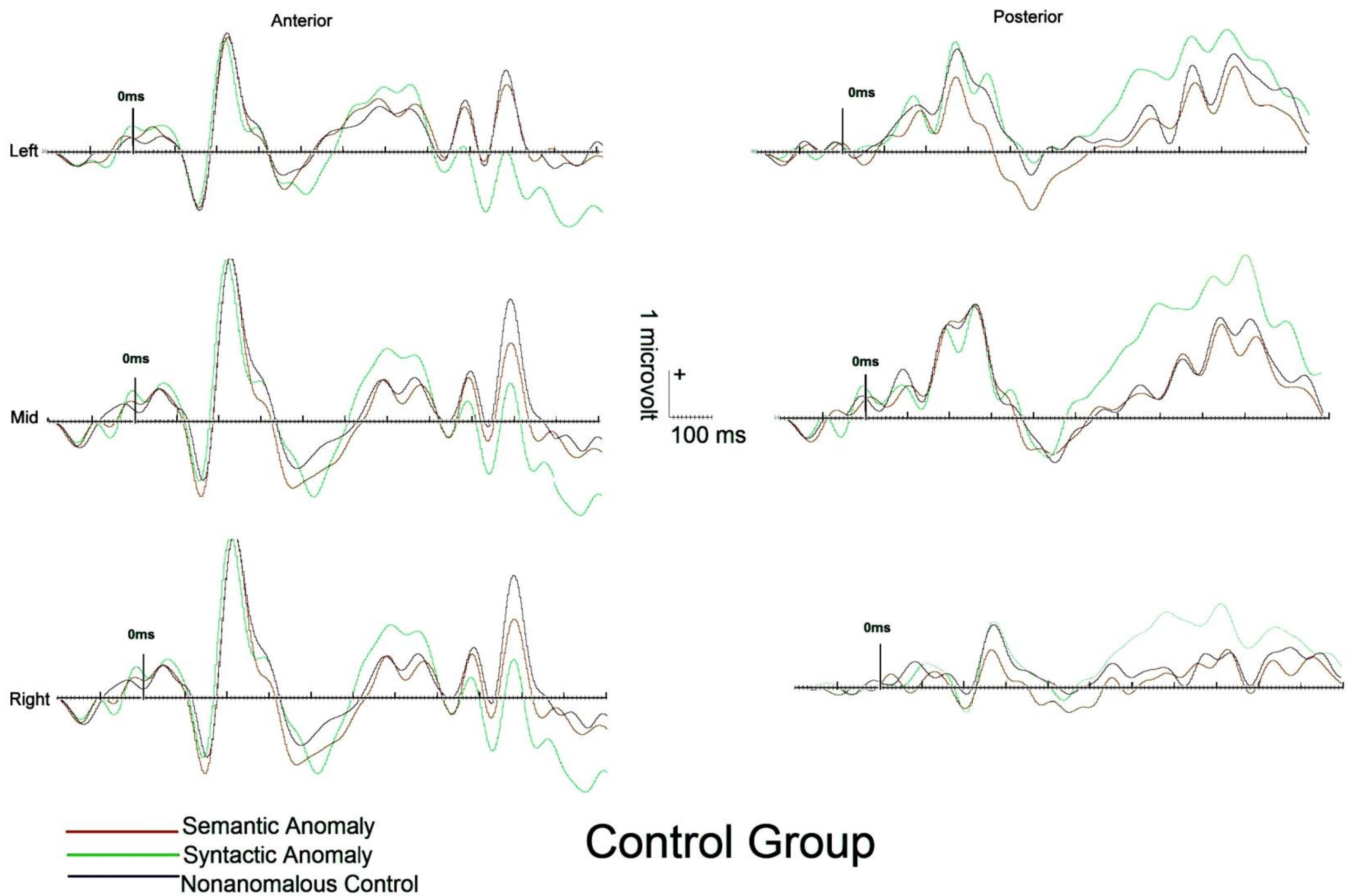


Figure 6-3. Grand-averaged nonanomalous, semantic anomaly, and syntactic anomaly ERPs from each electrode region examined for the control group. Microvolts on the *y*-axis, milliseconds on the *x*-axis. 0ms marks the onset of the target word after a 200ms baseline. 1100ms after the target onset is shown in each region. Note that positive polarity is up.

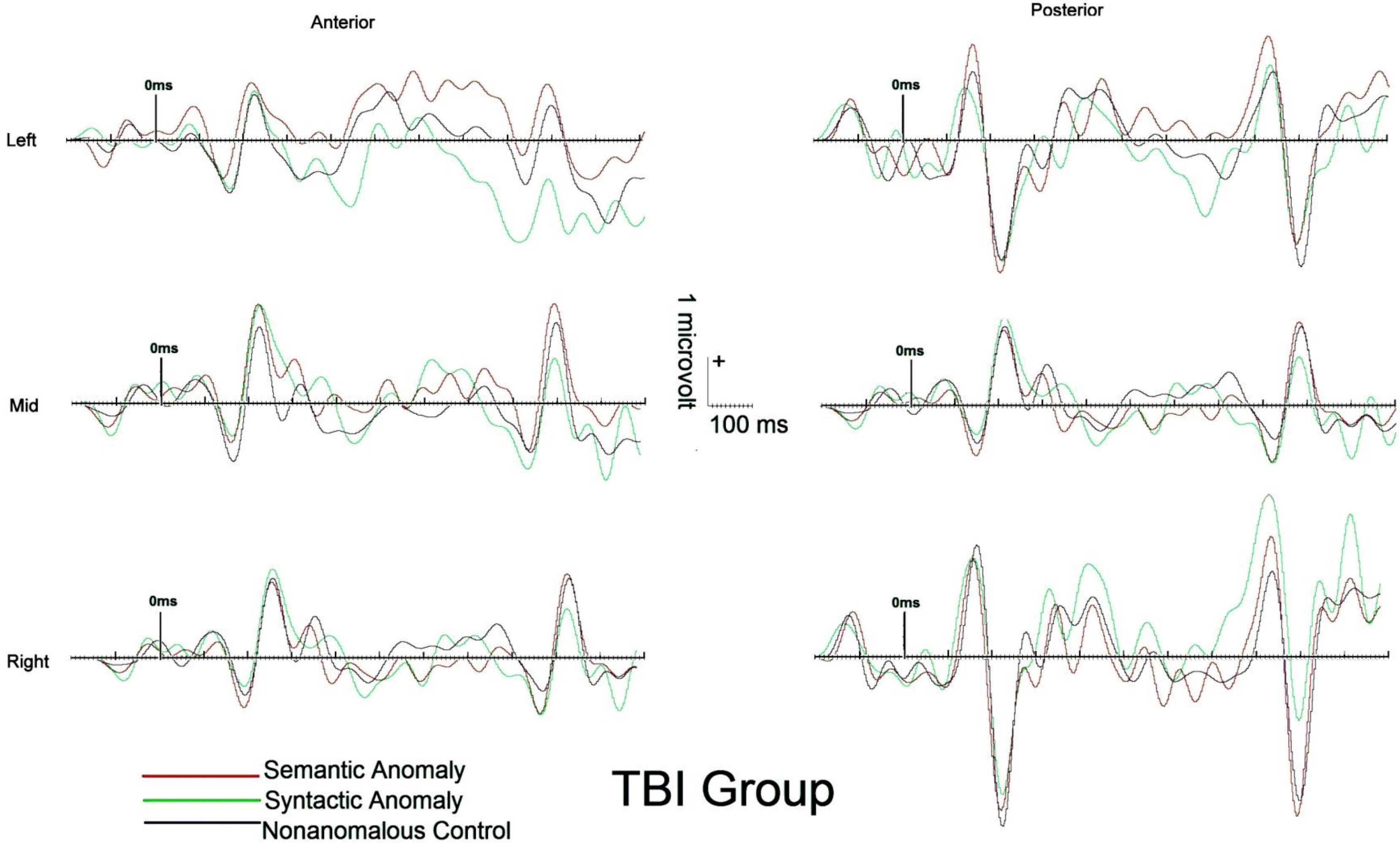


Figure 6-4. Grand-averaged nonanomalous, semantic anomaly, and syntactic anomaly ERPs from each electrode region examined for the TBI group. Microvolts on the *y*-axis, milliseconds on the *x*-axis. 0ms marks the onset of the target word after a 200ms baseline. 1100ms after the target onset is shown in each region. Note that positive polarity is up.

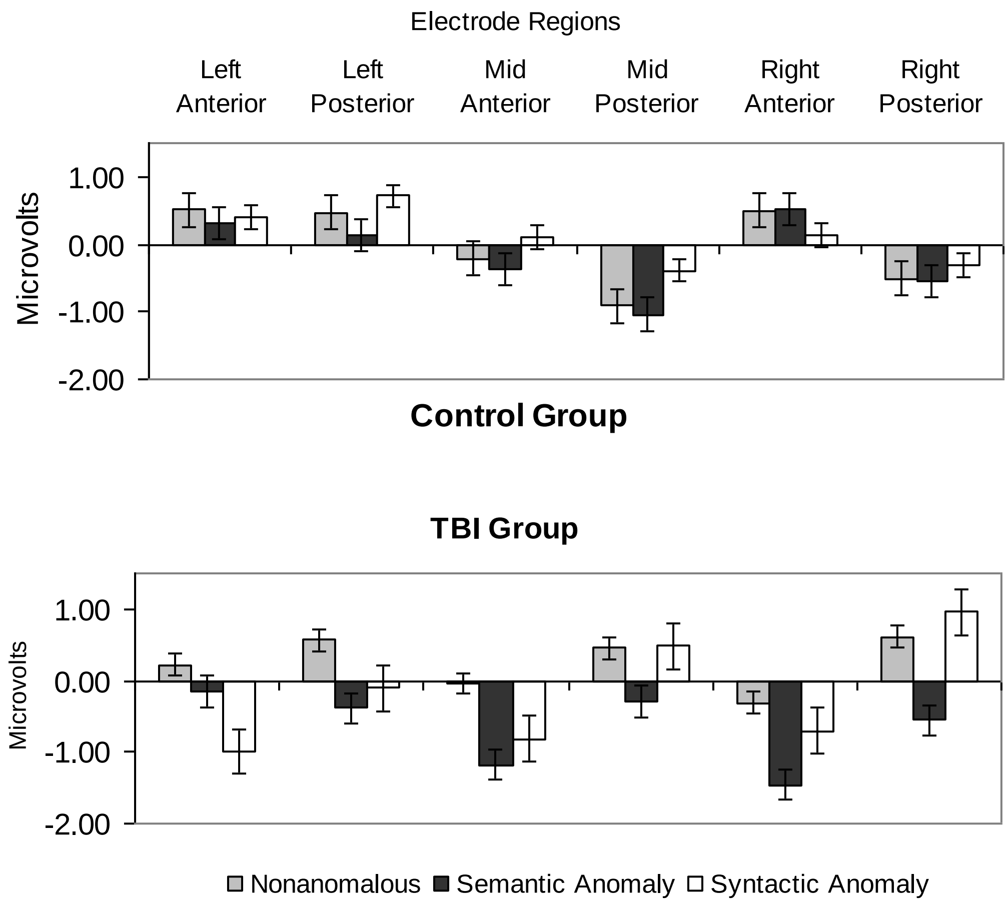


Figure 6-5. Mean amplitudes for the N400 component. Error bars reflect the standard error of the mean.

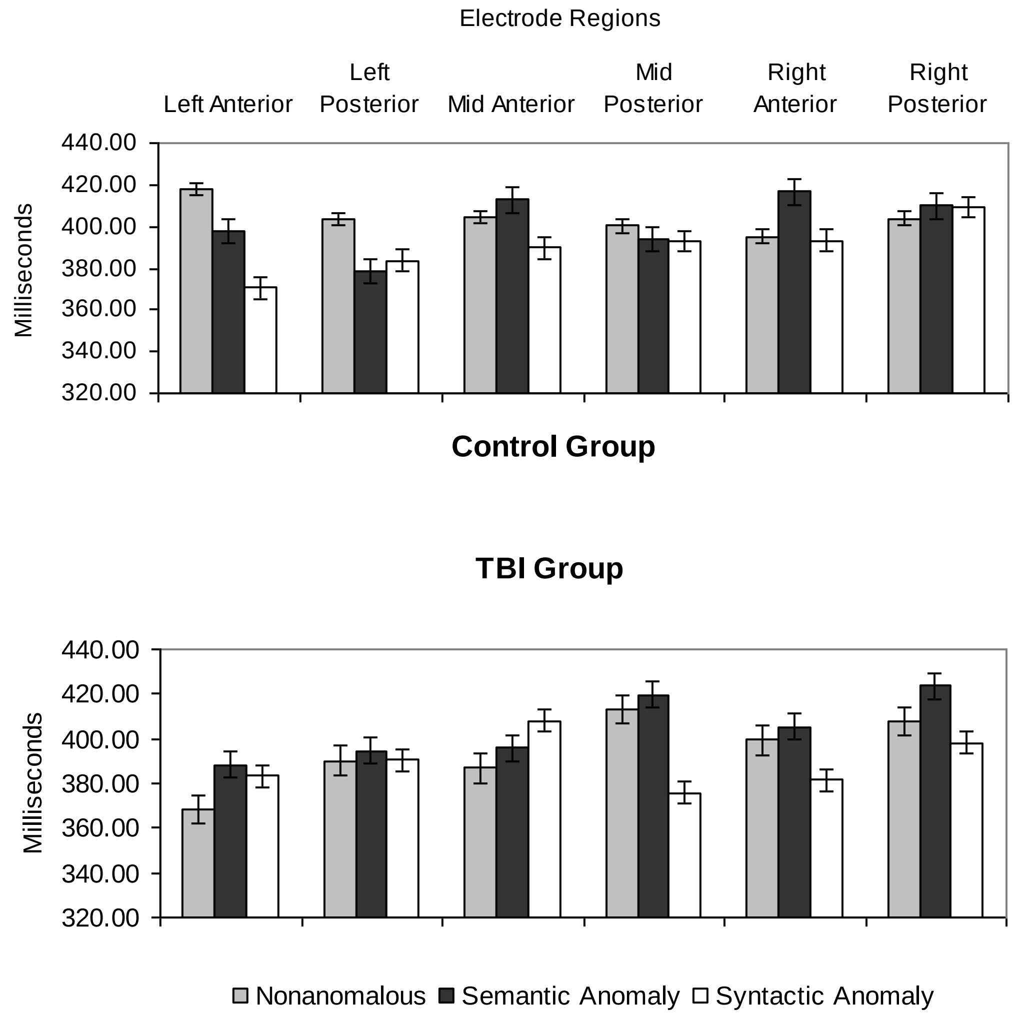


Figure 6-6. Peak latencies for the N400 component. Error bars reflect the standard error of the mean.

