Language Performance in Adults with Mild Traumatic Brain Injury

by

Rocío Sermeno Norman

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The dissertation is approved by the following members of the Final Oral Committee:
Lyn S. Turkstra, Professor, Communication Sciences and Disorders
Manish N. Shah, Associate Professor, Department of Emergency Medicine
Cynthia Fowler, Professor, Communication Sciences and Disorders
Margarita Kaushanskaya, Professor, Communication Sciences and Disorders
Barbara B. Bendlin, Associate Professor, Department of Medicine
Audra Sterling, Assistant Professor, Communication Sciences and Disorders

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Dedication

To David, James, and Caleb

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ABSTRACT

Adults with mild traumatic brain injury (mTBI) are at risk for developing persistent cognitive, physical, and psychological symptoms. Adults with mTBI often report difficulties meeting the demands of everyday communication. Studies which characterize mTBI-related communication functions are needed in this growing area of rehabilitation and research. Speed of information processing is expected to affect communication because of the speeded nature of conversation.

In this dissertation, we report data from three studies designed to characterize language performance after mTBI. For two studies, we tested a speed-based hypothesis based on the evidence that speed of information processing is an area of cognitive impairment for many people after mTBI. We compared performance to an OI group to discriminate the effects of brain versus general trauma in the subacute stage of recovery from mTBI. Results indicated that on experimental naming and comprehension tasks, individuals with mTBI performed in a comparable way to OI controls. The effect of a condition of speed was statistically significant for the group as a whole, but differences could not be attributed to mTBI specifically. In addition, accuracy and reaction time were correlated with injury and symptom variables such as sleep quality and fatigue. Our third study aimed to characterize communication in adults with mTBI by measuring self-perception of communication problems and comparing these responses to a group of adults with moderate to severe TBI and a community based comparison (CC) group. The mTBI group identified fewer areas of deficit in communication competence than any of the study groups and there were only significant differences between groups at the opposite ends of the injury spectrum. The study findings suggest that perhaps a combination of a demanding linguistic tasks combined with strict temporal response windows can be a potential method for further study. These studies provide evidence that although injuries of this nature are considered "mild," the issues surrounding appropriate assessment, treatment, and recovery are complex and should be regarded in future research.

Keywords: adult, brain injuries, communication, mild traumatic brain injury, language

CHAPTER 1

Introduction

Introduction

Traumatic brain injury (TBI) is a major public health concern in the United States. In 2013, over 2.8 million individuals incurred traumatic brain injuries, and 80% of those injuries were classified as being mild in severity (Dhawan, Rose, Krassioukov, & Miller, 2006; Taylor, Bell, Breiding, & Xu, 2017). Mild traumatic brain injury (mTBI) is defined as:

> a traumatically induced injury manifested by at least one of the following 1) any period of loss of consciousness; 2) any loss of memory for events immediately before or after the accident; 3) any alteration in mental state at the time of the accident 4) focal neurological deficits that may or may not be transient; but where the severity of the injury does not exceed loss of consciousness for approximately thirty minutes of less; after thirty minutes an initial Glasgow Coma Scale (GCS) of 13-15; post-traumatic amnesia not greater than 24 hours. (American Congress of Rehabilitative Medicine, 1993a)

While the majority of adults who incur mTBI or concussion, a term that will be used interchangeably in this paper, recover fully within the first three months post-injury (L. Carroll et al., 2004), a small percentage experience persistent cognitive, physical, and psychological symptoms from six months to several years post-injury (Bernstein, 2002; Iverson, Gaetz, Lovell, & Collins, 2004; Makdissi, Davis, & McCrory, 2015). In recent years, research concerning the lifelong effects of mTBI has garnered the interest of the scientific and public. Much of this interest is driven by evidence that TBI is a risk factor for progressive diseases such as dementia, mild cognitive impairment, or chronic traumatic encephalopathy (Stern et al., 2011).

Language skills have often been regarded as a measure of recovery after TBI (Catroppa & Anderson, 2004; LeBlanc et al., 2014; Novack, Alderson, Bush, Meythaler, & Canupp, 2000). Assessment of language performance, an important aspect of general communication assessment, is typically included in health-related questionnaires and outcome measures such as the Functional Independence Measure (Keith, Granger, Hamilton, & Sherwin, 1987) and the Functional Assessment Measure (Wright, 2000), which are used to track recovery after in the weeks and months after injury. These measures are routinely used by rehabilitation personnel to monitor progress and medical status, inform prognosis for recovery, and track outcomes (Cifu et al., 1997; Keyser-Marcus et al., 2002; van Baalen, Odding, & Stam, 2008). Previous research by LeBlanc et al. (2014) has shown that patients who can express themselves in the acute stage of TBI have shorter lengths of stay in the hospital and generally experience more favorable discharge dispositions (i.e., they are discharged home and do not require assisted-living care). Conversely, deficits in receptive, expressive, and social language skills have been linked with many negative outcomes in the years post-injury, including reduced quality of life and social integration (Galski, Tomkins, & Johnston, 1998), difficulty with return to employment (Rietdijk, Simpson, Togher, Power, & Gillett, 2013), and impaired social interaction (March & Knight, 1991). These outcomes and the language profiles of individuals with moderate to severe TBI are well known in the rehabilitation community and have been documented by over three decades of research (Mozeiko, Le, Coelho, Krueger, & Grafman, 2011; Peach, 2013; Snow, Douglas, & Ponsford, 1998; Yang, Fuller, Khodaparast, & Krawczyk, 2010).

Speech-language pathologists are trained to assess and treat individuals with TBI at every stage of recovery. Communication deficits associated with TBI have been aptly named "cognitive-communication disorders" to reflect the fact that the origin of these deficits is cognitive rather than linguistic, perhaps due to the diffuse rather than focal damage typical of TBI (Coelho et al., 2013; Coelho, Lê, Mozeiko, Krueger, & Grafman, 2012). This literature greatly informs clinical practice for individuals with moderate to severe TBI; however, language characteristics of individuals with mTBI remain relatively unexplored.

In this introduction, we will summarize the available literature on receptive and expressive language performance after mTBI. First, we propose that the cognitive basis for language deficits in this population is reduced speed of information processing, a common and long-lasting cognitive symptom after mTBI. Next, we will introduce three studies designed to test a speed-based hypothesis in different yet relevant contexts: a naming task, a sentence interpretation task, and self-reports of everyday communication.

Mild Traumatic Brain Injury and Language

The paucity of research in language after mTBI may be attributed to difficulty capturing language deficits in this population (Parrish, Roth, Roberts, & Davie, 2009). Duff, Proctor, and Haley (2002) found that language tests used routinely by speech-language pathologist, such as the Boston Naming Test (BNT; Goodglass, Kaplan & Weintraub, 1983) and the Scales of Traumatic Brain Injury (SCATBI; Adamovich & Henderson, 1992), were not sensitive enough to detect mild deficits in language expression. In fact, the language deficits exhibited by mTBI patients are so subtle that they are often overlooked in the acute care setting, leading to under-diagnosis of patients with language disorders secondary to mTBI (Blyth, Scott, Bond, & Paul, 2012; Stout, Yorkston, & Pimentel, 2000). Standardized clinical instruments, often developed for diagnosing localized deficits such as those associated with aphasic language disorders, have proven to be limited in sensitivity and specificity for mTBI-related language deficits (Tucker & Hanlon, 1998).

A study by Blyth and colleagues (2012) illustrated the limitations of language screening in the acute phase of TBI. The authors reported the under-diagnosis of high-level communication disorders in the acute setting due to the use of inappropriate measures. They demonstrated that in a large acute care hospital in Australia this under-diagnosis of individuals who could benefit from speech-language intervention was due to two sources: 1) the use of a cognitive screening tool, the Cognistat (Kiernan, Mueller, Langston, & Van Dyke, 1987), which has a ceiling effect for individuals with high-level cognitive deficits (as is the case in mTBI); and 2) the use of language measures meant to identify linguistic deficits such as those demonstrated by individuals with aphasia rather than the "broader-based" communication problems observed in individuals with mTBI. In their comparison of the Cognistat and the Cognitive Linguistic Quick Test (CLQT) (Helm-Estabrooks, 2001), they found that the CLQT better identified individuals with cognitive-communication impairments, which the authors attributed to the more demanding nature of CLQT tasks such as generative naming and storytelling, which were sensitive to the subtle language deficits exhibited by individuals in the acute phase of mTBI. There was no correlation between the results of language testing and prognostic demographic factors, so it is difficult to speculate about the source of language deficits observed in this study. However, the authors' findings are consistent with other mTBI language studies; that is, standardized tests lack sensitivity and predictive power, and negative findings from standardized tests can contribute to under-diagnosis of individuals who might benefit from speech-language services post-injury.

A feasibility study by LeBlanc et al. (2014) proposed a new measure, the Protocol of Montreal (MEC), to identify the effects of TBI on conversational skills. The MEC is a checklist evaluation of 17 communication behaviors for assessing communication at the bedside during the acute stage of TBI. The sample included 108 adults with mTBI. Participants with mTBI demonstrated deficits in word-finding, self-correction of errors, and expression of ideas. Participants with mTBI also produced inappropriate or unexpected comments and inappropriate comment switches, and showed lack of verbal initiative, excessive talking, repetitiveness, and interruptions. Results indicated that 32% of the TBI group had scores below the 10th percentile on the discourse subtest of the MEC, the D-MEC. The authors also found a correlation between the D-MEC and cognitive and language tests included in the battery, such as the Trail Making

Test (Reitan, 1958), the Hopkins Verbal Learning Test (Brandt, 1991), and the Boston Naming Test (Goodglass et al., 1983). Speeded measures included in the D-MEC were also informative; speech rate (which previously had been defined as a measure of efficiency and lexical processing) was affected in 26.67% of the sample as well as "losing track of conversation" in 5-7.7%.

This study highlighted the consequences of poor language skills in the acute-care setting. In addition, D-MEC scores were correlated with patient discharge outcomes: those with better language scores were discharged home or given outpatient care instead of long-term care or inpatient rehabilitation. These findings underscore the importance of language in predicting patients' ability to reintegrate into the community.

As TBI-related communication problems are thought to reflect underlying cognitive impairments rather than focal language deficits, communication symptoms may be best understood in the context of cognitive skills that are known to be affected post-injury. In the next section, we review cognitive impairments specific to mTBI as a foundation for understanding language performance in this group.

Mild Traumatic Brain Injury and Cognitive Changes

While there appears to be a research gap in the area of language after mTBI, cognitive changes after mTBI have been well analyzed by the research community. This line of research has included experimental paradigms designed to investigate the effects of mTBI on cognitive functions. Innovative research using methods such as neuroimaging and electrophysiology has correlated structural and functional damage after mTBI to cognitive performance. Studies exploring cognition after mTBI have predominantly used a multi-modal approach to mTBI cognitive assessment, including a combination of standard neuropsychological test batteries, questionnaires, and objective measures such as diffusion tensor imaging and event-related potentials. By employing these subjective and objective methods, researchers have found a significant association between mTBI sequelae and deficits in attention, working memory, executive function, and speed of information processing along the continuum of recovery (Dean & Sterr, 2013; Frencham, Fox, & Maybery, 2005; Johansson, Berglund, & Rönnbäck, 2009; Miotto et al., 2010; Tombaugh, Rees, Stormer, Harrison, & Smith, 2007).

TBI and Speed

Speed of information processing is defined as "time required to execute a task within a finite time period" (DeLuca & Kalmar, 2013), and has been found to be consistently impaired in individuals with TBI of all severity levels. Leininger and Kreutzer (1992) cited speed of information processing as a basic cognitive skill that "supports and enables" more complex cognitive functions" (p.173), such as working memory and executive functions. Work in this area spans several decades and is consistent with the idea that TBI induces cognitive slowing (Ben-David, Nguyen, & van Lieshout, 2011). Findings in the literature include significant group differences between individuals with TBI and healthy comparison peers on neuropsychological tests of speed of information processing, 10 years or more post-injury (Draper & Ponsford, 2008; Hetherington, Stuss, & Finlayson, 1996).

Meta-analyses and controlled experimental studies in mTBI have found speed-based impairments in both the acute phase of mTBI (De Monte, Geffen, & Massavelli, 2006) and in the chronic phase of recovery (Dean & Sterr, 2013). In a meta-analysis by Frencham et al. (2005), results from 17 previous studies were pooled to calculate effects of mTBI on cognitive variables. Individuals with mTBI ($n=634$) were compared to healthy peers ($n=485$). Speed of information processing had the largest effect size ($g = 0.47$, $p < .001$). This finding was in accordance with that of Binder, Rohling, and Larrabee (1997), who conducted the first meta-analysis of cognitive changes after mTBI.

Cognitive slowing has traditionally been operationalized as response times on timed neuropsychological tests such as the Trail-Making Test, WAIS-IV Digit span, and the n-back tests (Felmingham, Baguley, & Green, 2004). Across studies, individuals with mTBI invariably perform cognitive tasks at a slower pace than their healthy peers. These changes in speed are commonly revealed through experimental measures of reaction time (RT) on tasks such as symbol-digit (Draper & Ponsford, 2008), the Stroop Test (Ben-David et al., 2011), and tests of attention (Ríos, Periáñez, & Muñoz-Céspedes, 2004). RT measures are widely accepted as measures of cognitive processing time (Grön, 1996) and have consistently been shown as a reliable measure of differences in cognitive processing between individuals with TBI and no TBI (Ziino & Ponsford, 2006). Tests of both simple and choice RT have demonstrated slowed processing for individuals with TBI (Green et al., 2008; Grön, 1996; Hetherington et al., 1996), (Ríos et al., 2004; Stuss et al., 2005; Stuss, Murphy, Binns, & Alexander, 2003). Spikman, van Zomeren, and Deelman (1996) observed that individuals with TBI also had lower accuracy when neuropsychological tests were performed under time pressure and increased accuracy when they were allowed to pace themselves.

In addition, Ríos et al. (2004) found that difference between individuals with TBI and a healthy comparison group disappeared when speed was controlled. Tombaugh et al. (2006) found that TBI severity was strongly correlated with processing speed as measured by an adjusting interval between stimuli on the Paced Serial Addition Test (PASAT) (Gronwall, 1977). That is, the interval between stimuli increases when the participant makes an error and decreases when the response is correct, thereby making speed of presentation contingent on accuracy. The researchers argued that this approach was a more direct measure of speed of information processing compared to methods utilized in prior research. Delayed RTs have implications far beyond just a slower response time. Slowed response time has downstream effects on cognitive functions dependent on speeded information processing, and contributes to performance on tests of attention, executive function, and verbal memory (Dymowski, Owens, Ponsford, & Willmott, 2015; Miotto et al., 2010; Woods, Yund, Wyma, Ruff, & Herron, 2015). Speed deficits can account for deficits in planning and organization, and these deficits can be reflected not only on standardized tests but in functional tasks such conversational discourse, a naturally speeded task requiring efficient processing of an acoustic signal (Montgomery & Evans, 2009). Felmingham et al. (2004) proposed that speed mediates complex thinking in TBI and compared this mediating effect to those observed in the aging population (Salthouse, 1992). The underlying mechanism of these behavioral speed deficits is still unclear, and there is still debate about whether speed comprises a subcomponent of attention (Whyte, 2010), or if attention deficits are merely a product of speed of information processing deficits (Mathias & Wheaton, 2007).

The biological basis of speed of information processing has also been debated in the neuroscientific literature. Studies using research methods such as neuroimaging and electrophysiology have been implemented to localize areas of the brain responsible for the speed deficits described above. Because of the white matter injury typically associated with mTBI, affected individuals are believed to have fewer resources or mental capacity for information transmission, due to damage to brain regions that mediate interhemispheric transmission of information, such as the corpus callosum. Abnormalities in prefrontal cortical regions, corpus callosum, and subcortical white matter have been correlated with cognitive dysfunction in mTBI (Lipton et al., 2008; Lipton et al., 2009). Mathias and colleagues (2004) found that the volume of the corpus callosum was 15-20% smaller in patients with a history of mTBI. Niogi et al. (2008) presented similar findings in their study of the corona radiata and uncinate fasciculus, white matter tracts also vital for information transmission.

In addition to this deficit in processing resources, some studies have suggested that there are problems at the level of resource allocation, defined as “a person’s ability to divide mental resources between concurrent mental activities” (Montgomery & Evans, 2009). Electrophysiological studies using evoked potentials (EPs) have informed this thinking. EP studies, particularly studies using the P3 response, have been quite informative in this regard. Reduction in the P3 response is thought to reflect a deficit in resource allocation (Polich, 2007). Broglio, Pontifex, O'Connor, and Hillman (2009), and Kashluba, Hanks, Casey, and Millis (2008) found that young adults who were three years post-mTBI injury demonstrated deficits (such as increased latency and reduced amplitudes) in the P3b and N2 responses, indicating decreased resource allocation capacity.

Furthermore, the P3 has been shown to index attention processing, and studies using attention tasks have shown longer latency times and decreased amplitudes in adults with mTBI (Dupuis, Johnston, Lavoie, Lepore, & Lassonde, 2000; Gaetz, Goodman, & Weinberg, 2000; Gosselin et al., 2012; Lavoie, Dupuis, Johnston, Leclerc, & Lassonde, 2004; Thériault, De Beaumont, Gosselin, Filipinni, & Lassonde, 2009) despite similar task performance. Ozen, Itier, Preston, and Fernandes (2013) found a significant difference in latency and amplitude on the P3 potential between individuals with mTBI and healthy controls using oddball task and n-back tasks, which are standard methods for eliciting the P3 response.

It is important to note that studies of speed in mTBI, like many studies in this population, have suffered from methodological challenges. Experimental groups have varied considerably in injury type, participants with intracranial injuries, and moderate TBI have been grouped with participants with mTBI (Kashluba et al., 2008); control groups have not been well matched demographically (Johansson et al., 2009; Ponsford et al., 2000); researchers have failed to account for the effects of practice on test-taking (Ponsford et al., 2000); there have been reports of missing data (Kashluba et al., 2008); and studies have included small samples that are not well described (e.g., authors did not report detailed exclusion and inclusion criteria) (Miotto et al., 2010). Researchers investigating the effects of acute TBI have also included participants under the influence of alcohol, and this has confounded cognitive performance results (De Monte, Geffen, May, & McFarland, 2010). However, considering the amount of evidence demonstrating impairments in speed of information processing after mTBI and the important role speed plays in enabling complex thinking, pursuing research aimed at assessing the role of speed on language performance, while complex, is a worthy task.

The Effect of Speed of Information Processing on Expressive Language Performance in mTBI

Researchers have characterized the effect of speed on language in mTBI by administering standardized tests (King, Hough, Walker, Rastatter & Holbert, 2006) or experimental spoken tasks under timed conditions (Barrow et al., 2003, 2006), or by including timed variables in narrative tasks (e.g., number of words per minute; (Galetto, Andreetta, Zettin, & Marini, 2013; LeBlanc et al., 2014; Stout et al., 2000). Studies that have used speeded measures in expressive language experiments are listed in Table 1.

Standardized Tests

King et. al (2006) used computerized versions of the Test of Adult and Adolescent Word

Finding (TAWF) and the Test of Word Finding in Discourse (TWFD) (German, 1990, 1991) to evaluate word-finding after mTBI under timed conditions by manipulating presentation time and response time. The TAWF assesses word-finding in a variety of linguistic contexts such as sentence completion, picture naming, and category naming. The TWFD is a test of narrative discourse that uses three pictures as stimuli. The resulting discourse samples are then scored for productivity, word-finding behaviors, and total “t-units” defined by Hunt (1965) as “one unit of meaning.” Ten individuals with mTBI and 10 education-matched typical adult participants completed the TAWF and the TWFD. Results of this study revealed a main effect of group and test, with the mTBI group having significantly delayed reaction times compared to healthy controls on the TAWF, which was speeded. In contrast, there were no group differences in latency on the TWFD, the unspeeded task; pre-experimental measures of vocabulary skill (i.e., The Peabody Picture Vocabulary Test) showed no significant differences between the groups. The authors stated that the combination of reduced lexical access and the speeded conditions under which the TAWF was administered accounted for differences in confrontation naming in participants with mTBI. The TAWF had a temporal response condition – participants were told to respond within 5000 ms – and any response beyond that time limit was considered a latency error. Conversely, the TWFD does not have a strict response window, scores are given for word-finding behavior, productivity, and t-units. On the TAWF, the mTBI group had significantly slower response times than the control group, and on the TWFD scores did not differ significantly between the groups.

The authors attributed their findings to the speeded nature of the TAWF vs. the TWFD. They stated that confrontation naming requires efficient lexical access and that completing this task under speeded conditions places a higher cognitive load on individuals with mTBI, who may have compromised information-processing abilities. The results should be interpreted with caution, however, as this study had a small sample size with participants who were not well characterized (i.e., details such as time post-injury, mechanism of injury, and concomitant neurobehavioral symptoms were not reported, and these factors can potentially affect cognitive function). Furthermore, the discourse task warrants a closer analysis; while the authors measured latency, they did not calculate other measures potentially more sensitive to speed, such as speech rate, number of hesitations, or number of mazes. The inclusion of these measures would allow a more comprehensive evaluation of discourse skills in adults with mTBI.

A study by Crawford, Knight and Alsop (2007) aimed to determine the effect of speed of information processing deficits on the performance of individuals with mTBI who also had persistent symptoms, using the word fluency task from the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) (Randolph, 2012) and the Controlled Word Association Test (COWAT) (Benton, 1967). The authors hypothesized that cognitive slowing could account for verbal fluency problems in this population. This study was innovative in that, rather than analyzing measures such as speech rate by traditional methods (i.e., transcription), the process was automated via a computerized program that transformed audiotaped recordings into continuous sound waves. The authors then calculated the number of words produced within a certain time window. Results indicated that for both the semantic task (RBANS) and the verbal fluency test (COWAT), individuals with mTBI not only produced fewer words than a healthy comparison group but also were slower to initiate their first word on the task. Participants with mTBI also generated more words on the RBANS Task when compared to the COWAT, but this difference was not statistically significant. The slow response time evidenced by the mTBI group is perhaps a reflection of the inefficient resource allocation for language tasks, the effect of which was magnified by the strict time limits imposed by the tests.

Experimental Tasks

Barrow et al. (2003) studied speeded category naming in adults with mTBI, arguing that traditional neuropsychological tests were not sensitive enough to detect mild language impairments in this population. The authors manipulated variables such as speed of presentation, category, vocabulary level, and image quality (color vs. non-color), and measured effects on response latency and accuracy. Participants with mTBI responded more slowly than age-matched control participants, and this finding was most apparent when language tasks systematically increased in complexity (i.e., vocabulary level). The authors posited that limiting response time and controlling difficulty level were the most appropriate methods for detecting subtle changes in language production in the mTBI population. Participants with mTBI also had fewer accurate responses and more perseverative errors, particularly under high complexity conditions such as for black and white "artifact" (i.e., manmade) objects and colored natural objects. The authors found main effects of group, vocabulary level, category, color, and speed. Overwhelmingly, mTBI group errors fell under the category of perseveration; participants merely named the pictured item rather than produce the name of a new item.

The Barrow et al. (2003) task can be interpreted as requiring allocation of resources efficiently and in a timely fashion. This study introduced the concept of increasing cognitive complexity and demands under the constraints of strict time limits, which taxed adults with mTBI. However, it is worth reporting that participants in this study were within 5 days post-injury (i.e., during hospitalization for injury-related symptoms or complications), a time of low cognitive reserve in which all biological efforts are used to restore chemical balance and adequate blood flow in the brain (Giza & Hovda, 2001). Thus, results could be attributed to general injury factors rather than brain damage specifically.

Barrow et al. (2006) replicated their findings with a novel cohort, using the same stimuli, and results were consistent with the 2003 study, i.e., longer latency times for participants with mTBI and a greater number of errors, although in this study errors were semantic rather than perseverative. Participants named a word related to the item shown but could not name another item in the same category (e.g., "suitcase" for "airplane"). The authors attributed the increased latency times in the mTBI group to two sources of increased cognitive load: 1) an increase in difficulty for the experimental task, as target words varied developmental age of acquisition; and 2) the speeded nature of the task.