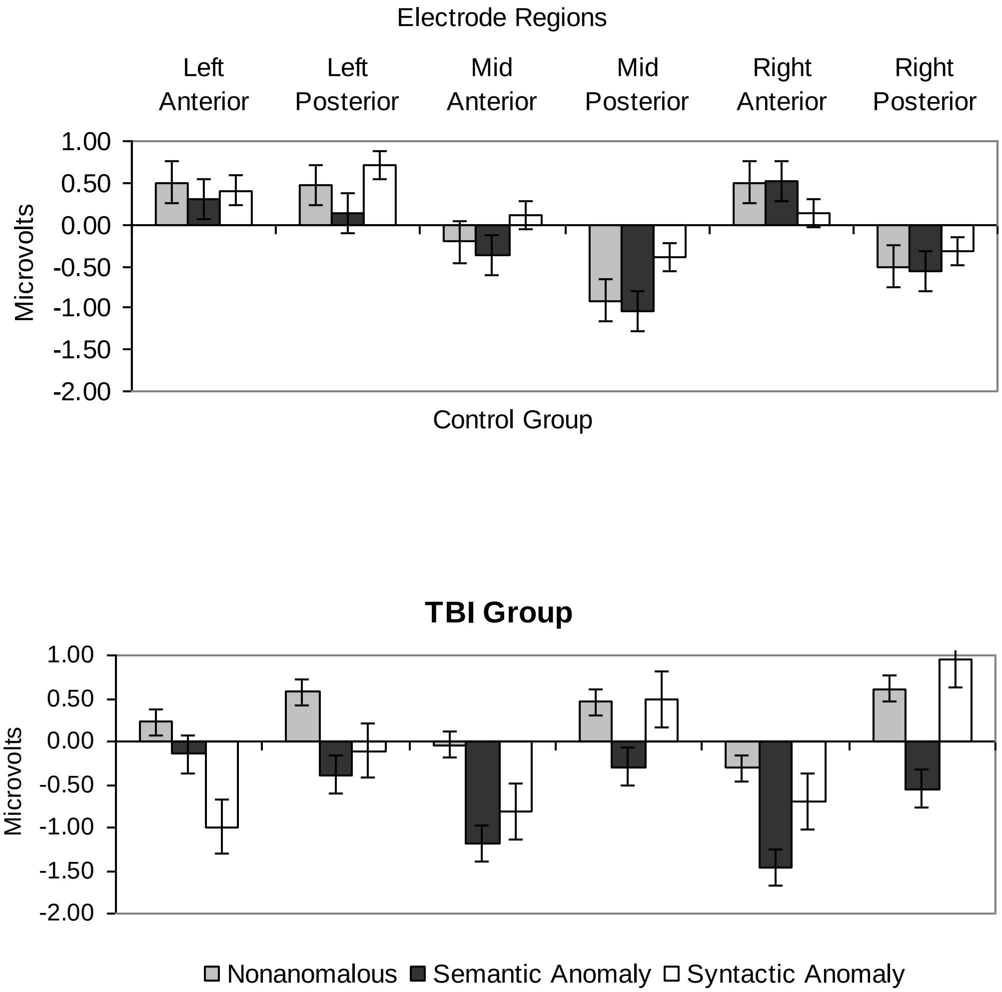
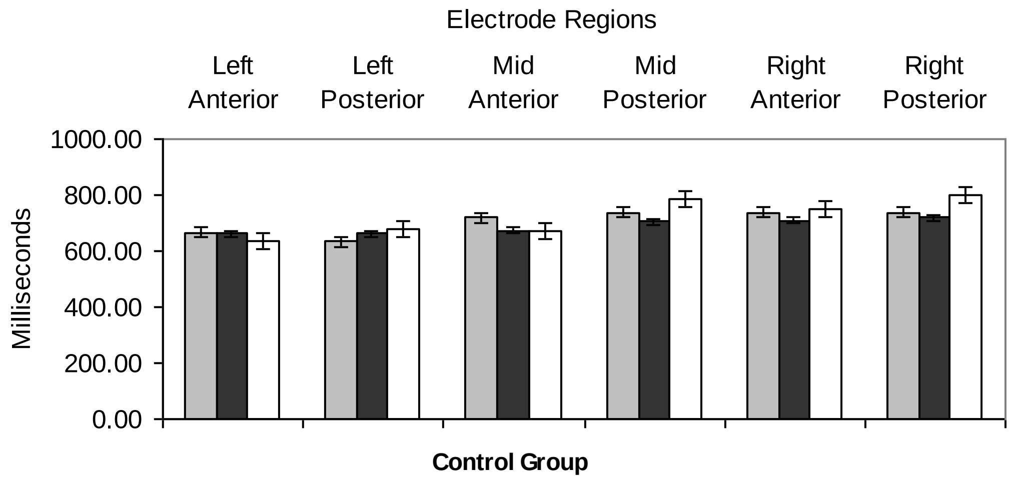


Figure 6-7. Mean amplitudes for the P600 component. Error bars reflect the standard error of the mean.



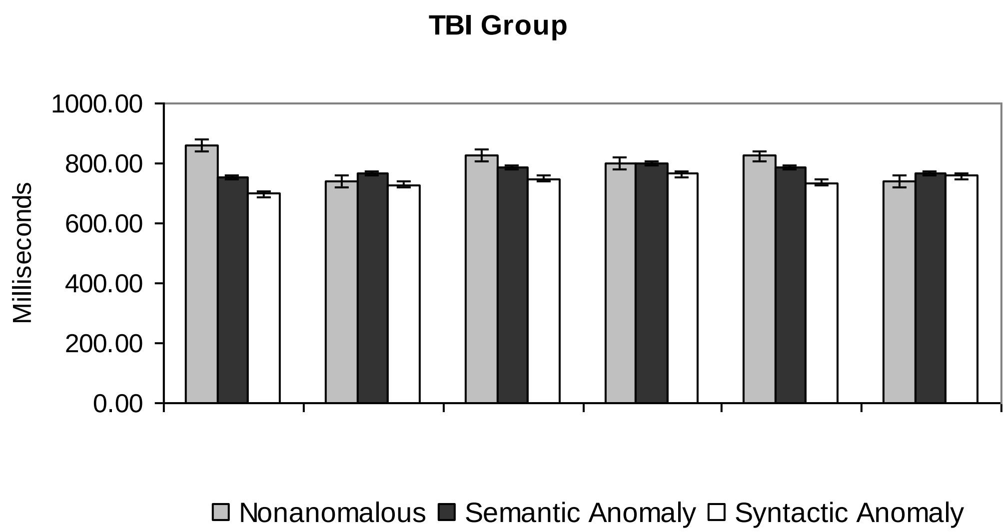


Figure 6-8. Peak latencies for the P600 component. Error bars reflect the standard error of the mean.

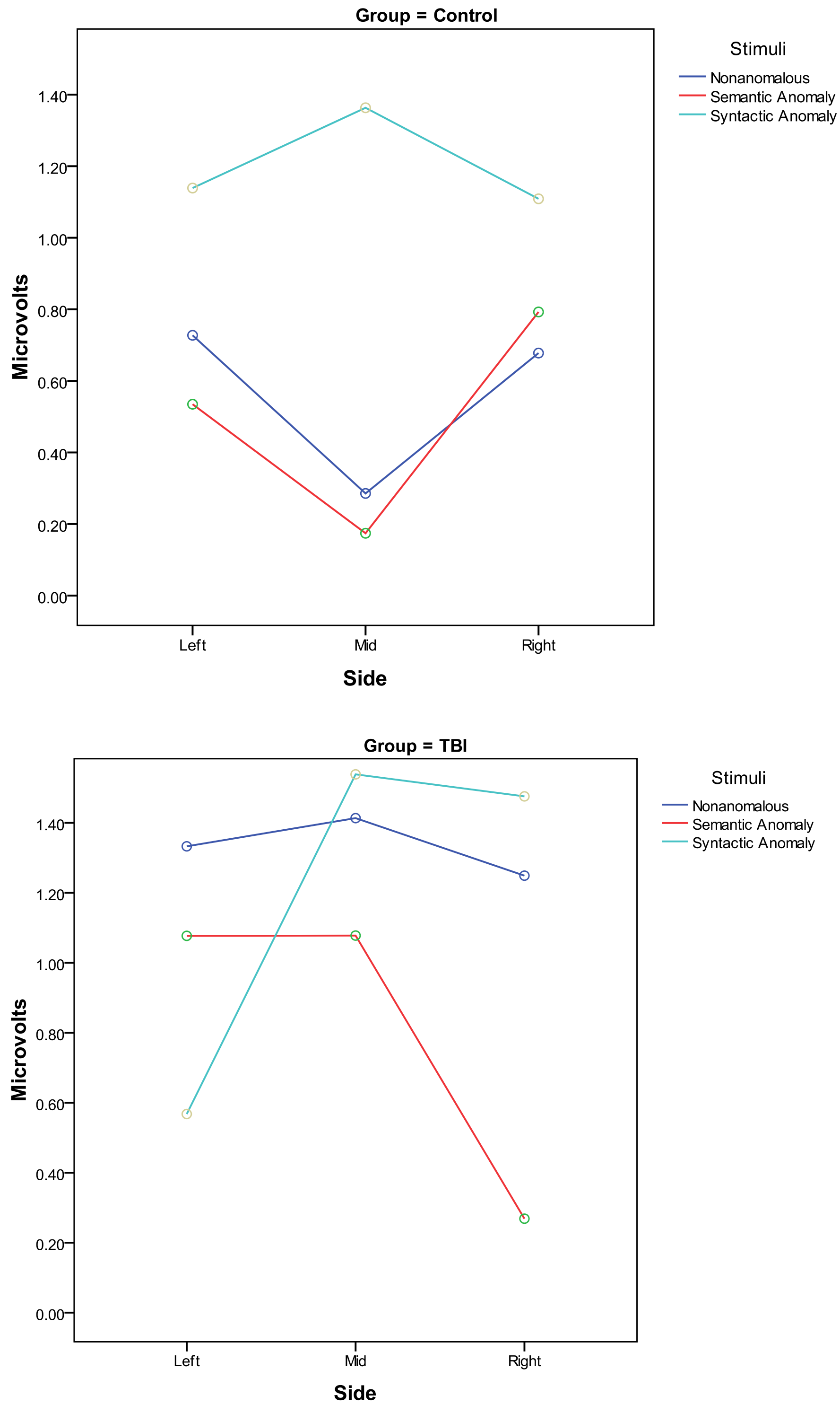


Figure 6-9. P600 mean amplitudes shown separately for each group to show the Group x Stimuli x Side significant interaction (*p*=.02).