Although the 2006 study by Barrow and colleagues clearly demonstrated significant differences in performance, the study had several limitations. Most notably, members of the group with mTBI were compared to age-matched healthy participants, which may not be the most accurate and appropriate comparison group. Individuals with mTBI have undergone acute trauma and are recovering from injury, so factors such as the overall effect of injury must be considered when designing mTBI studies. There is evidence that trauma in general can confound scores on neuropsychological tests (Meares, Shores, Batchelor, & Baguley, 2006) and general trauma can induce psychological and somatic symptoms similar to those of mTBI (Landre, Poppe, Davis, Schmaus, & Hobbs, 2006). To control for these potential confounds, researchers have recommended using orthopedic injury (OI) comparison groups, which allow researchers to isolate brain effects from general trauma effects (Levin, Shum, & Chan, 2014). In addition, researchers have argued that OI comparison groups are valid because they likely share demographic, pre-injury characteristics (e.g., risk-taking behavior) with participants with TBI, and if recruited from the same medical facility, OI comparison groups have had comparable levels of medical care for their injuries (Landre et al., 2006; Troyanskaya et al., 2016), which could affect overall outcomes. Overall, the inclusion of an injured group without head trauma adds scientific rigor to study design (Troyanskaya et al., 2016).

The ability of time-based measures to detect subtle deficits in performance and their resistance to practice effects was central to the aim of Tombaugh et al. (2007), who studied speed of information processing in mild and severe TBI. The authors based their study on the advantage of timed-based measures such as reaction time to accurately describe long-term cognitive changes in the TBI population, partly because reaction time measures were regarded as resistant to practice effects. In their development of the Computerized Tests of Information Processing (CTIP), they included measures of simple, choice, and semantic reaction time, which were sensitive to effects of injury severity and complexity. Participants with mTBI in the Tombaugh et al. (2007) study performed with worse outcomes from uninjured controls and from participants with severe TBI on a semantic reaction time task, which required participants to decide whether a word that appeared visually on a computer screen matched a category name above each word. This finding illustrates the idea that semantically challenging tasks magnify difficulties in processing information (Timmerman & Brouwer, 1999).

Discourse Tasks

Stout et al. (2000) compared language performance of adults with and without mTBI on a validated picture description task and a storytelling task. The authors used response speed, measured by speaking rate, as a proxy for what they referred to as “cognitive efficiency.” The authors theorized that discourse tasks emulate real-life cognitive demands, as they require individuals to “initiate, organize and sequence linguistic skills” (p. 16). They predicted that individuals with mild, moderate, or severe TBI would all demonstrate slower speaking rates than healthy controls. Discourse samples were collected in response to two stimuli: the “Cookie Theft” picture from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983) and a story-telling task based on a familiar childhood fable. Measures included number of words and syllables per minute, concepts per minute, mazes (i.e., revisions), words per t-unit, and words per maze. The study sample was heterogeneous: it included open and closed head injuries of all severities, as well as individuals with anoxia and spinal cord injury, all of whom were, on average, two years post-injury.

Results for mTBI participants were reported separately, and indicated that indeed, when compared to the control group, individuals with mTBI produced significantly fewer syllables per minute (149.8 vs 192.2) and concepts per minute (21 vs. 26.4). Similar trends were found on the story-telling task. While the participants with mTBI produced adequate verbal content (i.e., their stories were grammatical and made sense to listeners), the content was produced at a much slower rate and with more mazes than those of the control participants. Interestingly, there was a significant within-group difference in performance between the picture description task and the story retell performance, with more syllables produced per minute in the story retell. The authors posited that the story retell was a less demanding task because a model was provided by the test administrator, so information processing limitations would have less influence on performance. By contrast, the picture description task required the participant to use organization, sequencing, and decision-making (e.g., knowing which elements to include in the story and when to conclude the story). These findings underscore the contribution of cognitive skills to performance on expressive language tasks, and suggest that tasks requiring more complex skills (e.g., initiating a story versus retelling one) are more sensitive to the effects of cognitive impairments.

Scores on outcome measures were quite variable within the TBI group, which the authors attributed to variable length of time post-injury in the sample. Time post-injury has been identified in previous research as a variable of interest when considering cognitive performance, as there is evidence that performance improves over time post-injury (Karr, Arenshenkoff, & Garcia-Barrera, 2014), but patients also may become more symptomatic as they attempt to resume their life activities (Landre et al., 2006), so the time course of symptoms is unclear. Because of this complex evolution of cognitive symptoms over time, studies of mTBI must ensure that participant samples are comparable in time post-injury.

Using a picture description task, Galetto et al. (2013) relabeled the skills introduced by Stout (i.e., planning, organization) as "macro linguistic skills" and hypothesized that deficits in these skills were central to the language complaints of individuals with mTBI. In a sample of 10 adults with mTBI in the chronic phase (M = 39.1 months after injury), 13 adults with mTBI in the acute phase, and 13 healthy controls, the authors analyzed expressive language using the Picnic Scene picture description task from the Western Aphasia Battery, a battery of neuropsychological tests, and two standardized cartoon picture sequences. Participants were asked to "describe the three stories" (p.652). These storytelling tasks were used to measure speed-based variables such as productivity (number of words, speech rate, and mean-length utterances). Scores on neuropsychological tests and narrative task measures did not differ significantly between the groups. However, on the story-telling task individuals with chronic mTBI had lower speech rates, more coherence errors, and produced fewer information units when compared to healthy controls performing the same tasks. The authors attributed their results to a "general reduction in resources" in adults with mTBI. They posited that adults with mTBI used greater cognitive effort to efficiently select words and thus demonstrated a slower speech rate. Consistent with prior research cited earlier in our review, the authors attributed discourse-level language deficits to “inefficiency in linking their utterances and producing adequate amount of information,” which were viewed as a result of having fewer cognitive resources at their disposal. Although the study had a small sample size, the design and methodology had several strengths. For example, to ensure that short-term memory did not confound assessment of language productivity, the picture stimulus remained in view during the participant’s performance of the speaking task.

Receptive language performance after mTBI

After a careful review of the literature examining language function after mild TBI, it became clear to us that studies have focused on language expression and not language comprehension. With the exception of one study, discussed below, to our knowledge there are currently no published studies examining language comprehension after mTBI. However, a number of studies have hinted at deficits at the functional level of comprehension in adults, adolescents, and children with mTBI, such as self-reported difficulty understanding a classroom lecture or written material in a textbook (see Table 2). Studies have predominantly relied on standardized tests and self-reporting on questionnaires as main outcome measures. The results of the studies reviewed in the following section suggest problems with auditory comprehension after mTBI. These studies have employed diverse methodological approaches such as neuropsychological testing, region of interest neuroimaging, assessment of evoked potentials, and validated and non-validated questionnaires.

Standardized Tests

Blyth’s study (2012) comparing the sensitivity of the Cognistat versus the CLQT in acute mTBI included measures of receptive language. Specifically, the CLQT Story Retell Subtest required language comprehension and the Cognistat included comprehension of one- to three-step commands, using objects placed in front of the participants. Although the story-telling task was more sensitive in identifying comprehension problems among participants, scores on both tasks were confounded by possible impairments in other cognitive functions such as working memory or attention. Determining the degree to which these other cognitive functions may have influenced performance on this task was beyond the scope of the study; however, these findings suggest that comprehension problems are worth exploring in individuals post-mTBI.

Cognitive Evoked Potentials

Much of what we do not know about language performance after mTBI can be attributed to a lack of quantitative, unbiased, reliable assessment methods. Assessment using cognitive evoked potentials (EPs) has the capacity to fill this void in a way that behavioral testing cannot. One benefit of using cognitive EPs in mTBI is that, unlike most neuropsychological tests, they are resistant to practice effects and malingering (sometimes a concern in mTBI) and are free from behavioral response bias, which could be confounded motor impairments. While most of the EP literature has focused on the P300, the use of the P600 is of particular interest when studying the effects of mTBI on language processing. The P600 is a late-latency evoked potential that is elicited with language, specifically, syntactic processing (Hahne & Friederici, 1999).

Key-DeLyria (2016) used the P600 to determine whether there were P600 amplitude differences between adults with a TBI history (n=4) and a group of uninjured adults (n=21). The participants with TBI all reported problems with reading and schoolwork after their injuries and denied having any language or reading difficulties pre-injury. The author posited that individuals with TBI would encounter more difficulties processing sentences than would healthy controls, and that these differences would be manifested in lower P600 amplitudes. This hypothesis was based on the idea that “the P600 is elicited with language stimuli, but it could be affected by general cognitive deficits that also affect syntactic processing” (Key-DeLyria, 2016).

The P600 response was elicited using a sentence processing task with subject-verb agreement mismatches. The authors predicted that adults with TBI would have longer latencies and smaller mean amplitudes on the task, which they believed would be consistent with difficulties organizing and slow processing of syntactic information. The first task was a sentence comprehension task (no ERP recordings were collected during this task) and the second was a grammaticality judgment task with sentences presented in a rapid serial visual representation (RSVP). The RSVP method, in which one word at a time is presented on the screen, allowed the author to match the ERP data to specific words in the stimuli. The first task required participants to answer comprehension questions by pressing a button for “yes” or “no,” and accuracy and reaction times (RTs) were collected. The RSVP questions also required a keyed “yes” or “no” response; participants were asked to decide whether a sentence was grammatically “good,” and accuracy and RTs were collected. The primary outcome measure for this task was ERP amplitude and latency, which were collected via EEG and processed offline.

One of the four participants in the TBI group had mTBI, and both group and individual results were reported. The author found no significant effects of group, condition, side, or region on P600 mean amplitudes; however, when scores were analyzed independently, the participant with mTBI had fewer accurate responses to comprehension questions and filler sentences than the control group. This participant also tended to take longer to read whole sentences.

Limitations of the study included the very small sample size and the limited reliability of the P600 response for the injured group; however, the author stated that the differences in waveform between the groups provided biological evidence that individuals with TBI process sentences differently. The lack of a statistically significant relationship between the P600 response and language measures was attributed to limitations in the language measure, a sentence task. The author stated that while a grammaticality judgement task such as the one used in the study might be suitable for individuals with purely linguistic deficits related to focal lesions, the subtle language deficits that are characteristic of cognitive-communication disorders after TBI might require a more sensitive measure. Despite these limitations, results of this exploratory study suggest that language comprehension difficulties after mTBI are worthy further investigation.

Questionnaires

Studies using symptom questionnaires after mTBI have frequently included questions about functional comprehension. Work by Ransom et al. (2015) aimed to unravel the academic effects of concussion on children and adolescents who were symptomatic (n=109) or non-symptomatic (n=240) after concussion, using a structured school-focused questionnaire. The questionnaire asked parents if their children had new or worsened school problems during concussion recovery, and included items such as whether the child had “difficulty understanding material.” On this question, 84% (n=49) of students who had yet to recover from their injuries responded in the affirmative. This finding was significantly different from results for students who had recovered from their injuries, of whom only 3% (n = 6) reported this symptom. The symptomatic group reported more symptoms overall, and these symptoms positively correlated with a greater number of academic problems perceived by the students themselves and by their parents.

Wasserman, Bazarian, Mapstone, Block, and van Winjngaarden (2016) used self-reporting in their study of academic dysfunction after concussion in high school and college students. The authors employed a prospective cohort study design to identify high school and college students who had been diagnosed with mTBI or an isolated musculoskeletal injury (MSK) in three emergency departments in the Northeast United States, with the MSK group serving as a comparison. The authors followed up student ED visits with a telephone interview one week and one month after injury, and administered their own self-report measure, the Academic Dysfunction Measure, which included comprehension questions such as “I have trouble understanding the material presented in class,” “My classmates understand material faster than I do,” and “I have to reread things to understand the material.”

Results indicated that students with mTBI took longer to return to school than students with MSK injuries. A larger proportion of students with mTBI reported an increase in academic problems post-injury and a greater need for academic accommodations (e.g., extra time on tests and tutoring) than the group without concussion. However, at one month post-injury, there were no statistically significant differences between the two groups.