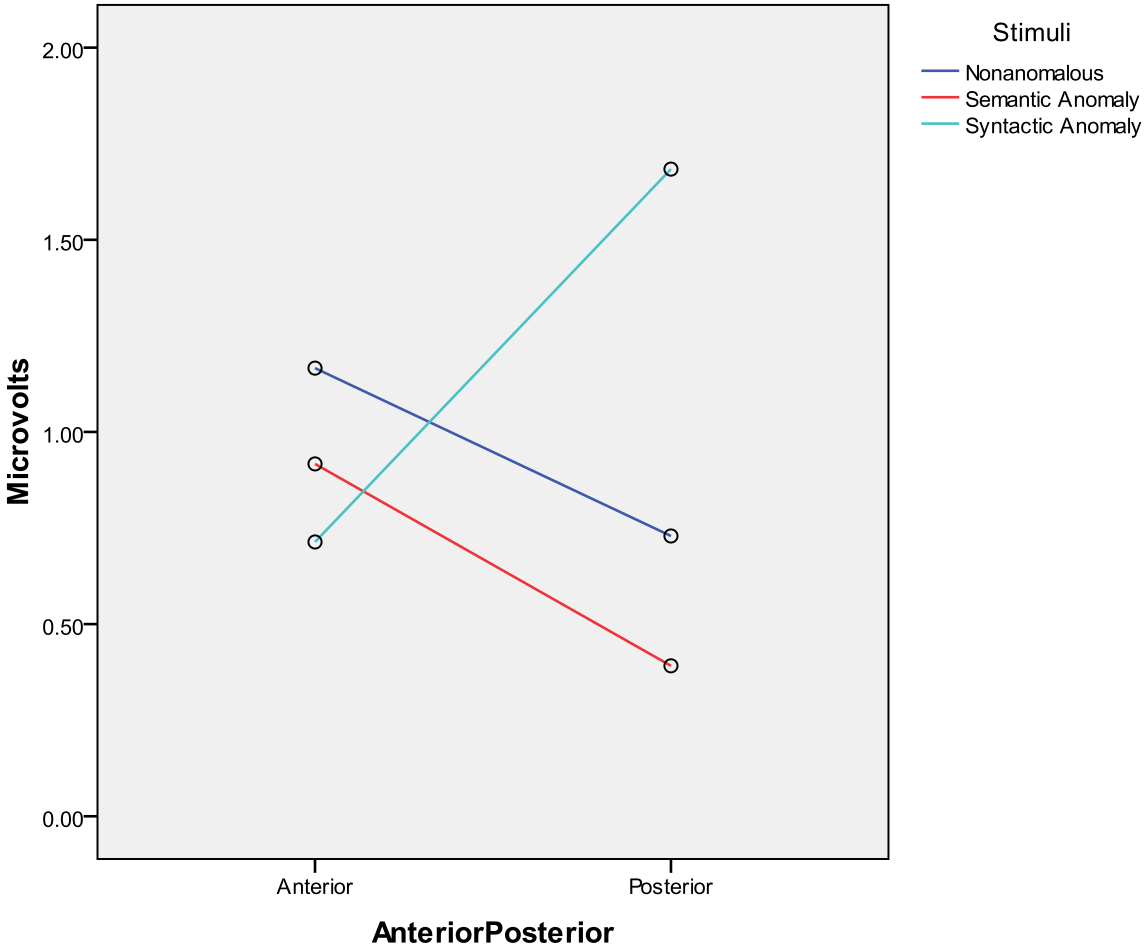


Figure 6-10. Mean amplitudes combined across groups for the P600 component to show the Stimuli x Anterior/Posterior significant interaction (*p*<.001).

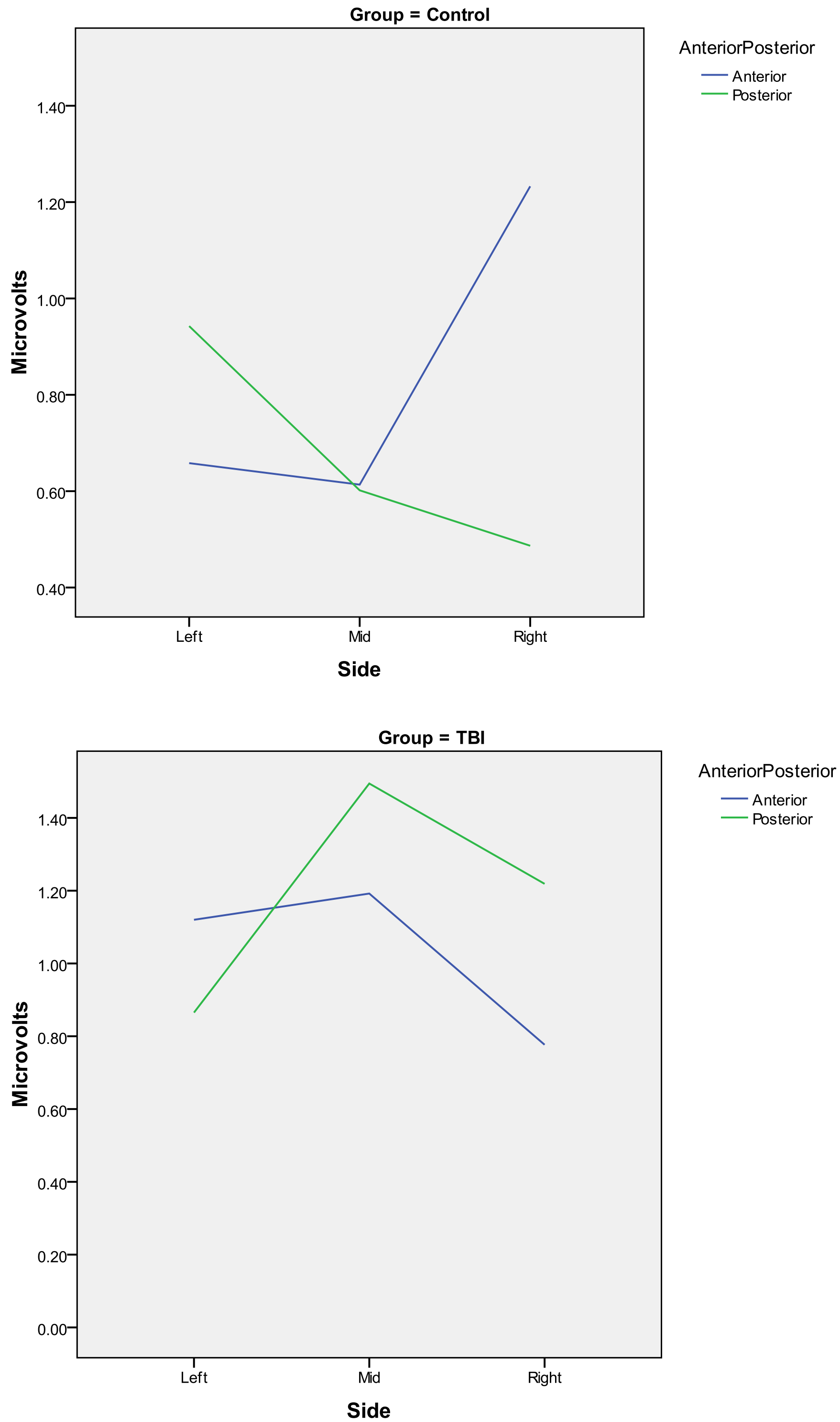


Figure 6-11. P600 mean amplitudes shown separately for each group to show the Group x Anterior/Posterior x Side significant interaction (*p*=.03).

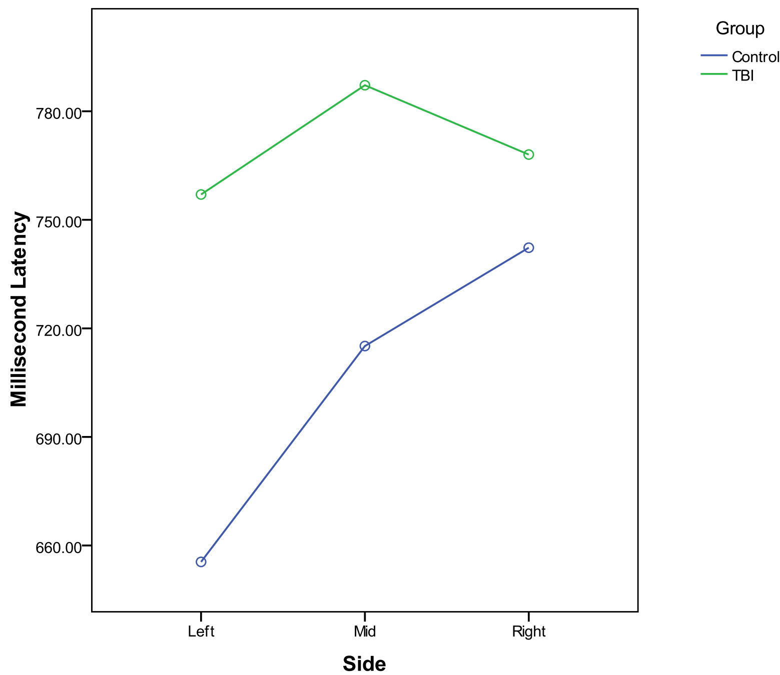


Figure 6-12. P600 peak latencies showing the Group x Side interaction (*p*=.06).

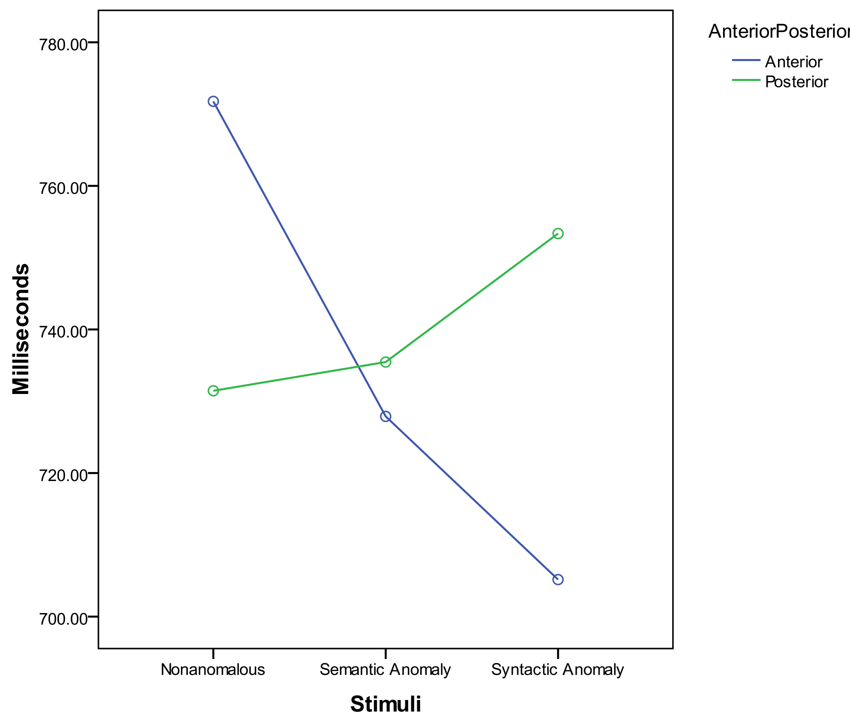


Figure 6-13. P600 peak latencies showing the Stimuli x Anterior/Posterior interaction (*p*<.01).

CHAPTER 7
DISCUSSION

Reading Comprehension Performance

This experiment examined the relationship between reading and cognitive components, such as executive function and speed of processing, in healthy young adults and a small group of traumatic brain injury (TBI) survivors. The first aim of this project was to determine whether reading comprehension is impaired in TBI survivors relative to matched controls. As predicted, comprehension performance in TBI survivors was significantly impaired relative to the control group, though not in all conditions. Although they were expected, finding significant group differences was surprising given that the TBI group size was extremely small. The TBI group was significantly less accurate on rapid serial visually presented (RSVP) sentence judgments. There were also interactions between anomaly type and group on whole sentence comprehension accuracy and RTs that did not quite reach significance. In particular, the TBI group was slower to respond to comprehension questions about syntactically anomalous sentences.

Comprehension and Cognition

The second aim of this study was to determine whether comprehension was related to cognitive impairments. However, there were only two group differences on cognitive measures: Digit Span Backwards (DSB) and Digit Symbol Substitution. However, there was quite a bit of individual variability on the cognitive tasks within the control group. In fact, the participants with TBI numerically outperformed many of the control participants on several tasks, including the WCST, even though the performance difference was not significant. Cognitive impairments were therefore not apparent in our small TBI group; thus, we looked at the relationship of comprehension and cognition in the combined groups.

The patterns of correlations between comprehension and cognition were not entirely straightforward. Whole sentence comprehension question accuracy for semantically and syntactically anomalous sentences was related only to Digit Symbol Substitution and Trails tasks indicating a relationship between comprehension question accuracy following anomalous sentences to processing speed and visual set shifting. Sequence maintenance may also be the underlying related cognitive factor between whole sentence comprehension and the Digit Symbols and Trials tasks. RTs to these same questions, however, were related only to Digit Span Forward (DSF) and DSB for semantically anomalous and nonanomalous control sentences. The relationships to working memory, set shifting, sequence maintenance and processing speed measures may be due to the fact that comprehension questions required both reading of the question and reanalysis of the previously seen sentence. The sentence recall may be fairly verbatim, much like the DSF task to which it correlates. The relationship to working memory, executive function and processing speed are in accordance with results from the pilot study described in Chapter 4 and with previous findings linking cognitive control, working memory and language (Frattali et al., 2007; Hinchliffe et al., 1998; Youse & Coelho, 2005).

Depression and Comprehension

Whole-sentence self-paced reading times for all three types of sentences were strongly related to the Beck Depression Inventory (BDI) and syntactically anomalous reading time was related to the State Trait Anxiety Inventory (STAI) Trait score. Further, RSVP nonanomalous sentence judgment accuracy was related to the BDI, and RSVP syntactically anomalous sentence judgment RTs were related to the BDI and the STAI-State scores. Therefore, depression and anxiety levels interfered with accuracy in judging sentences in RSVP as well as reading times for whole sentences and response times to judge syntactically anomalous sentences. One explanation of this is that depression likely plays a role in a variety of cognitive impairments including executive function and working memory (Porter, Gallagher, Thompson & Young, 2001; Rose & Ebmeier, 2006). Porter and colleagues found that patients with major depressive disorder who were not on psychotropic medications had significantly impaired cognition, especially for tasks of vigilance, spatial working memory, strategy and verbal fluency. Consistent with other findings (e.g. Just & Carpenter, 1992; Kemper & Sumner, 2001; MacDonald & Christiansen, 2002; Waters & Caplan, 1996), working memory was also linked to sentence comprehension in the current study. However, BDI and working memory measures were not correlated in this study, suggesting that they are accounting for different portions of variance in comprehension.

There have been a limited number of studies indicating that language performance or at least language use may be affected by depression, mostly in studies of older adults (e.g. Emery & Breslau, 1989; Rude, Gortner & Pennebaker, 2004). In a study of young adult college students, Rude and colleagues (2004) found differences in language use among those with depression. Specifically, those with depression used the word ‘I’ significantly more than those who had never had depression or than those who formerly had depression. Emery and Breslau (1989) found a few significant differences between normal elderly and elderly with depression on auditory complex sentence comprehension tasks from the Western Aphasia Battery and other tasks of syntactic complexity.

A directly relevant study by Ruchsow, Groen, Spitzer, Hermle, Buchheim and Kiefer (2008) directly examined the relationship between the ELAN, N400, LAN and P600 using RSVP in patients with major depressive disorder. The N400 had been examined in relation to depression previously (Deldin, Keller, Casas, Best, Gergen & Miller, 2006), but the relationship between the observed negative semantic bias in people with depression did not appear to affect the N400 component. Ruchsow and colleagues also found that their group with depression had a similar N400 component to the control group. In addition, there were no observed group differences for the ELAN or the LAN. However, the group with depression did not show a P600 effect in their study while the control group did. This finding is relevant to our study since we found a relationship between comprehension performance on semantic and syntactic anomalies and depression symptoms on a scale meant to screen for depression. I plan to look more closely at the relationship between the ERP results and the depression scale in future analyses. The Ruchsow et al. study collected a wider variety of depression and anxiety measures and included information about medication, but they did not utilize the scores in their analysis. Their scores and medication information were used to confirm the presence of a severe depressive disorder. Our findings suggest that depression symptoms may relate even at a much milder severity level, since all of our participants scored in the normal-mild range on the BDI. Therefore, more detailed assessment to identify and describe symptoms could be used to develop a more complete picture of the relationship between mood disorders and language processing.

Exploring this relationship is important to future studies because the prevalence of depression is quite high in the general population with a lifetime prevalence 16.5% of the US population (Kessler, Berglund, Demler, Jin & Walters, 2005), 15.6% of undergraduates in a large survey study (Eisenberg, Gollust, Golberstein & Hefner, 2007), and 42% of brain injury survivors (Kreutzer, Seel & Gourley, 2001). Depression and mood disorders complicate educational and vocational success, and any reading problems associated with those problems could potentially compound the difficulties.

RSVP Performance and Cognition

RSVP sentence judgments and cognition also had several notable relationships. Perhaps most notable is the absence of statistical relationships between almost all cognitive measures and accuracy on semantically or syntactically anomalous sentences. The Shipley vocabulary task correlated with syntactically anomalous RSVP sentence judgment accuracy and the DSB with semantically anomalous RSVP sentence judgment accuracy, but there were no other significant correlations. It is not immediately clear what would be special about the one measure, especially in light of the more limited and generally good individual accuracy range of the RSVP accuracy of syntactically anomalous sentences (>.74 for both groups). Vocabulary is clearly related to language comprehension (Braze, Tabor, Shankweiler & Mencl, 2007), and a higher vocabulary size might free up language processing resources so that syntactic errors are detected. However, there was no correlation between the Shipley and other sentence measures. Another explanation is that the Shipley task and the accuracy on RSVP syntactic anomaly judgments were both related to exposure to print (Braze et al., 2007). Vocabulary and knowledge of syntactic structure are likely to be related to this exposure as discussed by MacDonald and Christiansen (2002) and could, potentially, explain the relationship to the syntactic condition as opposed to other conditions overall.

The accuracy of responses to semantically anomalous RSVP sentences were split between a subgroup that did very poorly (just below chance and lower) and people that did more comparably to the other tasks (at .8 and higher). Accuracy on the RSVP semantically anomalous condition correlated with whole sentence, semantically anomalous comprehension, and RSVP accuracy on the semantic condition correlated significantly with comprehension question accuracy and self paced reading time in the whole sentence task across all conditions. RTs to the RSVP semantically anomalous condition were significantly slower compared to other conditions, but there was not a split between subgroups as in accuracy. Neither was there a significant correlation between RTs and accuracy rates in the same RSVP semantically anomalous condition. The RSVP task was always presented first to avoid the task being over-learned before the EEG data was collected. The correlations between accuracy in the semantic anomaly condition of the two tasks suggest that the very poor accuracy on the semantically anomalous condition is due to more than simply misinterpreting task instructions or simply looking for the verbs ending in *-ing*. That is, we cannot accept the explanation that the poorer comprehenders were only looking for grammatical errors (despite being explicitly told not to) in the RSVP task, because the same group also took longer to read whole sentences and was poor on comprehension questions to the same set of sentences. One possibility is that the group who made more errors, which included the TBI group, were overall poorer readers who required longer exposure times to the verbs to activate the selectional restrictions of verbs in the semantic anomaly condition than what was provided in the RSVP task. This possibility does not explain the correlation to the whole sentence task, but it may explain the much worse performance on the RSVP task.

The subgroup that did poorly on the semantically anomalous RSVP sentence judgments may also have been limited by working memory to only processing RSVP sentences shallowly. Shallow processing here refers to not fully integrating the sentence into a higher semantic representation or even a fully developed syntactic representation, terminology also used by Wassenaar and Hagoort (2007) when referring to patients with Broca's aphasia. Shallow processing in individuals with lower WM spans is consistent with previous literature (Lee & Newman, 2010; Swets et al., 2007). Additionally, shallow processing in RSVP reading is consistent with the findings of the pilot study, described in Chapter 4. Shallow processing may have led to the particular problems with the semantically anomalous condition because there was no overt cue that a sentence was incorrect as there was in the syntactically anomalous condition (-*ing*).

In contrast to the lack of relationships between RSVP anomalous sentence judgment accuracy and cognition, nonanomalous control-sentence judgment accuracy correlated with the North American Adult Reading Test (NART), DSF, DSB and Digit Symbol Substitution. As mentioned, the TBI group did significantly worse on the DSB and Digit Symbol, but there were no group differences on the NART or DSF. The nonanomalous sentence judgments may have engaged normal language processing and thus the same cognitive variables needed during normal language processing. In addition, the necessity of double checking to confirm the absence of errors may have further engaged working memory. This possibility is seemingly disputed by the lack of correlations between RTs and cognitive measures in the nonanomalous condition (i.e. if people are double checking the goodness of the sentence, why aren't they taking longer to do it?). One possibility is that participants may have made their decision about the goodness of some sentences prior to the prompt appearing, leading to the very fast observed RTs (within 1 second) for both groups. Thus, the RSVP RTs may not completely reflect processing time differences between conditions, but rather the signaling of a previously computed decision or their confidence of that decision.

The N400 and P600

The third aim of this study was to investigate whether typical electrophysiological markers of sentence processing like the N400 and P600 differ in mean amplitude and latency between groups. Our prediction that there would be group differences in the N400 and P600 was partially supported. The only group effect found for the N400 window was in amplitude differences across observed electrode regions, independent of stimulus manipulations. Anterior and posterior electrode regions were similar for left and mid electrodes in the control group, but the right posterior region detected a larger amplitude than the right anterior region. The TBI group, in contrast, had larger amplitudes at left and right anterior than at posterior regions, and mid anterior and mid posterior regions were similar. The amplitude differences across regions may indicate processing differences between groups, but it is difficult to interpret without other significant group or stimuli differences.

The lack of a condition-related N400 effect could be related to task or to material effects. It is possible that participants only processed shallowly in some way to complete the task at the expense of deep semantic processing leading to both the poor accuracy in the semantically anomalous condition and the lack of a condition-related N400 effect.

There could also have been an effect related to animacy violations, which were present in most, but not all of the sentences we used. In the Osterhout and Nicol (1999) study where the stimuli largely originated, a robust N400 effect was found, but their task was slightly different than ours. There was a 1450ms interval between the sentence and the prompt (my study did not include a delay interval before the prompt), but participants were asked to accept sentences that were both semantically and grammatically well-formed as in our study.

Kuperberg and colleagues (2007) offer an alternate explanation for the lack of a condition-related N400 effect in the current study. They found that animacy violations (e.g. ‘For breakfast the eggs would *eat* toast and jam.’) elicited a P600 with a smaller N400 response, and their task also included acceptability judgments that followed the final word of each sentence after 1100ms. When the agreement violation in the sentence was semantic but not animacy related (e.g. ‘For breakfast the boys would *plant* flowers in the garden.’), they found an N400 but not a P600 response. The possibility of an effect of animacy on what type of ERP component is elicited is worth further study. A future analysis of this dataset will explicitly examine the role of animacy on the N400 and P600 responses. It may be the case that sentences with an animacy violation may have elicited a P600 instead of the intended N400 effect.

Another possible explanation for the lack of an N400 effect could be that participants simply did not notice the semantically anomalous word in the RSVP sentences which would also lead to the lack of a condition-related N400 observed here and the errors in judgment in the behavioral measures. Furthermore, the critical verb, from which ERPs were measured, was unfortunately not always the point where the sentence became anomalous. There would not likely be any observable difference on the measures we collected between a focus on syntactic anomalies due to the task and a lack of deep processing (or full integration) of semantic information leading to poor semantic anomaly judgment accuracy. Moreover, shallow semantic processing could also be linked with the use of RSVP rather than the stimuli, as was suggested during the pilot study. That is, word-by-word processing could make identifying semantic anomalies difficult, consciously (as measured through our judgment task) or unconsciously (as measured by the N400). Shallow processing due to RSVP combined with a task bias to focus on morphological markers of syntax and the use of animacy violations as the main semantic violation in this study could have led to the surprising lack of a condition-related N400 effect.

In support of my original prediction and in contrast to the findings for the N400, there were significant differences between groups for the P600 window. The TBI group had a later latency across all stimuli, not related to condition, and visual inspection revealed that there were polarity differences between the groups within that window. This later latency could be related to a general slowing of processing, consistent with the Digit Symbol Substitution group difference, as it was not particularly tied to one type of stimulus. Unexpectedly, the TBI group had negative deflections rather than positive going deflections as in the control group, although there was not a significant group difference in amplitude. The left posterior negative polarity observed for syntactic anomalies in the averaged TBI group waveform held true only across individual waveforms for 3 participants with the other two participants showing a pattern more like the normal individual waveforms reflecting the individual variability that was expected.

This split was not obviously related to severity, etiology or any behavioral measures, including accuracy or reaction times. A split between subgroups is not unexpected, as TBI survivors as a group are a highly heterogenous population to begin with, and the studies looking at the P600 in people with Broca's aphasia also found subgroups (Wassenaar et al., 2004; Wassenaar & Hagoort, 2007).

The reason for the large negative going wave in the syntactic anomaly condition in the 500-900ms time window is not clear and could simply be an artifact of the extremely small group size. Alternatively, it could reflect a difference in processing when syntactic anomalies are encountered, and it does suggest that these three individuals were sensitive to the ungrammaticality since it is largest for the syntactic anomaly condition. A similar late negative going component has been found under certain conditions in second language processing (Sabourin & Stowe, 2008). It has been interpreted to reflect the recruitment of working memory resources when it has a frontal distribution, and in the case of non-native speakers, the negativity to grammatical errors could actually reflect a positivity for the nonanomalous sentences. Sabourin and Stowe describe this positivity in response to the grammatical condition as reflecting the fact that non-native speakers might see a chance of success in processing the sentences. In this study, people with language impairments might show a more positive going wave to the nonanomalous and semantic anomalous sentence types because they are attempting to process those sentences more fully in the absence of a overt syntactic error. The scalp distribution in the TBI group is different from frontal distribution observed by Sabourin and Stowe in non-native speakers, however, but the possibility would be interesting to address in future studies.

Taken together with behavioral performance differences, P600 differences both between groups and within the TBI group suggest that event-related potentials (ERPs) are a promising tool for sentence processing impairment identification. The findings raise the possibility of fundamentally different strategies for processing syntax in some people with the possibility that a subset of the TBI group and possibly of the control group is processing sentences shallowly for a variety of reasons, such as task demands or mode of presentation. Additional studies with larger groups and a wider variety of complex syntactic structures would be necessary to reveal the relationship between observable processing differences and ERP waveforms.

Clinical Implications

These results have several clinical implications. First, the TBI group did show evidence for language processing differences at the sentence level that could be leading to challenges in school or work settings. They had near-significantly worse accuracy and significantly slower reading times in the whole sentence task. They showed that they may not have been fully integrating semantic information especially in the word-by-word condition, and they may have been using a compensation strategy to complete the tasks that did not require deep processing or full integration of semantic or syntactic sentence level information. Furthermore, performance was related to processing speed and working memory suggesting that these skills do need to be supported to support reading, which is current clinical practice (Coelho et al., 2005; Hinchliffe et al., 1998; McDonald et al., 2000; Turkstra et al., 2005). However, our results suggest that reading for depth or for semantic integration is a potential clinical target, even at the sentence level, that is not typically addressed even when TBI survivors receive language therapy (Coelho et al., 2005; Turkstra et al., 2005). Poor semantic integration at the sentence level would make accurate comprehension of a passage in a textbook, article or book difficult and slow. The relationship between sentence reading measures and depression also has important clinical implications. Language processing problems may be more productively addressed after depression is treated. The possibility of a relationship between language and depression has ethical implications for those who work with people who have depression such as doctors, counselors and pharmacists who should be made aware of the link. These findings suggest that even a non-clinically significant number of depression symptoms may adversely affect language performance and should be addressed. Finally, cognitive fatigue may have differentially affected the performance of the TBI group (Belmont, Agar, Hugeron, Gallais & Azouvi, 2006), and should be addressed in future analyses by examining performance changes over the course of the experiment or splitting testing over more than a single session. Fatigue is important to address in future studies because it is not controlled for by other measures such as severity or time since injury, which are unrelated (Belmont et al., 2006). It can be related to a wide variety of factors that would be difficult to control for such as fatigue from coping with attention deficits and slowing, depression or pituitary insufficiency, but fatigue itself could be screened.