While the Wasserman et al. (2016) study claimed to be the most comprehensive study of academic dysfunction after mTBI, it had limitations. The authors’ outcome measure, while based on preexisting literature and pilot-tested by the authors, was not validated prior to its use and scores were not correlated with neuropsychological measures of performance or individual student academic records. In fact, there was no face-to-face interaction with participants, which raises questions about response validity. Also, the subjective nature of this study makes it vulnerable to internal threats of validity such as the possible confounding effect of somatic and psychological symptoms common after mTBI. The psychological effects of mTBI in particular cannot be overlooked, as prior research has shown that cognitive impairments and psychological recovery often occur at the same time in this population (Sveen, Ostensjo, Laxe, & Soberg, 2013). In addition, while the group with concussion was not significantly different from the MSK-injury group in age or sex, there were significant differences in race and socioeconomic status. A strength of the study was that participants in the comparison group were demographically similar to those in the mTBI group and had sustained an injury. The lack of a significant group difference at one month post-trauma underscores the importance of choosing comparison groups who have experienced a comparable trauma rather than healthy community-based controls.

In conclusion, this review of research in the area of language comprehension after mTBI reflects the current state of the science; that is, there are few studies and the ones that do exist report mixed findings and have major methodological weaknesses. Outcome measures have primarily consisted of subjective and descriptive measures rather than objective and experimental measures, and basic cognitive mechanisms underlying language performance have yet to be established. The field currently lacks a well-designed prospective study of language comprehension performance after mTBI that combines neuropsychological testing, validated experimental measures that are based on a theoretical model of mTBI cognitive impairments, self-reporting of symptoms, and an appropriate comparison group. The combination of these approaches is important in order to place communication studies in the context of existing neuropsychological research in mTBI, to compare results to other samples, and most importantly, to test hypotheses that will better characterize communication signs and symptoms in adults with mTBI.

SUMMARY & RATIONALE FOR STUDY

Characterizing language performance after mTBI is an important area of study because intact language performance is critical for vocational, social, and academic success (Ruben, 2000; Thatcher, Fletcher, & Decker, 2008). Moreover, high-level cognitive functions, such as planning, organizing, and communicating abstract thoughts via written or oral language, rely on the ability to process language efficiently (Whiteside et al., 2016). Language production and comprehension require us to make sense of a "fleeting acoustic signal and build structure and meaning in a moment"(Montgomery, Evans, Gillam, Sergeev, & Finney, 2016), so it is critical to study language under speeded and unspeeded conditions. Speed not only is important because it plays a critical role in everyday language functions, including word-finding and comprehension of rapidly moving conversations, but also because reduced speed of cognitive processing is a hallmark of mTBI. Preliminary studies have shown that when individuals with mTBI are asked to perform language tasks under speeded conditions, their accuracy declines and their efficiency is compromised. These studies, however, have significant limitations, including variability in severity among participants; lack of details about important demographic factors such as time post-injury, mechanism of injury, and concomitant neurobehavioral symptoms; use of standardized tests that lack sensitivity and specificity; and use of narrative tasks that confound language processing with other cognitive demands. This area of research lacks a well-designed study of expressive and receptive language performance under timed and untimed conditions with a demographically similar control group.

In the acute stages of mTBI, defined as 2 weeks post-injury, individuals may experience cognitive, physical, and psychological symptoms. The period of time between three weeks to three months after initial injury, will be referred to as the subacute stage of recovery in this paper. Studies to date have focused on either the acute or chronic stages of recovery. However, the subacute stage is important because it represents the appropriate time window for intervention: effective treatment cannot occur without identifying problems early, and, if left untreated, patients are at risk for developing secondary symptoms such as anxiety or depression that can confound interpretation of cognitive symptoms (Bohnen & Jolles, 1992). Problems need to be identified early enough to refer patients to appropriate medical providers such as trained speech-language pathologists. Results from a well-designed, controlled study would inform both assessment and treatment in this critical time window for treatment for individuals at risk for developing persistent communication problems.

To address the gap in knowledge about language performance after mTBI during this time period, we designed a prospective cohort study of adults with mTBI and a comparison group of OI peers. The prospective studies were designed to avoid potential confounds and biases which have been reported in the mTBI literature and may impact cognitive outcomes (L. Carroll et al., 2004). These include variability in age, education level, time post-injury, injury type, history of learning disability or neurological disorder and level of medical care.

The overall aim of this dissertation was to characterize language performance and everyday communication problems after mTBI, focusing on the role of speed of information processing. Participants completed validated neuropsychological tests such as the Wechsler Adult Intelligence Scale Processing Speed Index (Wechsler, 2008) and NIH Toolbox Cognition Battery (Gershon et al., 2013). Participants also completed two experimental tasks, the Whatdunit? Task (Montgomery et al., 2016) and the Barrow Category Naming Task (Barrow et al., 2006); and an everyday communication questionnaire that is widely used in TBI studies, the LaTrobe Communication Questionnaire (Douglas & O'Flaherty, 2000). To connect the current sample to the literature, we also administered tests commonly used to characterize adults with mTBI, including the Neurobehavioral Symptom Inventory (Soble et al., 2014), and the

Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989; Royle & Lincoln, 2008).

Specific aims were as follows:

- ***Aim 1****: To compare expressive language performance between individuals with mTBI and individuals with (OI) under speeded and unspeeded conditions.*
- ***Aim 2****: To compare language comprehension performance between individuals with mTBI and individuals with OI under speeded and unspeeded conditions.*
- ***Aim 3:*** *To identify communication problems in the everyday lives of adults with mTBI vs. OI controls.*

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Table 1. Studies of Expressive Language Performance after mTBI.

Authors	Selection Criteria	Experimental Group	Comparison Group	Task/Dependent Variables
Stout, Yorkston & Pimentel (2000)	High school graduates who spoke standard English, had adequate hearing, no history of drug abuse of psychiatric problems requiring hospitalization no other diagnoses associated with cognitive problems, individuals with aphasia were excluded, Level of Cognitive Function Scale < V, excluded if injury occurred before age 15 or if they had motor speech impairments that would impact speech rate	94 TBI, but some subjects reported TBI + anoxia/ MS/SCI (mTBI=39, Mod TBI=22, Severe TBI= 33). Level of severity based on Glascow Coma Scale (GCS) and CT/MRI findings or consensus rating between SLP and NP. **Time post**: 25 months, SD: 29 months	38 educationally-comparable controls without history of TBI	Picture description (Cookie Theft from BNT), story retell task (audio short story)/Quantity, efficiency, # of syllables & contents/minute, # mazes, words/maze
Barrow et. al (2003)	Galveston Orientation and Amnesia Test to ensure participants were not in PTA, SCATBI-mild or normal. No prior head injuries, educational or learning disabilities, attention deficit, language difficulties, or psychological or visual impairments. Passed visual screener (naming items on the computer)	24 mTBI **Time post**: 5 days post but before d/c from hospital Native English-speaking, 11 years+ of education, mTBI as defined by GCS scale. 20 participants with LOC and 4 with PTA. 20 participants with MVA as cause of injury, 3 falls, 1 assault	24 age-matched controls, native-English speaking, mostly education matched 18-55 years old	Category naming task/accuracy and reaction time

Barrow et. al (2006)	mild, non-penetrating TBI, admitted to hospital, no or insignificant lesion per CT, SCATBI- normal or mild, GOAT >78. No prior head injuries, educational or learning disabilities, attention deficit, language difficulties, or psychological or visual impairments. Passed visual screener (naming items on the computer)	24 English speaking adults, ages 18-53 **Time post:** 1 week	24, native English speaking, age matched controls, 18-55	Category naming task/accuracy and reaction time
King et al. (2006)	native English speakers, no hx of etoh abuse or drug abuse, no dx of mental illness or developmental illness, recruited from review of medical records from local level one trauma facility	10 mTBI, defined by ACRM definition Mean age: 28.8 Mean education: 13.7 **Time post:** not reported	10 age and education matched normal participants Mean age: 28.8 Mean education: 14	Test of Adolescent and Adult Word Finding (TAWF) Test of Word Finding in Discourse (TWFD)/accuracy and latency
Crawford et. al (2007)	Met criteria for Post-concussion syndrome (PCS) according to DSM-IV and referred to hospital (symptoms for 6 weeks or more after injury). Exclusion: history of neurological or psychiatric disorder or treatment with medication that was likely to cause cognitive deficits	20 individuals (10 M, 10 W) with mTBI **Time post**: 6-12 weeks	20 healthy controls, each matching a patient for age, gender, and current occupation and recruited from the community	Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) and Controlled Word Association Test (COWAT)/semantic and verbal fluency, first response latency and IRT between end of one word and beginning of

				the other
Blyth et. al (2012)	out of PTA per Westmead PTA scale, not on opiates for pain relief. Excluded if they had a history of head injury, psychosis, neurological deficit, chronic drug and alcohol abuse or younger than 16 yrs. old, native English speakers	83 mTBI per GCS. Had at least one of the following: 1) traumatic changes on CT per radiologist 2) any period of LOC 3) loss of memory for events before or after events 4) alteration in mental state (GCS between 13-14 on admission to ED) **Time post:** 4.4 days after injury, mean= 2 days	no comparison group	CLQT, Cognistat/story retell, word fluency
Galetto et. al (2013)	Excluded history of psychiatric, neurological illness, learning disabilities, hearing or visual loss, aphasia	10 chronic mTBI (with diagnosed GCS scale > 13 at time of injury) **Time Post**: ~3.25 yrs. post injury	13 neurologically healthy controls normal range of performance on Raven's progressive matrices, normal performance in NP	WAIS-R picture description task
LeBlanc et al. (2014)	Excluded aphasia	mild (n=108) moderate (n=54), & severe TBI (n=53) **Time post:** within 3 weeks post-injury	no comparison group reported	Montreal Conversational Discourse Test (D-MEC)/ checklist of behaviors (some are timed some are not, length of stay and discharge disposition

Table 2. Studies of Language Comprehension after mTBI.

Authors	Selection Criteria	Experimental Group	Comparison Group	Task/Dependent Variables
Blyth et. al (2012)	Native English speakers, out of PTA. Excluded if they had a history of head injury, psychosis, neurological deficit, chronic drug and alcohol abuse or younger than 16 yrs. old,	83 mTBI per GCS. Had at least one of the following: 1) traumatic changes on CT per radiologist 2) any period of LOC 3) loss of memory for events before or after events 4) alteration in mental state (GCS between 13-14 on admission to ED) **Time post:** 4.4 days after injury, mean= 2 days	None	CLQT, Cognistat/Story Retell subtest
Key-DeLyria (2016)		2 participants with mTBI	Healthy control group (n=21)	P600
Ransom et al. (2015)	5-18 yrs. old Injury within 28 days of evaluation, confirmed concussion Parent of concussed child	Actively symptomatic group (n=109)	Recovered group (no cognitive or elevated symptoms) (n=240)	Concussion Learning Assessment of Cognition and Symptoms for Children; Post-Concussion Symptom Inventory (parent and self-report form)
Wasserman et al. (2016)	ED diagnosis of concussion (ACRM criteria) or MSK injury (excluded if injury to head, neck, chest or abdomen)	High school and college students with diagnosed with mTBI in ED (n=70)	High school and college students with MSK injuries (n=108)	Academic Dysfunction Measure

CHAPTER 2

Manuscript 1

Communication and Speed in Adults with Mild Traumatic Brain Injury

Rocío S. Norman[1], Manish N. Shah[2] and Lyn S. Turkstra[1,3],

1 Department of Communication Sciences and Disorders, University of Wisconsin-Madison

2 University of Wisconsin-Madison, School of Medicine and Public Health, Berbee Walsh Department of Emergency Medicine

3 Neuroscience Training Program and Department of Surgery, University of Wisconsin-Madison

Corresponding Author:

Rocío S. Norman

University of Wisconsin-Madison

Department of Communication Science and Disorders

1975 Willow Drive

Madison, WI 53706

Email: rocio.norman@wisc.edu

Phone: 210-367-1600

Abstract

Objective: This study aimed to characterize expressive language performance in adults with mTBI. We hypothesized that individuals with mild traumatic brain injury (mTBI) would demonstrate longer reaction times (RTs) and greater error rates when compared to the orthopedic injury (OI) group on a category-naming task, particularly on speeded tasks.

Method: Participants were 20 adults (12 females) with mTBI and 21 adults with OI (15 females) ages 18-55 years who had been seen in an Emergency Medicine Department and were discharged to home after mTBI or OI. Our primary task was a category-naming task adapted from previous studies (Barrow et al., 2003, 2006) which has been shown to be sensitive to naming deficits after mTBI. This task was adapted and administered under speeded and unspeeded conditions in order to test a speed-based hypothesis.