Limitations

There were several weaknesses in this project that should be taken into account for future studies. First and foremost, our extremely limited TBI group size prevented a more extensive exploration into the relationship among behavioral and electrophysiological variables and group membership. A larger group would allow for more detailed and powerful analyses and will be necessary to make any more generalized conclusions about these data. Despite this limitation, however, group differences were still found suggesting that the hypothesized group differences in reading may be more powerful than initially suspected.

A second limitation of the sample used in this study was that nearly all of the participants in both groups were undergraduates. The homogeneity of the sample prevents generalization of the results to a more varied group. On the other hand, the sample is entirely appropriate due to the nature of the task. Reading tasks are one of the particular challenges for student survivors of TBI and one of the groups most in need of further research on the effects of TBI on reading. The number of students surviving concussions is likely underreported and therefore an interesting subgroup of the TBI population as a whole.

The cognitive tasks used also did not likely fully account for all of the cognitive interactions present with the reading tasks, but that is unsurprising given the exploratory nature of the study and the time limitations. The interactions seen between working memory and tasks requiring processing speed provide a starting point for future cognitive batteries. The interaction with simple depression and anxiety screening measures also provide a useful starting point.

Undesirable task related influences on sentence processing are also easily addressed in future studies, though difficult to tease apart in the current data. It is unclear in this study whether the task influenced how the RSVP sentences were read and therefore the N400 response. Part of the strength of using electrophysiological data is that ERPs can be elicited in the absence of a task. A task may exacerbate or mask any observed processing, and it is important to distinguish the possibilities. Between the possible task related effects in this current study and possible task-related effects in the

TBI population in general, future studies should consider a task free ERP study to identify and examine sentence processing effects in TBI groups. An ERP study using auditory stimuli is another option to look at sentence processing that has been used in the ERP literature looking at aphasia (Hagoort et al., 1996; Swaab et al., 1997; Waassenaar et al., 2004; Wassenaar & Hagoort, 2007).

Conclusion

This study confirmed that reading is a complex skill that is strongly tied to cognitive processing. In particular, verbal memory, executive function, processing speed and vocabulary are related to sentence comprehension. Furthermore, depression and immediate anxiety symptoms may affect sentence reading time and comprehension. The overall goal of this study was to explore the relationship between reading and cognition in TBI. The results provided evidence that reading is a challenge to TBI survivors, especially in light of the fact that four of the five participants were undergraduates. It also suggested that reading processes and reading impairment vary individually. Further exploration of the relationship between cognition and reading and especially mood and reading is warranted given the strong relationships found in this study.

APPENDIX A
RSVP SENTENCE STIMULI WITHOUT COMPREHENSION QUESTIONS

RSVP Sentences (nonanomalous/syntactic anomaly/semantic anomaly)
A live audience will witness/witnessing/powder the performance by the new composer.
A new computer will work/working/paint for many years if maintained properly.
After Jane's accident, she found it difficult to drive/driving/boil for several months.
After the pleasant meal, the couple will tip/tipping/light the waiter well.
Alison used a hammer to crack/cracking/kiss the small lock open.
At the end of the day, the dog always waits/waiting/peaks in the driveway.
At the front desk, the receptionist will register/registering/cope new appointments in the calendar.
Betsy went out to the orchard to pick/picking/melt apples for a pie.
Bob's rubber raft hit/hitting/loves a rock, which punctured it badly.
By the end of the semester, the student will earn/earning/pump a good grade.
Critics say that the rap songs might tend/tending/learn to lead young people astray.
Every day at three, the newspapers should land/landing/dance on the porch out front.
For the appetizer, the waitress will recommend/recommending/air the cheese dip.
Hopefully the painter will notice/noticing/core the areas that need an extra coat of paint.
It was hard to get the infant to smile/smiling/vote for the photographer.
Mary knew that the food at the hotel would cost/costing/fight too much.
Most physicians believe that the new drugs can prevent/preventing/study many forms of disease.
My brother bet that this spider could climb/climbing/type faster than you could.
My grandfather's habit of chasing geese might shock/shocking/stab you, but he is quite normal otherwise.
My mother worried that she would not have time to vacuum/vacuuming/box before the party.
Simple vegetable oil is used to fry/frying/plow the vegetables for the soup.
So many bugs live in the garden, they must devour/devouring/buy a whole cabbage every minute.
Susan was worried that her kitten would scratch/scratching/lift the young child.
The accountant wants to count/counting/bat the expense as part of a donation.
The administrator will supervise/supervising/upset the plumber behind the new house.

The army did not ambush/ambushing/read while the soldier was digging the trench.
The assistant was told that the alibi would prevent/preventing/consider an indictment.
The astronomer thinks he should map/mapping/close the new star system first.
The astronomer's argument might prove/proving/shout that there are three canals on the moon.
The baby’s teeth are so sore that the pacifier might hurt/hurting/cheat her too much.
The biography will fall/falling/laugh off the shelf if the shelf moves.
The black widow spider likes to hide/hiding/sigh in dark places.
The blue knit hat will warm/warming/warn the boy while he plays outside.
The booklet says that the contraceptive will fail/failing/complain if used too sparingly.
The boss might study/studying/kick the analysis more closely next time.
The bus driver did merge/merging/contract correctly on the busy freeway.
The busy stepfather plans to visit/visiting/staff every holiday with his wife.
The carrots need to boil/boiling/frighten before the stew is served.
The cats will not eat/eating/bake the food that Mary gives them.
The children want to play/playing/star with the ball outside in the sunshine.
The circus elephants get on their hind legs and stand/standing/chirp, which impresses the audience.
The city workman will fix/fixing/bake the bus that broke down yesterday.
The clowns will entertain/entertaining/weigh everyone when the circus is here next month.
The colors in the sweater should not fade/fading/walk when the sweater is washed.
The couple’s newborn baby sneezes/sneezing/types so much that they took her to the doctor.
The courier asked the administrator to sign/signing/golf for the package.
The courier will drop/dropping/wipe off the form for her to sign.
The cowboy always gives his horse a chance to drink/drinking/fish from the stream.
The cowboy will rescue/rescuing/faint the calf that is stuck in the ravine.
The crowd will debate/debating/loan whether the army will advance without warning.
The customer will pay/paying/ferry only if he likes the steak.
The decorator for the mansion will hang/hanging/roof new artwork in the parlor.
The deer might spring/springing/coast away from the water if they sense the danger.
The deer will leap/leaping/scheme away if you do not move quietly.
The defendant’s account of the incident did not match/matching/paste the one given by the

codefendant.
The dog will beg/begging/grip if you start eating that steak.
The dust on the stored furniture will aggravate/aggravating/remedy the allergies of the man.
The experienced classroom instructor will observe/observing/channel the new students talking.
The fancy French clock does not tell/telling/ask the time during power failures.
The farmhouse is so old that it scares/scaring/writes the neighbors.
The football player wants to practice/practicing/contact the routine again tonight.
The gangster in the car might chase/chasing/nibble the man running down the street.
The gas stove will leak/leaking/bar again if it is not fixed properly.
The general agreed to discharge/discharging/pen the soldier who had been injured.
The girl wanted to hug/hugging/ticket her brother before he got on the bus.
The guitarist wanted to present/presenting/carve the new piece for the crowd.
The hiker used his last match to start/starting/tie the fire.
The house painter will paint/painting/feed the hall a bright color.
The kindergarteners knew to glue/gluing/market the shapes to the construction paper.
The landlord might collect/colleting/fan rent late from the family tomorrow.
The lecture by the professor will take/taking/sprout all afternoon to finish.
The leftover pizza will mold/molding/drive if it is left out too long.
The lever on the basement wall does not shut/shutting/lift off the power supply.
The little boy went to kiss/kissing/pity his mother on the cheek.
The man in the parked van might honk/honking/echo the horn.
The man will prepare/preparing/stable the leftover turkey tomorrow for dinner.
The manager will vacuum/vacuuming/salt the storage room for the furniture.
The mercenaries want to hunt/hunting/praise for the escaped prisoner tomorrow.
The minister truly does believe/believing/nurse that everyone will benefit from it.
The mother and father do love/loving/institute their daughter very much.
The movers did not think that the piano would weigh/weighing/cough as much as it did.
The musicians in the booth will rehearse/rehearsing/explode the song before they perform.
The musicians will tune/tuning/justify their instruments before the performance this evening.
The nanny will dress/dressing/sink the toddler in warmer clothes if it is snowing.
The new brand of toothpaste could help/helping/beg to provide protection against disease.

The new chemical additive may tend/tending/desire to lower the freezing point of water.
The new cop needs to pursue/pursuing/pipe the criminal down the busy street.
The new crop of corn should feed/feeding/scrape everyone in the state.
The new dance routine should entertain/entertaining/rush the bored audience tonight.
The new detergent is supposed to polish/polishing/burn the floors with ease.
The new fighter plane can fly/flying/walk faster than anyone had expected.
The new heater in the maid's room should dry/drying/find the laundry.
The new romance novel should sell/selling/leak in every store this year.
The new software package will print/printing/glue very elaborate pictures on nice paper.
The new songs will impress/impressing/chance the singer of the band.
The new species of orchid will thrive/thriving/sing in tropical regions.
The new stepfather will have to disclipline/discliplining/lead the toddler for hitting his brother.
The new teacher will supervise/supervising/cash the exam for the students.
The newly planted grass will grow/growing/swim quite a bit during the next year.
The office manager might budget/budgeting/impact for a department party for the holiday.
The old engineer could still invent/inventing/pile new devices to save time.
The pacifier we bought in Japan will soothe/soothing/drop the cranky baby.
The parked truck will delay/delaying/respect oncoming traffic in the street.
The peregrine falcon chicks always chirp/chirping/staple until the father brings food.
The pet cats will soon enjoy/enjoying/describe their evening meal together.
The platter of cheese will feed/feeding/edge all of the guests.
The playful dog will only sit/sitting/drain if given a treat.
The plumber said that the leaking water might seep/seeping/speak out from behind the refrigerator.
The policeman will catch/catching/brief the slow woman on the corner.
The poor author will write/writing/harness a new book for children.
The portrait of Uncle Henry does not look/looking/sing like him.
The powerful magnet will pull/pulling/learn defective parts from the assembly line.
The publisher hoped that the textbook would draw/drawing/hear students with a variety of interests.
The puppy seems to like/liking/call/calling to sleep a lot during the day.
The quiet nanny might read/reading/mortgage a book to the children in the park.

The rebel attack will surprise/surprising/pioneer the dictator of the country.
The red ants in Arizona will bite/biting/wash you if you are not careful.
The repairman thinks that the leaky tub might bother/bothering/ask the tenants downstairs.
The restaurant critic plans to compliment/complimenting/prejudice the well cooked veal.
The roommate will promise/promising/crawl to clean the den for the party.
The roses in the corner plot will thrive/thriving/spin in the sun.
The scientist will carefully review/reviewing/fork the research article with the professor.
The security camera at the bank will now take/taking/trip photographs of everyone.
The simulated accident might frighten/frightening/ignore the children enough that they will wear their bike helmets.
The stamp collector will buy/buying/spite as many stamps as he can find.
The stealthy tiger might attack/attacking/slow the village if it is hungry.
The supervisor's report found that the factory should train/training/hug workers more thoroughly.
The tailor will consider/considering/purse different designs for the new suit.
The tailor will patch/patching/pot the hole in the jeans for a small fee.
The tall runner did slip/slipping/raid on the wet track close to the finish line.
The tired assistant will iron/ironing/key the dress for the customer.
The tired detective might phone/phoning/value the lawyer about his notes.
The tourist could only hope/hoping/sweat to see the monument before leaving.
The tree in the backyard can not sprout/sprouting/sell new buds in this weather.
The two striped cats seemed to fight/fighting/tap all the time at the farm.
The undercover cop will inform/informing/range the actor during the raid.
The villagers needed to fish/fishing/treat in order to survive the winter.
The volunteers offered to repair/repairing/square the house for the family.
The waitress will serve/serving/shock the dinner in a few minutes.
The wallpaper was removed so the housewife could decorate/decorating/topple the wall.
The workmen in the ditch planned to dig/digging/inspire all the way to the pipe.
The young horse looked so fast that the gambler might bet/betting/twist on him.
The young lion is going to claw/clawing/type the baboon on the rock.
These types of grapevines do not fruit/fruiting/jog well in sandy regions.
This exotic spice may add/adding/seek the oriental flavor that John enjoys.

This expensive ointment will cure/curing/loathe all known forms of skin disease.
This old electric blender does not crush/crushing/own ice cubes anymore.
This rare herb can heal/healing/count the pains in your back.
This test of reasoning might fail/failing/hate to discriminate among students.
William thought that he would fit/fitting/dig right in with the crowd at the reception.