Results: Analysis of RT showed a significant main effect of condition (speeded faster than unspeeded). The mTBI group made more overall errors than the OI group in both conditions, and both groups made more errors in the unspeeded condition than in the speeded condition. The effect of speed was statistically significant for the group as a whole, but differences could not be attributed to mTBI specifically. Naming accuracy and RT in speeded and unspeeded conditions were correlated with injury and symptom variables of interest by group (poorer performance was related to higher symptom report).

Conclusions: Our data showed a marginal effect of group on accuracy of performance, which partially supported our hypothesis. Due to some of the correlations our study found between language measures and neurobehavioral symptoms, including sleep quality, these factors should be considered in research design as they can potentially affect outcomes.

Keywords: adult, brain injuries, communication, mild traumatic brain injury

Introduction

Traumatic brain injury (TBI) has been associated with expressive communication deficits in both the acute and chronic stages of the injury (LeBlanc et al., 2014). These deficits have been associated with negative long-term outcomes such as difficulty securing and maintaining employment (Rietdijk et al., 2013), social interaction limitations (McDonald, 2013) and reduced quality of life (Galski et al., 1998). Over the past three decades, there has been significant interest in characterizing communication after moderate to severe TBI (Coelho et al., 2013; Mozeiko et al., 2011; Yang et al., 2010). Studies of discourse have shown that adults with TBI often lack verbal cohesion and organization, and that these characteristics indicate cognitive rather than linguistic deficits (Coelho, Liles, & Duffy, 1991). Thus, deficits associated with TBI are commonly known as "cognitive-communication disorders" to reflect their cognitive nature (Coelho et al., 2013; Coelho et al., 2012).

There is considerable research on language disorders after moderate to severe TBI, but communication changes after mild traumatic brain injury (mTBI) have been overlooked by researchers, even while injuries of this severity currently make up 80% of TBIs in the US (Cassidy et al., 2004; Kraus et al., 1996). Although most people recover fully from mTBI (L. Carroll et al., 2004), a small percentage of individuals experience cognitive, physical, and psychological symptoms that persist beyond the typical recovery period, which is estimated to be between three weeks to three months after injury (Bernstein, 2002; L. Carroll et al., 2004; Iverson, 2005; Makdissi et al., 2015). Common symptoms after mTBI include headache, fatigue, forgetfulness, sleep problems, and dysfunction. These symptoms occur in both global cognitive abilities (Belanger & Vanderploeg, 2005) and in specific cognitive domains such as attention (Broglio et al., 2009) and speed of information processing (Dean & Sterr, 2013; Frencham et al., 2005). Deficits in the cognitive system can significantly affect communication skills, as the two domains are "intrinsically and reciprocally related in development and function" (American Speech-Hearing Association, 2005). Indeed, preliminary experimental studies of language after mTBI have shown that communication problems likely reflect cognitive rather than linguistic deficits. Stout and colleagues (2000) found that when compared to healthy adults, individuals with mTBI showed impairments such as linguistic inefficiency, disorganization, and fewer meaningful units per minute on experimental tasks, all of which hint at possible information processing deficits. Communication limitations resulting from these impairments might include difficulties performing tasks such as participating in conversations with multiple conversation partners, difficulty putting thoughts into words, and reduced fluency in connected speech (Cornis-Pop, Mashima, Roth, MacLennan, Picon, Hammond, Goo-Yoshino, et al., 2012).

Guidelines for mTBI indicate that early education and treatment are critical for ensuring positive long-term outcomes (Lundin, de Boussard, Edman, & Borg, 2006; Ponsford, Draper, & Schönberger, 2008). Education after mTBI involves informing the patient of positive expectations for recovery, and treatment emphasizes cognitive and physical rest with a gradual return to activity (Wright, 2014). Effective treatment cannot occur without early identification of problems; however, this identification is often difficult. The communication deficits exhibited by mTBI patients are so subtle, in fact, that they are often overlooked in the acute care setting, which leads to fewer patients identified with language disorders secondary to mTBI (Blyth et al., 2012; Stout et al., 2000). Therefore, it is necessary to identify problems early enough to refer patients to appropriate healthcare providers such as trained speech-language pathologist (SLPs). If individuals with mTBI miss this important window for receiving treatment, they may likely face challenges in communication exchanges in the workplace, the school setting, and everyday social interactions. Furthermore, research has shown that individuals who can express themselves in the acute stages of TBI have shorter lengths of stay and more favorable outcomes (Leblanc, De Guise, Feyz, & Lamoureux, 2006). Therefore, identifying these deficits early and intervening if it is warranted will prove invaluable for research and clinical reasons.

There are shortcomings in our assessment tools that contribute to the gap in knowledge about communication problems after mTBI. Although patients report problems with communication in their everyday lives and are often referred to SLPs for treatment, it has been a challenge to document these problems using standardized tests (Parrish et al., 2009; Tucker & Hanlon, 1998). Standardized language tests lack sensitivity and specificity for detecting the mild language deficits that are characteristic of mTBI (Krug & Turkstra, 2015; Turkstra, Coelho, & Ylvisaker, 2005). Blyth et al's 2012 study on mTBI language assessment found that the use of published tests such as the Cognistat (Kiernan et al., 1987) and the Cognitive Linguistic Quick Test (CLQT) (Helm-Estabrooks, 2001) led to under-diagnosing of patients with communication impairments at a large trauma center in Australia. The survey by Duff et. al (2012) found that SLPs providing care to adults with mTBI reported using standardized language assessments developed for individuals with language problems that are linguistic in nature (e.g., aphasia), not assessments developed for language deficits that are the result of cognitive impairments commonly associated with TBI such as impairments in executive functions, speed of information processing, or working memory. This mismatch between assessment constructs and patient symptoms leads to patients performing at ceiling level on standardized tests, and consequently to under-diagnosing of communication problems. Patients' performance scores may fall within the range of normal, yet they experience difficulty with routine communication demands. Language is a critical part of everyday functioning, and determining effects of mTBI on language performance is critical for developing appropriate assessments and treatment (Ruben, 2000; Worrall, McCooey, Davidson, Larkins, & Hickson, 2002).

The cognitive underpinnings of communication deficits in mTBI are unknown, but it is likely that they are cognitive domains known to be affected by mTBI. One promising cognitive candidate is speed of information processing, a domain known to be significantly affected in both the acute and chronic stages of recovery from mTBI (Dean & Sterr, 2013; Dymowski et al., 2015; Frencham et al., 2005; Lovell, Iverson, Collins, McKeag, & Maroon, 1999; Madigan, DeLuca, Diamond, Tramontano, & Averill, 2000; Tombaugh, 2006; Tombaugh et al., 2007). Speed of information processing has been generally regarded as a component of attention processes (Willmott, Ponsford, Hocking, & Schönberger, 2009), and neuropsychological studies have operationalized speed using experimental measures of reaction time (RT) on tasks such as the symbol-digit test (Draper & Ponsford, 2008), the Stroop test (Ben-David et al., 2011) and tests of attention (Ríos et al., 2004). RT measures are widely accepted as measures of cognitive processing time (Grön, 1996) and have consistently been shown as a reliable measure of differences in cognitive processing between individuals with and without TBI (Ziino & Ponsford, 2006).

In summary, mTBI is common in the US and can affect cognitive and communication function in both the acute and chronic stages of recovery. Most of our evidence regarding communication after mTBI comes from experimental research because standardized tests lack specificity and sensitivity for the subtle deficits characteristic of mTBI-related communication problems. Research in mTBI has focused primarily on cognitive impairments after injury without full consideration of how these cognitive changes affect language performance and everyday communication (Raskin, Mateer, & Tweeten, 1998). Speed of information processing in particular likely plays a critical role in everyday communication functions such as word-finding, especially when responding under time pressure. This hypothesis is consistent with results of studies demonstrating that individuals with mTBI have slower speech rate, more effortful naming, and fewer ideas and longer latency times on language tasks when compared to healthy adults (Galetto et al., 2013; K. A. King, Hough, Vos, Walker, & Givens, 2006; Stout et al., 2000).

Because of the pressing need to capture communication problems soon after injury, it is necessary to characterize language problems that occur in this early stage and develop effective diagnostic tools and evidence-based treatments for communication disorders after mTBI. The present study characterized language problems using time-based measures of spoken language performance (i.e., RT) and manipulated demands for speed, which are recommended methods in mTBI research (Tombaugh et al., 2007). Participants were tested in the sub-acute stage of recovery from mTBI (three weeks to three months after injury). This range of time was chosen in order to avoid factors related to the increased risk for developing secondary symptoms such as anxiety or depression that can confound interpretation of cognitive test results (Bonhnen & Jolles, 1992).

The mTBI group was compared to an age- and education-matched sample of adults with non-surgical orthopedic injuries (OIs) such as fractures or lacerations, also within the three week to three-month period after their injuries. The use of OI controls is critical in the study of mTBI, as they allow researchers to statistically control for the effects of trauma on participants, recognizing that a traumatic event in and of itself will change the participants' performance. Furthermore, researchers have argued that OI comparison groups are valid because they likely share demographic, pre-injury characteristics (e.g., risk-taking behavior) with participants with

TBI, and if recruited from the same medical facility, as our participants were, they have had comparable levels of medical care for their injuries (Landre et al., 2006; Troyanskaya et al., 2016). We chose to include the OI comparison group here to differentiate the impact of neurological injury to effects of general physical trauma on our variables of interest, as this was not done in prior studies. We hypothesized that individuals with mTBI would demonstrate longer RTs and greater error rates when compared to the OI group, particularly on speeded tasks. Research in this area will add to the knowledge about this complex clinical group and inform the development of appropriate communication assessments and interventions, which are currently lacking in the field of SLP.

Method

Participants and Procedures

The study employed a prospective comparison between groups of adults with mTBI and OI. Participants in both groups had presented to the Emergency Medicine Department at the University of Wisconsin-Madison and had been diagnosed with mTBI or a non-surgical OI by a physician, physician assistant, or nurse practitioner (see Appendix A for diagnostic codes). After initial evaluation and care for their injuries, both mTBI and OI participants were discharged to the home, and they participated in the study 3-12 weeks after their injuries.

All procedures were approved by the Institutional Review Board at the University of Wisconsin-Madison. Potential participants were identified via a medical chart review by research personnel with valid clinical access. Recruitment procedures are listed in Appendix B. Participants were actively recruited from April 2016 to March 2017. Participants were mailed a letter stating that they were being contacted because of a recent visit to the emergency department and that they were potentially eligible for the study. We identified 212 participants as potential participants via the medical chart review. These potential participants were called by the first author for telephone screening to determine eligibility for the study. The first author attempted to contact potential participants at least three times via telephone. If contact was made and potential participants expressed interest in participating, they were screened for the study inclusion criteria, and if criteria were met, a research appointment was scheduled no later than one month after the telephone screening. Participants provided oral consent for the telephone screening and written consent at the time the study was completed. Participants were compensated $25 per hour to complete the study tasks. On average, most participants completed the study in 2.5 hours.

Participants were included if they were ages 18-55 years and reported English as their primary language. We chose the cutoff age at 55 years to reduce age-related cognitive effects as a confounding variable. Individuals in the mTBI group were included if they were diagnosed with ICD9 Codes 850* and ICD10 Codes S06.0*, which was confirmed during the in-person interview using the following definition of mTBI:

> A blunt injury to the head or to the body with impulsive force transmitted to the head that resulted in any of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, drowsiness, blurred vision, memory difficulty or difficulty concentrating. (Eisenberg, Meehan, & Mannix, 2014)

Individuals in the OI group were diagnosed with non-surgical, traumatic OI as defined by ICD 9 Codes 800-829 and ICD 10 Codes S40-S49, S72, S82, and S92.

Exclusion criteria for all participants were: 1) history of pre-injury medical or neurological disease affecting the brain (other than concussion for the mTBI group), or language or learning disability; 2) indication of a health-care surrogate on the medical record; or 3) failure of a pure-tone hearing screening using an air conduction threshold of 30 dB Participants' hearing thresholds were below 30 dB at every frequency tested (500, 1000, and 2000 Hz). The hearing screening was completed at the time of the study by either a licensed SLP or a trained graduate assistant.

Participant Characteristics

Participants were 20 adults (12 females) with mTBI, and 21 adults with OI (15 females). Table 1 lists demographic characteristics and descriptive data. Injury information is included in Table 2. There were no significant between-groups differences in neurobehavioral symptoms or scores on standardized cognitive tests.

Category Naming Task

Our primary experimental task was the category-naming task adapted from previous studies (Barrow et al., 2003, 2006). Adaptations were that the current study included both speeded and unspeeded conditions (the original task solely used a speeded condition), picture stimuli were from a different source (Rossion & Pourtois, 2004), and we used different criteria for categorization of the picture stimuli. Details are provided below.

Participants were asked to view 120 randomized pictures from the database, displayed individually on a computer monitor, and name one other item belonging to the same category as the picture in view. Sixty items were blocked within each condition and conditions were counter-balanced. In the speeded condition, participants were instructed to "go as fast as you can," and in the unspeeded condition participants were instructed to "take your time." The picture stimuli were manipulated by presentation time (50 ms, 100 ms, and 200 ms), stimulus category (artifact or natural objects), and vocabulary difficulty level (1-4). Difficulty level was based on age-of-acquisition norms for words published by J. Carroll and White (1973) and was classified as <3 years, 3-4 years, 4-5 years, and 5+ years. All words were familiar to native English speakers per Rossian (2004) criteria: over 80% agreement and a score of 3 or more on a familiarity scale of 1-5, with 5 being most familiar. This spoken task uses the elements of *category level* and *speed* to impose a "cognitive load" on naming under experimental conditions (Barrow et al., 2006). For example, an item with a difficulty level of 4 (e.g., "artichoke") presented at 50 ms would be considered a high cognitive load item compared to an item with a difficulty level of 1 (e.g., "dog") and a presentation time of 200 ms.

We used E-prime software (Psychology Software Tools, 2012) fitted with a voice key (E-prime Chronos™ device) to capture the onset of voicing or voice-onset time (VOT). To accurately capture VOT, participants were asked to avoid using an article (e.g., "a" or "the") or vocalizing (e.g., "ah" or "um") before they responded. Answers were captured digitally on the Chronos™ device and scored manually by study personnel using the Audacity application. Following the Barrow (2003) procedures, we programmed E-prime to show participants a blank screen for 1000 ms, followed by a central fixation cross for 2500 ms, and pictured stimuli were displayed immediately after the presentation of the fixation cross. The response window was set at 3500 ms for all stimuli, and there was an interstimulus interval of 6000 ms (blank screen for 3500 ms and the central fixation cross for 2500 ms).

For determining accuracy of the responses, we used the Battig and Montague (1969) corpus of validated noun categorization as a guide. For items not contained in the Battig and Montague corpus, we used the *taxonomic feature type* classification from the McRae, Cree, Seidenberg, and McNorgan (2005) corpus, Appendix F, as these were the largest and most recent categorization norms. The McRae data were collected at McGill University, University of Southern California, and University of Western Ontario. We used all features except the superordinate feature, as including that feature would violate the experiment rule to "name another item in the same category as the one on the screen." In order for a participant's response to be considered correct, he or she had to produce a word that would be considered a coordinate (e.g., coyote--> *dog*), an individual (e.g., deer--> *Bambi)*, a subordinate (e.g., lettuce--> *romaine*), or a synonym (e.g., calf--> *baby cow*).

For the few items that did not fit neatly into the taxonomic approach, a blinded consensus was established among three independent raters. Following the procedure of Barrow et al. (2003), error types were categorized as perseveration, semantic, visual, non-response, or other (out-of-category response). Responses vocalized outside of the response window (3500 ms) were scored and, as in the previous study, were assigned a response time of 4750 ms, which was "the median time point between the offset of the response time for the stimulus item and the onset of the next picture." (Barrow et al., 2003; p.890)

Prior to the study's formal launch, the experiment was piloted on 2 adults with mTBI and 2 uninjured comparison adults who had participated in previous studies in the authors' lab. Preliminary data showed that for both conditions, the mTBI group completed the naming task at a slower pace than the comparison group. Preliminary analysis revealed a significant difference in reaction time on the Barrow Naming Task in the unspeeded condition, a marginal difference in the speeded condition. Accuracy levels were not significantly different between the groups on the Barrow Naming task, although there was a trend for participants without mTBI to perform with more accuracy. Based on this data, we determined that the task was feasible.

Medical record review

In order to accurately characterize the sample, the following information was extracted from participants' medical records: mechanism of injury, medical diagnoses, psychiatric diagnoses, medication use, dates of service in the UW Emergency Medicine department, referral to other providers upon discharge from the hospital, and medical lab/test results related to the ED visit. Demographic information such as date of birth, sex, race/ethnicity, and primary language were also collected for all participants.

Case History

A case history form was completed in a face-to-face interview after the participant completed a written consent form, which solicited information regarding demographic characteristic, health education and vocational history; current employment or academic performance; and medical and neuropsychological history related to the injury. Medical records were reviewed when it was deemed necessary.

Questionnaires

Neurobehavioral Symptom Inventory (NSI) (Soble et al., 2014). The NSI is a self-report measure of symptoms commonly associated with Post-Concussion Syndrome (PCS) that may emerge after mTBI. There are three scales included, based on the type of symptom: cognitive, somatic/sensory, and affective. Symptoms such as hearing difficulty and change in taste/smell would be considered somatic, slowed thinking or forgetfulness would be considered cognitive, and feeling anxious or depressed would fall under affective. This measure is widely used in civilian and military clinical and research settings.

Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989). As cognition can be affected by sleep and sleep quality (Wisseman-Hakes, Colantino, & Gargaro, 2009), we were interested in the amount and quality of sleep our participants reported. On the PSQI, participants rate sleep quality over the past month, and higher scores indicate poorer sleep quality. The PSQI yields scores in seven categories: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction.

Speech-Language and Cognitive Tests

WAIS Processing Speed Index (Wechsler, 2008). To describe general speed of information processing skills (non-verbal), we administered the WAIS-symbol search and coding subtests. These two subtests comprise the WAIS Processing Speed Index (WAIS-PSI).

NIH Toolbox Cognition Battery (Gershon et al., 2013). All subtests of the Cognition Battery were administered to characterize participants' general cognitive and language ability. Cognitive domains assessed were executive function (including inhibitory control), attention, episodic memory, language (Picture Vocabulary Test, Oral Word Recognition Test), and processing speed. Fully corrected scores were used for all analyses.

Speech Rate. Although our ICD criteria excluded individuals with speech disorders, participants could differ in general motor speech ability. To rule out group differences in baseline motor speech function, we assessed speech rate using stimuli from the Assessment of Intelligibility of Dysarthic Speech (Yorkston & Beukkelman, 1984), a widely used measure of motor speech performance. Speech rate was defined as average syllables per minute.

Rapid Naming Task (RAN). Individuals with aphasia or other acquired language disorders likewise were excluded from the sample, but participants could vary in general naming ability. To rule out group differences in general naming ability, we administered the Rapid Naming Test (RAN), developed by Montgomery et al. (2005) using (Rossion & Pourtois, 2004) picture stimuli. Participants were asked to name pictures displayed individually on a computer screen, as quickly as possible. Accuracy and voice-onset time were recorded. We administered the RAN at the end of the session, so its demands on speeded performance would not influence performance on the experimental tasks.

Data Analysis

Main statistical analyses were conducted in SPSS Version 23.0 with the significance level set at $p < .05$. Post-hoc power analyses were conducted using G*Power Program (F. Faul, Erdfelder, Lang, & Buchner, 2007). Scaled demographic variables were tested with independent samples t-tests and categorical variables (e.g., sex, race) were tested using the chi-square statistic or a Fisher's exact test (e.g., for employment).

Our main study hypothesis was that individuals with mTBI would demonstrate language deficits as evidenced by longer reaction times and greater error rates when compared to OI participants, in the sub-acute stage post-injury. This was tested using a repeated measure analysis of variance (ANOVA) with main effects of group and condition on RT's and overall accuracy. As an exploratory analysis, we conducted a Pearson correlation between accuracy and RT on the naming task and time post-injury, NSI total scores, and PSQI total scores.

Results

Demographic characteristics of the sample are shown in Table 1. Fisher's exact test showed a significant difference in employment status between the two groups χ^2 (8, N=41) = 40.69, $p<.001$. There were no significant between-groups differences on any other variable. Injury characteristics for the group are shown on Table 2. There was a marginally significant difference in time post-injury for the study participants with mTBI compared to those with OI $t(39)=-1.474$, $p=.07$, with longer times post-injury in the mTBI group.

Results of questionnaires and tests are shown in Table 3. There were marginally significant differences on the NIH Toolbox Cognitive Battery overall score, with lower scores in the mTBI group, t (37) = 1.173, *p* = .08; and in speaking rate, t (30) = -1.42, *p* = .08, and faster speaking rate in the mTBI group. The two groups did not differ on NIH Toolbox Subtest scores (Working Memory, Processing Speed or Vocabulary), sleep quality, or neurobehavioral symptoms as measured by the NSI.

Repeated Measures ANOVA

Reaction time and accuracy data on experimental tasks are shown in Table 4. Analysis of RT showed a significant main effect of condition (speeded faster than unspeeded), Lambda=1 F (1, 39) = 58.05, *p*=.00, $\eta^{2=}$.04; no significant effect of group, F (1, 39) = .122, *p* = .38, $\eta^{2=}$.003; and no significant group-by-condition interaction, F (1, 39) = .011, *p* = .46, $\eta^{2=}$.00. Analysis of accuracy did not show a statistically main effect of condition, Lambda=.964 F (1, 39) = 1.455, *p*=.11, $\eta^{2=}$.04; a marginally significant effect of group, F (1, 39) = 1.75, *p* = .09, $\eta^{2=}$.04; and no significant group-by-condition interaction, Lambda=.997 F (1, 39) = .011, *p* = .46, $\eta^{2=}$.003.

Correlations

As an exploratory measure, we conducted Pearson correlations between the naming task dependent variables. Naming accuracy and RT in speeded and unspeeded conditions were correlated with injury and symptom variables of interest by group. See table 5 for results of correlations.

Time Post-Injury

Time post-injury was negatively correlated with accuracy in the unspeeded condition for the mTBI group; that is, participants who were further post-injury had lower accuracy scores. RT in the unspeeded condition for the OI group was also negatively correlated with time post-injury, with shorter RTs as time post increased. RT in the speeded condition had a marginally significant negative correlation in the same direction as the unspeeded condition. No other task variables were significantly correlated with time post-injury.

Sleep Quality

For both groups, sleep quality, as measured by the PSQI, was negatively correlated with accuracy and RT in both the speeded and unspeeded condition; as sleep quality scores decreased (implying improvement in sleep quality), accuracy increased. Reaction time in both conditions was positively correlated with sleep quality; as sleep quality scores increased (implying poor sleep quality), RT increased.

Speech Rate

For the mTBI group, speech rate had a marginally significant correlation with RT in both conditions i.e. the faster an individuals' speaking rate was, the faster they would perform on the task. All other correlations were non-significant. For the OI group, speech rate and speeded RT were negatively correlated and this was statistically significant, implying that as speech rate increased, RT decreased.

NSI

The NSI total score was negatively correlated with accuracy in the unspeeded condition in the mTBI group, i.e., participants with fewer neurobehavioral symptoms had higher accuracy on the naming task. The negative correlation between mTBI group's NSI scores and accuracy in the speeded condition approached significance. For the OI group, NSI scores were negatively correlated with accuracy in both conditions in the same direction as in the mTBI group, i.e., more symptoms associated with lower accuracy scores.

Error Patterns

Table 6 demonstrates error types by group and condition. Error patterns were summarized by tallying the number of errors in each error category (perseveration, semantic, out-of-category, or no response). The error rate for each group was calculated by dividing the total number of errors by the total number of trials per group. In both the unspeeded and speeded conditions, both groups made more semantic errors than any other type of error, and the mTBI group made more overall errors than the OI group in both conditions. Both groups made more errors in the unspeeded condition than the speeded condition.