APPENDIX B
WHOLE SENTENCE STIMULI WITH COMPREHENSION QUESTIONS

Whole Sentences (nonanomalous/ syntactic anomaly/ semantic anomaly)	**Nonanomalous Questions**		**Syntactic Questions**		**Semantic Questions**	
At the aquarium, there are otters that swim/ swimming/ fly and do tricks for the crowds.	Does the aquarium have otters?	Is the aquarium missing otters?	Does the aquarium have otters?	Is the aquarium missing otters?	Does the aquarium have otters?	Is the aquarium missing otters?
Billy bumped his bicycle, causing it to land/ landing/ sneeze into the street.	Did the bicycle land in the street?	Did the bicycle land on the sidewalk?	Did the bicycle land in the street?	Did the bicycle land on the sidewalk?	Did the bicycle sneeze into the street?	Did the bicycle sneeze into the sidewalk?
Fountain pens should not be used to sketch/ sketching/ dust since they were designed only for writing.	Were fountain pens designed for writing?	Were fountain pens designed for sketching?	Were fountain pens designed for writing?	Were fountain pens designed for sketching?	Were fountain pens designed for writing?	Were fountain pens designed for sketching?
In case of a break-in, the alarm system will warn/ warning/ swear that there is an intruder.	Will the alarm system warn that there is an intruder?	Will the alarm system warn that there is a storm?	Will the alarm system warn that there is an intruder?	Will the alarm system warn that there is a storm?	Will the alarm system swear that there is an intruder?	Will the alarm system swear that there is a storm?
In the nation's landfills, chemicals of different sorts may mix/ mixing/ hope to create lethal substances.	Do chemicals mix in the nation's landfills?	Do chemicals mix in the nation's parks?	Do chemicals hope to create lethal substances in the nation's landfills?	Do chemicals hope to create lethal substances in the nation's parks?	Do chemicals hope to create lethal substances in the nation's landfills?	Do chemicals hope to create lethal substances in the nation's parks?

One kangaroo at the San Diego Zoo would sometimes hop/ hopping/ write all day.	Will the kangaroo sometimes hop all day?	Will the kangaroo always hop all day?	Will the kangaroo sometimes hop all day?	Will the kangaroo always hop all day?	Will the kangaroo sometimes write all day?	Will the kangaroo always write all day?
People hope that the sculpture will inspire/ inspiring/ invent new forms of artistic expression.	Will the sculpture possibly inspire new forms of artistic expression?	Will the sculpture definitely inspire new forms of artistic expression?	Will the sculpture possibly inspire new forms of artistic expression?	Will the sculpture definitely inspire new forms of artistic expression?	Will the sculpture possibly invent new forms of artistic expression?	Will the sculpture definitely invent new forms of artistic expression?
Physicists will study/ studying/ lock the long report that arrived yesterday morning.	Did the long report arrive yesterday?	Did the long report arrive today?	Did the long report arrive yesterday?	Did the long report arrive today?	Did the long report arrive yesterday?	Did the long report arrive today?
She has a rag to dust/ dusting/ act the living room already.	Does she have a rag to dust the room?	Does she have a maid to dust the room?	Does she have a rag to dust the room?	Does she have a maid to dust the room?	Does she have a rag to clean the room?	Does she have a maid to clean the room?
The accountant will deliver/ delivering/ string the reports on the embezzlement to the detective.	Will the accountant deliver the reports?	Will the accountant deliver the checkbook?	Will the accountant deliver the reports?	Will the accountant deliver the checkbook?	Will the accountant deliver the reports?	Will the accountant deliver the checkbook?
The award winning play will run/ running/ leap for several more months.	The play will run for several more months.	The play will run for several more years.	The play will run for several more months.	The play will run for several more years.	The play will run for several more months.	The play will run for several more years.

The babies will cry/ crying/ graduate because they are hungry for their dinner.	Will the babies cry because they are hungry?	Will the babies sleep because they are hungry?	Will the babies cry because they are hungry?	Will the babies sleep because they are hungry?	Will the babies cry because they are hungry?	Will the babies sleep because they are hungry?
The baker wants to bake/ baking/ cast a wedding cake for the couple.	Does the baker want to bake a wedding cake?	Does the baker want to bake a ham?	Does the baker want to cast a wedding cake?	Does the baker want to cast a ham?	Does the baker want to cast a wedding cake?	Does the baker want to cast a ham?
The beavers in the pond sometimes chew/ chewing/ melt the garden hose.	Will the beavers occasionally chew the hose?	Will the beavers always chew the hose?	Will the beavers occasionally chew the hose?	Will the beavers always chew the hose?	Will the beavers occasionally melt the hose?	Will the beavers always melt the hose?
The bored audience might watch/ watching/ button the new show and dance routine.	Will the audience possibly watch the new show?	Will the audience definitely watch the new show?	Will the audience possibly watch the new show?	Will the audience definitely watch the new show?	Will the audience possibly button the new show?	Will the audience definitely button the new show?
The boxes in the attic may still hold/ holding/ find many old photographs and souvenirs.	Do the boxes in the attic possibly hold old photographs?	Do the boxes in the attic definitely hold old photographs?	Do the boxes in the attic possibly hold old photographs?	Do the boxes in the attic definitely hold old photographs?	Do the boxes in the attic possibly find old photographs?	Do the boxes in the attic definitely find old photographs?
The bull that escaped could smash/ smashing/ send the wooden fence around the meadow.	Will the bull possibly smash the fence around the meadow?	Will the bull definitely smash the fence around the meadow?	Will the bull possibly smash the fence around the meadow?	Will the bull definitely smash the fence around the meadow?	Will the bull possibly send the fence around the meadow?	Will the bull definitely send the fence around the meadow?

The butcher will chop/ chopping/ influence the meat for the long line of customers.	Will the meat be chopped for the customers?	Will the vegetables be chopped for the customers?	Will the meat be chopped for the customers?	Will the vegetables be chopped for the customers?	Will the meat be chopped for the customers?	Will the vegetables be chopped for the customers?
The chatting students tried to ignore/ ignoring/ fence the scowling librarian at the desk.	Did the chatting students try to ignore the librarian?	Did the chatting students try to chat with the librarian?	Did the chatting students try to ignore the librarian?	Did the chatting students try to chat with the librarian?	Did the chatting students try to ignore the librarian?	Did the chatting students try to chat with the librarian?
The competitors will race/ racing/ age in the field with a large audience.	Will the field have a large audience?	Will the field have a small audience?	Will the field have a large audience?	Will the field have a small audience?	Will the field have a large audience?	Will the field have a small audience?
The composer agreed that his music should enchant/ enchanting/ question the public.	Did the composer agree about his music?	Did the composer disagree about his music?	Did the composer agree about his music?	Did the composer disagree about his music?	Did the composer agree about his music?	Did the composer disagree about his music?
The constable might question/ questioning/ cost the man from the convenience store.	Will the constable possibly question the man?	Will the constable definitely question the man?	Will the constable possibly question the man?	Will the constable definitely question the man?	Will the constable possibly cost the man?	Will the constable definitely cost the man?
The critic plans to complain/ complaining/ shop about the temperature of the meat.	Does the critic plan to complain?	Does the critic plan to leave?	Does the critic plan to complain?	Does the critic plan to leave?	Does the critic plan to shop?	Does the critic plan to leave?

The electrician will plug/ plugging/ spell the ceiling fan in when the power turns on.	Will the electrician spell the fan?	Will the electrician unplug the fan?	Will the electrician plug in the fan?	Will the electrician unplug the fan?	Will the electrician spell the fan?	Will the electrician unplug the fan?
The essay was due, so the student had to type/ typing/ gaze all night.	Did the student type all night?	Did the student sleep all night?	Did the student type all night?	Did the student sleep all night?	Did the student gaze all night?	Did the student sleep all night?
The fingerprints on the gun could prove/ proving/ judge that the defendant is innocent.	Will the fingerprints on the gun possibly prove the defendant's innocence?	Will the fingerprints on the gun definitely prove the defendant's innocence?	Will the fingerprints on the gun possibly prove the defendant's innocence?	Will the fingerprints on the gun definitely prove the defendant's innocence?	Will the fingerprints on the gun possibly judge the defendant's innocence?	Will the fingerprints on the gun definitely judge the defendant's innocence?
The flan might burn/ burning/ despair badly if the cook leaves the room.	Will the flan possibly burn badly?	Will the flan definitely burn badly?	Will the flan possibly burn badly?	Will the flan definitely burn badly?	Will the flan possibly despair badly?	Will the flan definitely despair badly?
The fugitive has to hide/ hiding/ repeat at the railway for a few months.	Will the fugitive repeat at the railway?	Will the fugitive repeat at the bus stop?	Will the fugitive hide at the railway?	Will the fugitive hide at the bus stop?	Will the fugitive repeat at the railway?	Will the fugitive repeat at the bus stop?
The gambler would cheat/ cheating/ sound the system if he could count cards.	Would the gambler cheat the system?	Would the gambler always obey the rules?	Would the gambler cheat the system?	Would the gambler always obey the rules?	Would the gambler sound the system?	Would the gambler always obey the rules?

The general admits that the missile might explode/ exploding/ call before leaving the area.	Did the general admit that the missile might explode?	Did the general admit that the missile will definitely explode?	Did the general admit that the missile might explode?	Did the general admit that the missile will definitely explode?	Did the general admit that the missile might call?	Did the general admit that the missile will definitely call?
The girl could hear/ hearing/ alter the music from two houses away.	Did the girl want to hug her brother?	Did the girl want to push her brother?	Did the girl want to hug her brother?	Did the girl want to push her brother?	Did the girl want to ticket her brother?	Did the girl want to push her brother?
The hidden door will open/ opening/ cook when the secret code is spoken.	Will the hidden door open with a secret code?	Will the hidden door open with a key?	Will the hidden door open with a secret code?	Will the hidden door open with a key?	Will the hidden door cook with a secret code?	Will the hidden door cook with a key?
The high court will judge/ judging/ wish whether he was wrong or not.	Will the high court judge him?	Will the high court avoid judgement?	Will the high court wish him?	Will the high court avoid wishing?	Will the high court wish him?	Will the high court avoid wishing?
The hikers noticed that the boulder seemed to rest/ resting/ live precariously on the mountain.	Did the hikers notice the boulder resting precariously?	Did the hikers notice the boulder resting securely?	Did the hikers notice the boulder resting precariously?	Did the hikers notice the boulder resting securely?	Did the hikers notice the boulder resting precariously?	Did the hikers notice the boulder resting securely?
The housewife in the kitchen had to bake/ baking/ enchant the cake early.	Did the housewife enchant the cake early?	Did the housewife enchant the cake late?	Did the housewife bake the cake early?	Did the housewife bake the cake late?	Did the housewife enchant the cake early?	Did the housewife enchant the cake late?
The inventive dancer might perform/ performing/ sketch a new routine for the crowd.	Will the dancer possibly perform a new routine?	Will the dancer definitely perform a new routine?	Will the dancer possibly perform a new routine?	Will the dancer definitely perform a new routine?	Will the dancer possibly sketch a new routine?	Will the dancer definitely sketch a new routine?

The investigation will persist/ persisting/ fry until the journalist finds real answers.	Will the investigation continue until answers are found?	Will the investigation stop until answers are found?	Will the investigation fry until answers are found?	Will the investigation stop until answers are found?	Will the investigation fry until answers are found?	Will the investigation stop until answers are found?
The lead singer did practice/ practicing/ space the badly performed song a few times.	Did the lead singer practice the song a few times?	Did the lead singer forget to practice the song a few times?	Did the lead singer practice the song a few times?	Did the lead singer forget to practice the song a few times?	Did the lead singer space the song a few times?	Did the lead singer forget to space the song a few times?
The local beers in Seattle will satisfy/ satisfying/ trip every beer drinker.	Will the beers satisfy every beer drinker?	Will the beers disappoint every beer drinker?	Will the beers satisfy every beer drinker?	Will the beers disappoint every beer drinker?	Will the beers trip every beer drinker?	Will the beers disappoint every beer drinker?
The loud reporter might annoy/ annoying/ beach the performers on the stage.	Will the reporter possibly annoy the performers?	Will the reporter definitely annoy the performers?	Will the reporter possibly annoy the performers?	Will the reporter definitely annoy the performers?	Will the reporter possibly beach the performers?	Will the reporter definitely beach the performers?
The maids clean/ cleaning/ trace the house while the family is away.	Will the maids clean the house?	Will the maids trash the house?	Will the maids clean the house?	Will the maids trash the house?	Will the maids clean the house?	Will the maids trash the house?
The man next door does own/ owning/ carpet his own boat at the lake.	Does the man next door own his own boat?	Does the man next door rent his own boat?	Does the man next door own his own boat?	Does the man next door rent his own boat?	Does the man next door carpet his own boat?	Does the man next door rent his own boat?
The meeting with the politician will continue/ continuing/ scratch in a few minutes.	Will the meeting continue in a few minutes?	Will the meeting continue in a few days?	Will the meeting continue in a few minutes?	Will the meeting continue in a few days?	Will the meeting continue in a few minutes?	Will the meeting continue in a few days?