Discussion

The aim of this study was to characterize expressive language performance in the sub-acute stage of mTBI. We aimed to accomplish this by describing performance accuracy and reaction time on an experimental expressive language task and comparing participants with mTBI to a demographically matched OI group. The task, which has been previously shown to be sensitive to naming deficits after mTBI, was adapted and administered under speeded and unspeeded conditions in order to test our hypothesis that reduced processing speed is a cognitive mechanism underlying mTBI-related communication problems.

Our data showed a marginal effect of group on accuracy of performance, which partially supported our hypothesis. Overall, individuals with mTBI performed with lower accuracy in both conditions; however, this difference did not reach statistical significance. Inspection of errors indicated that accuracy for both groups was affected primarily by errors of the semantic type, i.e., responses were associated with the pictured stimuli but did not satisfy criterion for correctness. Given that the majority of our normative data was from Battig and Montague's norms which were developed in 1969, it is likely that our participants' responses were reflective of changes in mainstream vocabulary in the US since that time.

The effect of speed was statistically significant for the group as a whole, but differences could not be attributed to mTBI specifically. A previous study testing speed effects in mTBI (Spikman et al., 1996) observed that individuals with TBI typically had lower accuracy when neuropsychological tests were performed under time pressure, and increased accuracy when they were allowed to pace themselves. In addition, Ríos et al. (2004) found that differences between individuals with TBI and controls on neuropsychological tests of attention disappeared when speed was controlled. Our study did not observe these effects.

On reaction time (as measured by word-onset time for responses) the difference in speed demands affected both groups in a similar and predictable fashion, i.e., participants responded more slowly during the unspeeded condition and sped up their responses in the speeded condition. Our between-groups comparisons revealed the opposite trend from what we predicted; the mTBI group responded faster than the OI group, however this was not statistically significant. This advantage was offset by the greater number of errors on the task and suggests that participants with mTBI may have completed the task using a speed/accuracy trade-off. Speed-accuracy tradeoff is a cognitive strategy that has previously been documented in the study of cognition in moderate to severe TBI (Battistone, Woltz, & Clark, 2008; Madigan et al., 2000), but to our knowledge, speed-accuracy tradeoff has not been documented in adults with mTBI. Modeling of speed-accuracy tradeoff appears to be a promising area of research, particularly in areas of study like mTBI, where statistical effects might be small in spite of significant clinical effects.

Our findings were in contrast to those of Barrow et. al (2003), who found a statistically significant effect of group on accuracy and reaction time on a category naming task, although there was a trend for the mTBI group to perform with less accuracy, as we predicted. Our study extends the work of Barrow and colleagues but also introduces a new, more detailed perspective. We accomplished this by designing a study with more stringent recruitment and scoring criteria, using a comparison group that was more comparable to the mTBI group, and enforcing a strict temporal study window (between three weeks to three months after injury). The prior studies have shown more robust group differences, perhaps because of differences in study design. Barrow (2003) and Barrow (2006) tested their mTBI participants within 1-7 days after their injuries, during a hospital admission and acute management of symptoms. The mTBI groups in the Barrow studies were compared to community-based controls who had not experienced neurological or psychological trauma; therefore, it is precarious to use data from that study to make implications about brain injury-specific effects, as these are conflated with the psychological effects of trauma. In contrast, our study participants had not been admitted for their injuries but rather had been discharged to home and experienced between three weeks and up to three months of recovery time. This time progression likely contributed to their recovery, making their performance more difficult to distinguish from the neurologically "typical" OI group. In addition, we excluded individuals who had experienced a loss of consciousness related to their mTBI, which possibly excluded from our study individuals with pronounced symptoms after TBI. This decision was motivated by our quest to avoid heterogeneity in the mTBI group and the possibility of including participants with more pronounced injuries. Indeed, the majority of our participants endorsed full recoveries; a large proportion of them reported resuming work and school activities soon after their injuries. Furthermore, our study compared the mTBI group to a demographically similar control group who had also experienced trauma. In essence, our experimental group was probably less symptomatic than Barrow's and our control group was probably more symptomatic, thereby increasing the challenge of finding a group difference in performance, particularly given our small sample size. Despite the lack of significant differences, we would argue that OI controls are a more valid comparison group than community-based controls in brain injury research, as they allow us to differentiate effects of a brain trauma from the effects of a general trauma.

The distinction in time post-injury between the current study and Barrow's is important as we consider the temporal nature of language recovery and physical recovery in general after neurological injury. In our study, we focused on the period in which individuals with mTBI would be most likely to seek services, and we also aimed to minimize psychological confounding variables such as depression and anxiety, which may be present in the chronic stages of recovery. Our decision to focus on a specific period post-injury was supported by the finding that time post-injury was negatively correlated with performance on our experimental tasks, suggesting that variability in time post-injury might have affected results of other studies.

Like Barrow (2003), in our study, a greater number of errors were deemed to be semantic in origin. Barrow et al. (2006) replicated their initial findings. They found a main effect of group that was magnified by an increase in vocabulary difficulty level in the stimuli. Participants in this study also reported a larger proportion of semantic errors rather than other types of errors. In their discussion, the study team justified their methodology and approach by stating that testing individuals under time constraints is the optimal method of study. Our study would indicate otherwise; testing individuals under time constraints is one of several conditions that might account for group differences.

Limitations and Future Directions

The limitations of our study include a small, culturally homogenous sample size, which may have contributed to our limited statistical power and to our limited ability to generalize to other populations. With our collected data and our observed effect sizes (which tended to be small), we conducted post-hoc power analyses. These analyses revealed a need for sample sizes between 96 to 456 participants to observe differences in our variables of interest (accuracy and sentence interpretation time) at 80% statistical power. This finding demonstrates a bigger issue in mTBI research and one which diverges from work in moderate to severe TBI research. In moderate to severe TBI research, it is common to have small sample sizes with larger effects, but because differences between individuals with mTBI and typical comparison groups are small (in our case, the differences in performance were either a few percentage points in accuracy or several milliseconds in interpretation time), we need large sample sizes to detect these subtle differences.

Furthermore, we can assume that the prior probability of cognitive-communication deficits in the mTBI population is likely less than 5% if we assume those individuals with persistent symptoms are those who would be likely to experience problems with cognitive-communication. Our study did not recruit a clinical sample of individuals with mTBI symptoms nor did we screen for cognitive-communication problems prior to enrolling in the study; therefore, the likelihood of detecting expressive communication deficits in the included mTBI sample was low. In addition, our study may have suffered from a sampling bias; we enrolled people who were not only invested in participating in research (sometimes months after their injuries) but who had flexibility in their employment and other life activities to do so. This limitation makes generalization of our results to other, more diverse mTBI populations tenuous.

Further directions for research include investigating differences in language performance between adults with mTBI and OI controls on measures of discourse as well as measures of language comprehension, both of which are critically important skills needed for effective communication and both of which naturally occur under speeded conditions within the context of everyday conversation. Due to some of the correlations our study found between language measures and neurobehavioral symptoms, including sleep quality, these factors should be considered in research design as they can potentially affect outcomes. Investigating the role of cognitive effort on language performance outcomes is another potential line of research. While communication studies traditionally focus on outcomes such as accuracy or reaction time, the role of elements such as mental effort should also be considered using both subjective and objective methods. In summary, the effect of neurobehavioral symptoms and cognitive effort should be further explored, as these factors potentially affect cognitive-communication performance.

Conclusions

In summary, results of our study partially supported our hypothesis and indicated practical differences between adults with mTBI and OI controls in expressive language performance, particularly in accuracy of responses. Our findings highlight the complexity of investigating language in mTBI and the important role of task selection, appropriate comparison groups and consideration of the effect of neurobehavioral symptoms and this will inform future research efforts.

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Table 1

Participant Demographic Characteristics

	mTBI (=20)	OI (n=21)
Age, y, mean (SD)	29.20 (10.77)	28.23 (7.58)
Age, range	19.6-52	18.5-48
Female, n (%)	12 (57)	15 (75)
African-American, n (%)	2 (9.5)	1 (5)
Education, y, mean (SD)	15.9 (1.61)	16.1 (2.04)
Employment Status*		
Unemployed, n (%)	2 (10)	1 (4.8)
Part-Time Employment, n (%)	1 (5)	7 (33.3)
Full-Time Employment	17 (85)	12 (57)
Other	0	1 (4.8)
Student, n (%)	8 (38)	5 (25)

*sig at .000

Table 2

Injury Characteristics of the Sample

	mTBI (n=20)		OI (n=21)
Time post-injury, d, mean (SD)	65.10 (18.06)	Time post-injury, d, mean (SD)	57.95 (12.64)
Participants with history of previous mTBI, n (%)	8 (40)	Participants with history of previous mTBI, n (%)	4 (19)[a]
Mechanism of Injury, n, (%)		Mechanism of Injury, n, (%)	
Moving Vehicle Accident	3	Moving Vehicle Accident	1
Fall	6	Fracture	9
Assault	3	Dislocation	5
Sports-related	4	Sprain	1
Hit head on structure	3	Contusion	1
Hit by cow	1	Inflammation	1
		Dog bite	1
		Unknown	2

[a] reported injuries in group occurred > 2 years prior to date of study participation

Table 3

Scores on NIH Toolbox Tests, Neurobehavioral Symptom Inventory (NSI), and Pittsburgh Sleep Quality Index (PSQI). Data are means (SD)

	mTBI (n = 20)	**OI (n = 21)**
NIH Toolbox Cognition Battery	52.63 (9.31)	57.14 (10.72)
NIH Toolbox Working Memory	46.29 (11.36)	50.32 (10.12)
NIH Toolbox Processing Speed	36.08 (7.51)	35.82 (9.16)
NIH Toolbox Vocabulary	55.65 (8.81)	57.87 (9.92)
NSI Total Score	18.11 (12.66)	13.66 (11.36)
NSI Affective Score	7.84 (4.00)	6.09 (5.60)
NSI Cognitive Score	3.75 (2.83)	2.76 (3.25)
NSI Somatic Score	6.17 (6.14)	4.80 (4.00)
PSQI- Sleep Quality	7.60 (4.41)	6.61 (4.23)
Speaking rate (Syllables/min)	214.61 (24.39)	200.29 (32.5)

Note. NIH=National Institutes of Health, NSI=Neurobehavioral Symptom Inventory, PSQI=Pittsburgh Sleep Quality Index

Table 4

Overall Accuracy (percentage correct) and Reaction Time (in msecs) by group and condition

	Acc-s	Acc-u	RT-s	RT-u
mTBI (n=19)				
Mean	73.66	75.49	1952.64	2451.23
SD	10.84	13.33	470.34	451.16
OI (n=19)				
Mean	77.21	80.47	2006.64	2491.44
SD	15.13	9.22	471.42	516.21

Table 5

Correlations between Naming Task Dependent Variables and Participant Characteristics

Variables			Time Post	Speech Rate	Sleep Quality	NSI Total[a]
mTBI n=20						
	Acc-s	Pearson Correlation	.149	-.025	244	-.378
		Sig.	.265	.465	.172	.067
	Acc-u	Pearson Correlation	-.362*	.069	-.525*	-.470*
		Sig.	.058	.404	.009	.029
	RT-s	Pearson Correlation	-.111	-.366	.551**	.174
		Sig.	.321	.090	.006	.252
	RT-u	Pearson Correlation	-.128	-.389	.435*	.239
		Sig.	.295	.076	.028	.177
OI n=21						
	Acc-s	Pearson Correlation	.180	-.389	-.032	-.688**
		Sig.	.217	.062	.446	.000
	Acc-u	Pearson Correlation	-.055	-.111	.207	-.514**
		Sig.	.407	.336	.183	.009
	RT-s	Pearson Correlation	-.309	-.417*	.272	.111
		Sig.	.086	.048	.116	.316
	RT-u	Pearson Correlation	-.404*	-.537	.185	.110
		Sig.	.035	.013	.210	.318

Note. NSI=Neurobehavioral Symptom Inventory
[a] Seventeen out of twenty (85%) mTBI participants included in this analysis
*Correlation is significant at the 0.05 level (1-tailed).
** Correlation is significant at the 0.01 level (1 tailed).

Table 6.