The newlywed couple will dance/ dancing/ port first on the dance floor.	Will the newlywed couple dance first?	Will the newlywed couple dance third?	Will the newlywed couple dance first?	Will the newlywed couple dance third?	Will the newlywed couple port first?	Will the newlywed couple port third?
The noisy ducks will soon waddle/ waddling/ skip away from the lake.	Will the manager possibly budget for a party?	Will the manager definitely budget for a party?	Will the manager possibly budget for a party?	Will the manager definitely budget for a party?	Will the manager possibly impact for a party?	Will the manager definitely impact for a party?
The pickpocket might flee/ fleeing/ sing from the policeman down the alley.	Will the pickpocket possibly flee down the alley?	Will the pickpocket possibly flee down the stairs?	Will the pickpocket possibly flee down the alley?	Will the pickpocket possibly flee down the stairs?	Will the pickpocket possibly sing down the alley?	Will the pickpocket possibly sing down the stairs?
The publisher wants the author to edit/ editing/ harm the novel again.	Does the publisher want the author to edit the novel?	Does the publisher want the author to trash the novel?	Does the publisher want the author to edit the novel?	Does the publisher want the author to trash the novel?	Does the publisher want the author to harm the novel?	Does the publisher want the author to edit the novel?
The raging bull will soon charge/ charging/ whistle at the waiting man.	Will the raging bull charge soon?	Will the raging bull charge later?	Will the raging bull charge soon?	Will the raging bull charge later?	Will the raging bull whistle soon?	Will the raging bull whistle later?
The receptionist will call/ calling/ reason all the clients in the afternoon.	Will the receptionist call all the clients?	Will the receptionist fax all the clients?	Will the receptionist call all the clients?	Will the receptionist fax all the clients?	Will the receptionist reason with all the clients?	Will the receptionist fax all the clients?

The report on the desk does describe/ describing/ steam the incident in great detail.	Does the report describe the incident in detail?	Does the report describe the incident without much detail?	Does the report steam the incident in detail?	Does the report steam the incident without much detail?	Does the report steam the incident in detail?	Does the report steam the incident without much detail?
The retired gymnast will coach/ coaching/ guess the athletes for the high school.	Will the gymnast coach the athletes?	Will the gymnast coach the debate team?	Will the gymnast coach the athletes?	Will the gymnast coach the debate team?	Will the gymnast coach the athletes?	Will the gymnast coach the debate team?
The rude crowd might interrupt/ interrupting/ stake the shy singer at the bar.	Will the crowd possibly interrupt the singer?	Will the crowd definitely interrupt the singer?	Will the crowd possibly interrupt the singer?	Will the crowd definitely interrupt the singer?	Will the crowd possibly stake the singer?	Will the crowd definitely stake the singer?
The scientist thinks that the lab is supposed to research/ researching/ neglect the problem more thoroughly.	Does the scientist think the lab should neglect the problem thoroughly?	Does the scientist think the lab should never neglect the problem?	Does the scientist think the lab should neglect the problem thoroughly?	Does the scientist think the lab should never neglect the problem?	Does the scientist think the lab should neglect the problem thoroughly?	Does the scientist think the lab should never neglect the problem?
The scouts planned to camp/ camping/ cure at the national park next winter.	Do the scouts plan to camp at the national park?	Do the scouts plan to camp at the house?	Do the scouts plan to camp at the national park?	Do the scouts plan to camp at the house?	Do the scouts plan to cure at the national park?	Do the scouts plan to cure at the house?
The sea lions can bask/ basking/ edit on the beach all day.	Will the sea lions possible bask all day?	Will the sea lions definitely bask all day?	Will the sea lions possible bask all day?	Will the sea lions definitely bask all day?	Will the sea lions possible edit all day?	Will the sea lions definitely edit all day?

The skipper in the boat will sail/ sailing/ match to the dock.	Will the skipper sail to the dock?	Will the skipper swim to the dock?	Will the skipper match to the dock?	Will the skipper swim to the dock?	Will the skipper match to the dock?	Will the skipper swim to the dock?
The skyscraper being built by the city would block/ blocking/ send out the sunlight.	Will the skyscraper block out the sunlight?	Will the skyscraper block out the garden?	Will the skyscraper block out the sunlight?	Will the skyscraper block out the garden?	Will the skyscraper send out the sunlight?	Will the skyscraper send out the garden?
The soccer player wanted to jog/ jogging/ whisper in order to warm up.	Did the soccer player want to jog?	Did the socker player want to rest?	Did the soccer player want to jog?	Did the socker player want to rest?	Did the soccer player want to whisper?	Did the socker player want to rest?
The solitary dancer might leap/ leap/ rule across the stage for the next scene.	Will the dancer possibly leap across the stage?	Will the dancer definitely leap across the stage?	Will the dancer possibly leap across the stage?	Will the dancer definitely leap across the stage?	Will the dancer possibly rule across the stage?	Will the dancer definitely rule across the stage?
The stage actor will complete/ completing/ calm the ending of the scene as planned.	Will the actor calm the ending of the scene?	Will the actor stop performing before the end?	Will the actor complete the ending of the scene?	Will the actor stop performing before the end?	Will the actor calm the ending of the scene?	Will the actor stop performing before the end?
The strawberry beds might tempt/ tempting/ sneeze rabbits and other hungry animals.	Will the strawberry beds possibly tempt the rabbits?	Will the strawberry beds definitely tempt the rabbits?	Will the strawberry beds possibly tempt the rabbits?	Will the strawberry beds definitely tempt the rabbits?	Will the strawberry beds possibly sneeze rabbits?	Will the strawberry beds definitely sneeze rabbits?
The student might crease/ creasing/ poison the paper to take better notes.	Will the student possibly crease the paper?	Will the student definitely crease the paper?	Will the student possibly crease the paper?	Will the student definitely crease the paper?	Will the student possibly poison the paper?	Will the student definitely poison the paper?

The supervisor of the plant wanted to observe/ observing/ top the work of the technician.	Did the supervisor want to top the work of the technician?	Did the supervisor want to do the work of the technician?	Did the supervisor want to observe the work of the technician?	Did the supervisor want to do the work of the technician?	Did the supervisor want to top the work of the technician?	Did the supervisor want to do the work of the technician?
The teacher said our report must not last/ lasting/ cry for more than ten minutes.	Should the report last no more than ten minutes?	Should the report last longer than ten minutes?	Should the report last no more than ten minutes?	Should the report last longer than ten minutes?	Should the report cry no more than ten minutes?	Should the report cry longer than ten minutes?
The therapist hoped that the new drug would calm/ calming/ clean the patient who was so anxious.	Did the therapist hope the drug would clean the patient?	Did the therapist hope the drug would excite the patient?	Did the therapist hope the drug would calm the patient?	Did the therapist hope the drug would excite the patient?	Did the therapist hope the drug would clean the patient?	Did the therapist hope the drug would excite the patient?
The toddler needed to cough/ coughing/ lean after smelling the smoke in the kitchen.	Did the toddler need to cough after smelling smoke?	Did the toddler need to swim after smelling smoke?	Did the toddler need to cough after smelling smoke?	Did the toddler need to swim after smelling smoke?	Did the toddler need to lean after smelling smoke?	Did the toddler need to swim after smelling smoke?
The tree branch will break/ breaking/ lecture if the wind is too strong.	Will the tree branch break if the wind is too strong?	Will the tree branch break if there is no wind?	Will the tree branch break if the wind is too strong?	Will the tree branch break if there is no wind?	Will the tree branch lecture if the wind is too strong?	Will the tree brach lecture if there is no wind?
The truck driver will park/ parking/ finish in the street and not the driveway.	Will the truck driver park in the street?	Will the truck driver park in the driveway?	Will the truck driver finish in the street?	Will the truck driver finish in the driveway?	Will the truck driver finish in the street?	Will the truck driver finish in the driveway?

The underpaid comedian will perform/ performing/ heal until the last guest leaves.	Will the comedian perform?	Will the comedian sleep?	Will the comedian perform?	Will the comedian sleep?	Will the comedian perform?	Will the comedian sleep?
The vacuum in the storage room should clean/ cleaning/ sketch all the furniture.	Will the vacuum sketch the furniture?	Will the vacuum stain the furniture?	Will the vacuum clean the furniture?	Will the vacuum stain the furniture?	Will the vacuum sketch the furniture?	Will the vacuum stain the furniture?
The volunteer coach will evaluate/ evaluating/ knit the performance of each player.	Will the coach evaluate each performance?	Will the coach evaluate each exam?	Will the coach evaluate each performance?	Will the coach evaluate each exam?	Will the coach knit each performance?	Will the coach knit each exam?
The woman wanted to hate/ hating/ shell her, but she enjoyed her company too much.	Did the woman enjoy her company?	Did the woman hate her?	Did the woman enjoy her company?	Did the woman hate her?	Did the woman enjoy her company?	Did the woman hate her?
Those small spiders would often spin/ spinning/ burn beautiful webs in the trees.	Do the small spiders often spin beautiful webs?	Do the small spiders often spin ugly webs?	Do the small spiders often spin beautiful webs?	Do the small spiders often spin ugly webs?	Do the small spiders often burn beautiful webs?	Do the small spiders often burn ugly webs?
We hoped that the news of the award would cheer/ cheering/ wash up the depressed student.	Will the award possibly cheer up the student?	Will the award definitely cheer up the student?	Will the award possibly cheer up the student?	Will the award definitely cheer up the student?	Will the award possibly wash up the student?	Will the award definitely wash up the student?

Where the road forks/ forking/ believes, we could not figure out which way to go.	Could they not figure out which way to go?	Could they figure out which way to go?	Could they not figure out which way to go?	Could they figure out which way to go?	Could they not figure out which way to go?	Could they figure out which way to go?

APPENDIX C
RSVP SENTENCE FILLERS WITHOUT COMPREHENSION QUESTIONS

RSVP Filler Sentences
The accident destroyed the new tire in a few seconds.
The adult posted the reward for the lost pet in the newspaper.
The air force commander bombed the enemies that were in a pit.
The army tank shot the weapon shed of the terrorist organization.
The artistic sketch pictured a green pasture out in the country.
The aspiring poet typed a trail of words on the page.
The bakery cook broke an egg white into the cookie dough.
The band calmed the rowdy observers at the sporting event.
The baseball player touched the ball with a light tap of the bat.
The battle damaged the fleet of naval ships off the coast.
The beginning pianist sold his old violin in the music store.
The big bubble narrowly escaped the pointy branch of the tree.
The biology professor measured the large wing of the rare bird.
The breeze flowed through the sails of the large boat.
The bright lightning blinded the scared passengers on the bus.
The brown calf played with his herd in the shadow of the tree.
The business convention misinterpreted the fiscal profile of the company last year.
The buzzing bees flew over the top of the pond.
A mosquito landed on the netted food near the campers.
The cardboard box sheltered the homeless native from the rain shower.
The clever customer determined the freight of the boxed cargo.
The cloud caught the colorful tip of the rainbow in the sky.
The cold whiskey filled the short cup to the rim.
The college student is learning about the aliens through a novel.
The construction worker pulled the toast out of the toaster for breakfast.
The construction team drilled the metal rod into the ground.
The costumer designed the cake for the birthday party that night.
The couple sought out the perfect couch for their new apartment.

My cousin bought me a vacuum from the department store.
The crowd judged the man based on the size of his waist.
The dangerous criminal plotted a murder and burial behind his family's back.
The dentist commanded the servant that worked in the mansion.
The detective voiced his concern for the woman over the phone.
The driver threw a green apple out of the window at an angle.
The established painter sent the romantic portrait to the museum in Philadelphia.
The experienced sergeant controlled the massive fort and all of the officers.
The experienced detective questioned the suspect in the expensive suite.
The experienced guide scaled the treacherous cliff with ease on the hike.
The fad diet promised a short round of rapid results.
The famous poet wrote the brief passage at the beginning of the book.
The fashion magazine considered a segment on winter wear for the cover story.
The fast hawk attacked the small animal over the sea.
The flash flood destroyed all of the lodges in the area.
The flat prairie circled the camp on the outskirts of town.
The floats rode down a one lane road throughout the parade.
The flowered stems framed the elegant arch in the castle garden.
The frame would not stick to the wall with just tape.
The gated entrance rose out of the forest wilderness in the north.
The genuine smile shaped the drama between the two sisters.
The grandfather trusted the workers in the day care center with his granddaughter.
The group of knights crowded into the fort before they left.
A professional styled the outlandish outfit of the guest speaker.
The hard fight secured the weapons from the building in the village.
The horse drawn carriage parked at the curb near the tourists.
The hungry flock ate the lush grass in the plentiful field.
The iron gate met the picket fence at the front of the property.
The judge filed a bunch of legal paperwork at the courthouse.
The judges rated the band and composer with a perfect score.
The kind nurse comforted the sick patient in the waiting room.
The large vessel silenced the prayers of the people in town.

The lawyer was seated at the bar with a drink in hand.
The lean messenger turned the red shoes so they would fit better.
The lightning struck the tall bridge on Tuesday night during the storm.
The link to the city aided the goals of the governor.
The lip-synched tune fooled the ecstatic fans at the concert.
I listened carefully to the loud thunder and pelting hail.
The long pipe oiled the drawbridge near the hinges at the front.
The long train on the track weighed a sum of one hundred thousand pounds.
The loud orchestra blocked out the opera singer's beautiful voice.
The lounge singer saved her wages to pay off her loans.
The man farmed the land with a tractor and a rake.
The mare landed the impressive jump in the amateur competition.
The captain guided the massive ship through the dangerous cape.
The master watched carefully over his fish in the large tank.
The military raid defeated a large branch of the terrorist organization.
The mold hated the intense heat of the arid environment.
My mother cooked fried fish for dinner and apple pie for dessert.
The motor forced the gas through the pistons in the car.
The movie recalled the birth of one of the greatest inventions of all time.
The movie star murdered her mate in the horror film.
The new coach traded his worst player in order to become a champion.
The new treasurer improved the financial disaster by holding many fundraisers.
The news channel taped the natural disaster from a distance.
The next speaker counted the watches on the front table.
The novel listed the lofty goals of the main character.
The old rug joined the pile of linens at the garage sale.
The old woman called the front desk of the resort for tea.
The old rabbi replied to the letter with a short prayer.
The older gentleman carried the worn saddle to the stables for the ride.
The painter emptied the new package of art supplies onto the table.
A parade of tractors rolled through the center of town.
The patriotic lieutenant battled the enemy with his men in the desert.

The people were angered by the buzzing bee that was on the bush.
The pony smelled the green grass on top of the hill.
The prestigious institute reviewed the pile of applications for the teaching position.
The prestigious bank assisted the flock of eager investors after hours.
The princess pocketed her private journal in the crowded room.
The prison guard signaled to the inmate with a hand sign.
The promising candidate failed the important interview on Tuesday afternoon.
The protruding pipe tripped the tourist in the hotel room.
The purple balloon crossed the green valley after sunset on Wednesday evening.
The quiet grandfather reached the old library just in time.
The receiver hurt his shoulder before the football game in Tennessee.
The red barn held the winning pony from the contest.
The refrigerated trailer shipped the specialty beef across the country.
The renowned poet spoke about the Italian landscape in his greatest work.
The researchers tested the new drug with a series of tests on the nose.
The resounding echo trailed the noisy camp of summer vacationers.
The respected scholar remarked about the new design for the engine.
The robed priest disputed the segment of the document about the church.
The rocky soil lined the slope of the tall mountain.
I completed a large jigsaw puzzle in the ski lodge during the blizzard.
The science professor named the planet in the distant galaxy.
The scientific tool fired a powerful beam of charged protons.
The navy stationed the seaman on the quiet sea base.
The seasoned farmer planted green peppers in the fertile valley.
The seasoned commander watched his troops with a pair of keen eyes.
The ship was grounded on the east coast of Florida.
The signal noted the steep curve in the road up ahead.
The skilled builder engineered the decorative mantle above the fireplace.
The small store feared the financial drain of the poor economy.
The soccer match leveled a track of grass on the playing field.
The spark rode the stem of the fuse on the explosive.
The sticky mud covered the dairy farm after the spring rains.

The stiff collar of my shirt brushed against my palm.
My strict aunt quieted my three brothers in the carpet store.
The talented builder developed a new roof for the church.
The tank raced the roll of rapid gunfire in the war zone.
The teacher phoned the library for a book about organs.
The team secured the loose lumber before the arrival of the storm.
The thick smoke passed the cape of the island after the volcanic eruption.
The tired pupil dreamed of more comfortable furniture for his dorm room.
We tracked our distance on foot with a computerized map.
The triple jump beat the lateral twist in the figure skating competition.
The unhappy queen suspected the flowers on her table because of the smell.
The unhealthy diet increased the weight of the participants in the study.
The visitor mailed the envelope at the post office on Thursday.
The visitor tasted the savory steak at the new restaurant.
The warm sunlight heated the small lake in the summer.
The water from the fountain cooled the sweaty foot of the child.
The wheel of the car missed the platform by an inch.
The wind storm moved across the small kingdom at a quick pace.
The witness viewed a photograph of the criminal in court.
The dress design called for a narrow skirt down to the ankle.
The woman's salary was wasted on skirts, shoes, and jewelry.
The young princess and elegant queen exchanged glances over the table.
The young teacher challenged her class with a heap of difficult assignments.
The young woman was troubled by her dream that was about an assault.
The young boy motioned to the scar on his elbow with sad eyes.
The hostile natives claimed their land from the new settlers.

APPENDIX D
WHOLE SENTENCE TASK FILLERS WITH COMPREHENSION QUESTIONS

Whole Filler Sentences	**‘Yes’ Questions**	**‘No’ Questions**
The hot steam from the shower kept the suite warm.	Did the steam keep the suite cool?	Did the steam keep the suite warm?
The lively seal traveled towards the sunset near the shore.	Did the lively seal travel towards the sunrise?	Did the lively seal travel towards the sunset?
The needle stick transferred the deadly poison from the frog.	Did the needle stick cure the poison?	Did the needle stick transfer the poison?
The doctor financed his medical school education with money from an accidental injury.	Was the education paid for with money from a scholarship?	Was the education paid for with money from an accidental injury?
The church minister permitted the tourist group to see the service.	Did the tourist group miss the service?	Did the tourist group see the service?
The flood killed many plants and animals in the kingdom.	Did the flood kill few plants?	Did the flood kill many plants?
The large orchestra stayed in the resort after the concert series.	Did the orchestra stay in the lodge?	Did the orchestra stay in the resort?
The coach rewarded his new team with a pint of ice cream.	Did the coach give his team warm up drills?	Did the coach give his team ice cream?
The hysterical laughter summarized the comical sketch of the politician in the paper.	Was there a professional portrait of the politician?	Was there a comical sketch of the politician?
The repairman rewired the phone line in the new apartment.	Was the phone line disconnected?	Was the phone line rewired?

The black bear fought the large creature in the forest.	Did the black bear fight in the meadow?	Did the black bear fight in the forest?
The rough tide rocked the small ferry back and forth.	Was the ferry sitting calmly on the water?	Was the ferry rocking on the water?
The rich lawyer welcomed his new clients over to his desk.	Did the lawyer welcome his partners?	Did the lawyer welcome his clients?
The tent moved around our campsite with the calm breeze.	Did the tent blow into the lake?	Did the tent blow around the campsite?
The adult interviewed the witness on trial in the courtroom.	Did the adult interview the witness in the office?	Did the adult interview the witness in the courtroom?
The tired server stepped with a limp up the stairs.	Did the server limp up the sidewalk?	Did the server limp up the stairs?
The loud motor shook the flimsy trailer in the parking lot.	Did the motor shake the car?	Did the motor shake the trailer?
The marinated steak supplied the savory juice for the gravy.	Did the roast supply the juice for the gravy?	Did the steak supply the juice for the gravy?
The priest administered the written prayer in church on Sunday.	Did the nun administer the written prayer?	Did the priest administer the written prayer?
The lieutenant planned the entire conference for the military academy.	Did the cadet plan the conference?	Did the lieutenant plan the conference?
The elegant dancer won a medal and became the state champion.	Did the soccer player win a medal?	Did the dancer win a medal?

The green mold grew on the fruit left out overnight.	Did the mold grow on the bread?	Did the mold grow on the fruit?
The policeman searched for his harness in his messy car.	Did the policeman search for his badge?	Did the policeman search for his harness?
The young doctor showed the hospital nursery to the new parents.	Did the nurse show the nursery to the parents?	Did the doctor show the nursery to the parents?
The small insect laid on the forehead of the man.	Did the insect lay on the man's arm?	Did the insect lay on the man's forehead?
The friendly nurse smiled at her new patient in the hospital.	Did the nurse frown at her patient?	Did the nurse smile at her patient?
The judge stored the bottles of alcohol in the cabinet behind the desk.	Did the judge store soda?	Did the judge store alcohol?
The boss smoothed out the quarrel with a lame joke.	Did the employee smooth out the quarrel?	Did the boss smooth out the quarrel?
The sad minister stood alone outside of the tiny cottage.	Did the minister stand inside the cottage?	Did the minister stand outside the cottage?
The accomplished musician taught the aspiring pianist on Monday afternoons.	Did the musician teach the violinist?	Did the musician teach the pianist?
The travelling scholar glimpsed the ship in the distance from the port.	Did the scholar glimpse a port?	Did the scholar glimpse a ship?
The federal government taxes liquor in order to build an empire.	Does the government ban liquor?	Does the government tax liquor?

The new steel decreased the weight of the heavy automobile.	Did the steel increase the weight?	Did the steel decrease the weight?
The anchor dropped into the sand to keep the boat still in the bay.	Did the anchor drop into the deck?	Did the anchor drop into the sand?
The busy sergeant marked the card with his personal stamp yesterday.	Was the card marked with his signature?	Was the card marked with his stamp?
The fabric of the shirt matched the texture of the long skirt.	Did the shirt clash with the skirt?	Did the shirt match the skirt?
The political convention displayed a bar graph of the results on the computer.	Were the results shown on a line graph?	Were the results shown on a bar graph?
The talented composer expressed his emotions and ideas through a string of music.	Were his emotions expressed through writing?	Were his emotions expressed through music?
The woman strained to see the moon that was on the bay's horizon.	Was the moon on the field's horizon?	Was the moon on the bay's horizon?
The art institute picked the winning portrait of the woman.	Did the woman pick the winning portrait?	Did the art institute pick the winning portrait?
The travel guide lost the troop of tourists in the busy city.	Did the travel guide lose the keys?	Did the travel guide lose the tourists?
The metal revolver was loaded in case there was a robbery.	Was the revolver unloaded?	Was the revolver loaded?
The powerful drill neared the oil deep under the ground.	Was the drill getting close to water?	Was the drill getting close to oil?

The brown hawk bit the trainer on her left cheek.	Did the hawk scratch the trainer?	Did the hawk bite the trainer?
The new jury examined the evidence for a gruesome murder.	Did the jury ignore the evidence?	Did the jury examine the evidence?
The robbery victim guarded the stables for hours after the incident.	Did the victim guard the house?	Did the victim guard the stables?
The leader returned the dinner plate after he was finished.	Did the leader keep the plate?	Did the leader return the plate?
The innovative musician sang the famous passage from the Shakespearian play on stage.	Did the musician sing a passage from Mozart?	Did the musician sing a passage from the Shakespearian play?
The famous actress wore a dress to the movie premier.	Did the actress wear pants to the premier?	Did the actress wear a dress to the premier?
The malicious post shocked the humble candidate in the campaign.	Did the post calm the candidate?	Did the post shock the candidate?
The keen observer reported accurate information of the quarrel to the news team.	Was the information reported inaccurately?	Was the information reported accurately?
The aluminum foil protected the slice of pizza in the refrigerator.	Was the pizza in the freezer?	Was the pizza in the refrigerator?
The kindergarten student drew a circle on the hot cement.	Did the student draw a square?	Did the student draw a circle?
The server boxed the tray of delicious food for the guests.	Did the chef box the food for the guests?	Did the server box the food for the guests?

The new employee was trained on the register at the store.	Was the new employee trained at the meeting?	Was the new employee trained at the store?
The metal rail supported the ski lift on the mountain.	Did the metal rail support the bridge?	Did the metal rail support the ski lift?
The sharp knife split the fresh pork at the dinner table.	Did the knife split the ham?	Did the knife split the pork?
The enemy submarine surfaced along the coast early yesterday morning.	Did the submarine surface last night?	Did the submarine surface yesterday?
The English teacher graded the spelling test with a pencil.	Did the teacher grade the test with a pen?	Did the teacher grade the test with a pencil?
The narrow corridor stopped at the edge of the small living room.	Did the corridor stop at the edge of the dinning room?	Did the corridor stop at the edge of the living room?
The officer's bark advanced the fleet of war ships along the coast.	Did the officer's bark cause the ships to retreat?	Did the officer's bark cause the ships to advance?
The movie star chose a fancy ring for her engagement.	Did the singer choose a ring?	Did the movie star choose a ring?
The cracked bell in the town rang loudly throughout the crowd.	Did the bell ring softly?	Did the bell ring loudly?
The strange creature surprised the troop of explorers in the rainforest.	Did the creature surprise the tourists?	Did the creature surprise the explorers?
The bright red cardinal quietly approached the covered porch for bird seed.	Did the cardinal approach the garden?	Did the cardinal approach the porch?

The alien built the flying vessel from materials in outer space.	Was the vessel built from materials from Earth?	Was the vessel built from materials in outer space?
The disciplined guard raised his gun toward the dangerous driver.	Did the guard lower his gun?	Did the guard raise his gun?
The wide receiver patted the sweat on his forehead with a towel.	Was his forehead dry?	Was his forehead sweaty?
The talented pupil painted the fruit in the still life.	Did the pupil paint the vase?	Did the pupil paint the fruit?
The tall oak tree pushed the root into the ground.	Did the root push into the house?	Did the root push into the ground?
The black button matched the dark wool on the coat.	Did the button match the cotton?	Did the button match the wool?
The foreign enemy desired the jeweled purse of the queen of Scotland.	Did the enemy desire the shoes?	Did the enemy desire the purse?
The experienced panel of engineers voted for the funniest joke.	Did the engineers vote on the design?	Did the engineers vote on the joke?
The long tunnel through the mountain cut the mileage in half.	Was the mileage doubled?	Was the mileage cut in half?
The policeman issued a statement about the robbery at the bank.	Was the statement about the kidnapping?	Was the statement about the robbery?

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BIOGRAPHICAL SKETCH

Sarah Key-DeLyria received her Bachelor of Arts in linguistics and cognitive sciences from Rice University in Houston, Texas, her hometown, in 2004. It was while at Rice that she first became interested in speech-language pathology research. She earned her Master of Arts in speech-language pathology from The University of Texas at Austin in 2006 where she studied aphasia treatment with Swathi Kiran and acquired apraxia of speech with Thomas Marquardt. While earning her Doctor of Philosophy at the University of Florida, she conducted research on cognition and language in the Language over the Lifespan Lab with Lori Altmann and in the Clinical-Cognitive Neuroscience Lab using electroencephalography (EEG) with William Perlstein. She has presented several posters and given talks about her research at national and international conferences. She also earned clinical certification in speech-language pathology from the American Speech-Language-Hearing Association (ASHA) while completing her studies.