Error Types by Group and Condition. Data are frequencies with percent of all responses in parentheses.

	mTBI	**OI**
Category Naming-Unspeeded		
Error Type		
Perseveration	36 (11.42)	26 (9.05)
Semantic	209 (66.34)	215 (74.91)
Out of category	39 (12.38)	24 (8.36)
No response	31 (9.84)	22 (7.66)
Total Errors	315 (26.25)	287 (22.77)
Category Naming- Speeded		
Error Type		
Perseveration	26 (2.16)	28 (2.22)
Semantic	188 (15.66)	139 (11.03)
Out of category	30 (2.67)	32 (2.77)
No response	50 (4.33)	49 (3.88)
Total Errors	294 (24.5)	248 (19.68)

CHAPTER 3

Manuscript 2

Language Comprehension after Mild Traumatic Brain Injury: The Role of Speed

Rocio S. Norman[1], Manish N. Shah[2] and Lyn S. Turkstra[1,3],

1 Department of Communication Sciences and Disorders, University of Wisconsin-Madison

2 University of Wisconsin-Madison School of Medicine and Public Health, Berbee Walsh Department of Emergency Medicine

3 Neuroscience Training Program and Department of Surgery, University of Wisconsin-Madison

Corresponding Author:

Rocío S. Norman

University of Wisconsin-Madison

Department of Communication Science and Disorders

1975 Willow Drive

Madison, WI 53706

Email: rocio.norman@wisc.edu

Phone: 210-367-1600

Abstract

Objective: The purpose of this study was to characterize language comprehension in mTBI by testing a speed-based hypothesis. We hypothesized that adults with mTBI perform worse than a group of adults with orthopedic injuries (OI) on an experimental language task.

Method: Participants were 19 adults with mTBI (11 females) and 19 adults with OI (14 females) ages 18-55 years who had been seen in an Emergency Medicine Department and were discharged to home after mTBI or OI. Participants completed the *Whatdunit* task, a sentence agent selection task (Montgomery et al., 2016) in speeded and speeded conditions.

Results: In the unspeeded condition, the mTBI group had a marginally significant difference (p=.09) in higher mean accuracy (M=89.46, SD=11.93) than the OI group (M=82.49, SD=19.15). In the speeded condition, the mTBI group performed with lower accuracy (M=79.80, SD=20.60) than the OI group (M=83.55, SD=16.17); however, this difference did not reach statistical significance. For interpretation time, there was a marginally significant interaction of sentence type (canonical or non-canonical word order) by group in the speeded condition but not in the unspeeded condition.

Conclusions: We reported a marginally significant group X sentence type interaction, but only in the speeded condition. This finding demonstrates that perhaps the combination of syntactic complexity combined with strict temporal response windows can be a potential method for further study. While our task might have been sensitive to cognitive processing abilities in both groups (as evidenced by the main effects of condition and sentence type), the task was not specific enough to capture mTBI-related deficits.

Keywords: adult, brain injuries, communication, mild traumatic brain injury

Introduction

Traumatic brain injury (TBI) is defined by the American Congress of Rehabilitation Medicine as a "traumatically induced physiological disruption of brain function" (Mild Traumatic Brain Injury Committee, 1993). Nearly 2.5 million individuals are affected by TBI in the United States each year and 87 percent of these individuals are treated in and discharged from emergency medicine departments (M. Faul, Xu, Wald, & Coronado, 2010a). The vast majority of these injuries are mild, and in recent years there has been an increased interest in characterizing the effects of these mild injuries, also called "concussions." Much of this research has been propelled by the growing awareness of mild TBI (mTBI) related to sports and mTBI being named the "signature injury" of the U.S. wars in Iraq and Afghanistan. This interest is also driven by studies in which mTBI has been found to be a risk factor for progressive diseases such as dementia, mild cognitive impairment, and chronic traumatic encephalopathy (Schneiderman, Braver, & Kang, 2008).

In the acute stages of mTBI, defined as two weeks post-injury, individuals may experience cognitive, physical and psychological symptoms (Giza & Hovda, 2001). At this time, the natural recovery course of mTBI is still debated in neuroscience research; however, estimates for recovery range from seven days for sports-related, uncomplicated concussions, and up to a year for individuals with certain risk factors including pre-morbid psychiatric diagnoses, for individuals who are elderly, and for those who are female (M. McCrea et al., 2009). However, a recent World Health Organization Task Force on mTBI reported that the evidence suggests most adults who incur mTBI no longer have cognitive or physical symptoms after three months post-injury (L. Carroll et al., 2004). This period of time, between three weeks to three months after initial injury, will be referred to in this paper as the "subacute" stage of recovery.

A large proportion of the research in mTBI, has focused on cognitive outcomes after injury (Karr, Areshenkoff, & Garcia-Barrera, 2014a; Raskin et al., 1998). These studies have been motivated by the pressing need to inform clinical and education practice. Issues such as calculating when an athlete can return to class or play in sports, or when an individual is “fit” for military duty, are significantly impacted by the individual’s cognitive status post-injury (Iverson & Gioia, 2016; Lange et al., 2012). In the acute to subacute stages of mTBI, adults might report attention, executive function and verbal and visual memory problems (Raskin et al., 1998). These symptoms negatively affect functional activities such as learning new information, reasoning, problem solving and processing incoming information (Cornis-Pop, Mashima, Roth, MacLennan, Picon, Hammond, Isaki, et al., 2012).

Communication skills include the ability to receive, send, process, and comprehend concepts, verbal or nonverbal information (American Speech-Language Hearing Association, 1993). These skills are often impaired in adults with moderate to severe TBI (Bittner & Crowe, 2007; Sohlberg, Griffiths, & Fickas, 2014). Communication impairments typically are viewed as downstream effects of cognitive impairments, hence their designation as “cognitive-communication disorders” (Coelho, DeRuyter, & Stein, 1996). Whether the same is true for adults with mTBI remains largely unexplored.

The lack of evidence on communication after mTBI often stems from the current scarcity of valid instruments to assess and quantify communication problems after mTBI. Assessment of language problems after mTBI is currently a challenge for providers, and communication disorders may be underdiagnosed in the acute stage of mTBI due to a lack of sensitive instruments (Blyth et al., 2012; Duff et al., 2002; Stout et al., 2000). Blyth et al’s (2012) study on mTBI language assessment found that published measures such as the Cognistat (Kiernan et al.,

1987) and the Cognitive Linguistic Quick Test (Helm-Estabrooks, 2001) had no predictive value for communication disorders. Instruments used routinely by speech-language pathologists (SLPs) either lack specificity and sensitivity or have yet to be norm-referenced on individuals with mTBI (Krug & Turkstra, 2015; Turkstra et al., 2005). This issue of a gap in knowledge and inadequate tools negatively impacts clinical care and contributes to many language problems “under-recognized” in the acute setting (Blyth et al., 2012). In a 2016 survey of certified speech-language pathologists in the state of Wisconsin (Riedeman & Turkstra, 2016), 30% of respondents reported being “Somewhat Confident to Not Confident” in treating individuals with cognitive-communication symptoms related to TBI and reported that mTBI was a particular area of concern in clinical practice.

mTBI and Language Comprehension

Research has shown that adults with mTBI report functional communication problems for activities requiring language comprehension (e.g., following a fast-paced multi-person conversation) after injury (Key-DeLyria, 2016; Ransom et al., 2015; Wasserman et al., 2016). Few published studies exist in this area, and those available have primarily focused on students affected by sports-related concussions.

A study of academic dysfunction in high school and college students in the U.S. by Wasserman and colleagues (2016) reported that students with a concussion took longer to return to school when compared to a group with isolated musculoskeletal injuries. The authors’ primary outcome measure, The Academic Dysfunction Questionnaire, included questions such as “I have trouble understanding the material presented in class,” “My classmates understand material faster than I do,” and “I have to reread things to understand the material.” A larger proportion of students with mTBI reported an increase in academic problems post-injury and a greater need for academic accommodations (e.g., extra time on tests and tutoring) than the musculoskeletal-injury group. The inclusion of these comprehension items in the measure suggests that the authors deemed comprehension, particularly within the context of learning, as a critical aspect of academic success. In Ransom and colleagues' (2015) study of academic problems post-mTBI, 84% (n=49) of students with persistent mTBI symptoms reported "difficulty with understanding material" compared to 3% of students who had recovered from their injuries.

A group study by Key-DeLyria (2016) provided preliminary evidence that individuals with mTBI take longer to process syntactical information and that performance is marked by lower accuracy when compared to peers without mTBI. Using cognitive-evoked potentials (i.e., the P600 potential) to measure comprehension in individuals with and without mTBI, this study found no major significance of group, condition, or mean P600 amplitudes, yet when data were analyzed independently for one participant with mTBI, this person had fewer accurate responses to yes/no comprehension questions and tended to take longer to read sentences. However, the authors found no significant association between the P600 measures and scores on the experimental sentence task, indicating that perhaps the measure was not sensitive or specific enough to capture mTBI-related comprehension deficits, despite the participant's report of symptoms.

Attempts to use published language measures for documenting mTBI-related comprehension deficits have been plagued by confounding variables in the selected tests. For example, Blyth and colleagues' (2012) study comparing the sensitivity of the Cognistat versus the Cognitive-Linguistic Quick Test included measures of receptive language in their assessment of language function in the acute stages of recovery after mTBI. The Story Retell subtest of the CLQT and the Following Commands subtest of the Cognistat were used as indices of language comprehension. Although the study team found that the Story Telling task was more sensitive in identifying deficits among participants than the Following Commands task, this is an untenable conclusion, as both of these subtests are demanding not merely on language comprehension but on working memory and attention, which shows that test results can be confounded by possible impairments in other cognitive functions such as working memory or attention. To what degree these other cognitive functions may have impacted performance on this task was beyond the scope of the study. However, these findings demonstrated that comprehension problems are worth exploring in individuals post-mTBI, despite the arduous task of selecting appropriate measures.

In summary, there are few published studies of language comprehension in adults with mTBI. The few studies available have primarily documented comprehension deficits using self-report on questionnaires, published language tests, and objective measures that do not correlate well with experimental methods. Using these approaches has certain limitations. Questionnaires such as those in Wasserman et al. (2016) and Ransom et al. (2015) are subjective; they depend on the respondent having intact awareness of his or her current skill level. Standardized tests also present limitations, as scores on test constructs (such as comprehension) are often confounded by impairments in other cognitive skills such as working memory or executive function; therefore, sensitivity and specificity are compromised. Experimental language tasks, including one employed by Key-DeLyria (2016), are promising methods that highlight the need to validate language tasks for use in mTBI research.

This review of the research in the area of comprehension after mTBI concludes by reflecting on the current state of the science. There are a limited number of published studies on mTBI, and most of them report mixed findings. The field currently lacks a well-designed prospective study of language comprehension performance after mTBI that uses a combination of neuropsychological testing, proven experimental measures, self-report of symptoms with valid tools, and most importantly, one that tests a hypothesis in order to better identify the source of the complaints.

Cognition and mTBI

In contrast to comprehension, cognition is a well-studied area in mTBI research (Karr, Areshenkoff, & Garcia-Barrera, 2014b), and cognitive skills in general are known to affect communication (S.Y. Chabok, S.R. Kapourchali, E.K. Leili, A. Saberi, & Z Mohtasham-Amiri, 2012a; Coelho, 2007; Youse & Coelho, 2005). Communication disorders associated with TBI are referred to as "cognitive communication disorders," recognizing that communication signs and symptoms reflect underlying cognitive impairments, rather than being linguistic in nature (S.Y. Chabok, S.R. Kapourchali, E.K. Leili, A. Saberi, & Z. Mohtasham-Amiri, 2012b; Coelho, 2007; Youse & Coelho, 2005). Focal cognitive deficits are rare in mTBI (M. McCrea et al., 2009), but it is unknown at this time whether even subtle changes in cognitive skill affect communication in this population. Perhaps one way to identify a mechanism for communication problems after mTBI, is to explore a cognitive domain known to be affected after mTBI.

The most commonly reported sequela of mTBI is reduced speed of information processing (Dean & Sterr, 2013; Frencham et al., 2005; Kashluba et al., 2008; Ponsford et al., 2008; Zwaagstra, Schmidt, & Vanier, 1996). Speed consistently has been found impaired in individuals with acute (Ponsford et al., 2000) or remote mTBI (Dymowski et al., 2015; Miotto et al., 2010). This work spans several decades and coincides with the idea that TBI induces cognitive slowing (Ben-David, Nguyen, & van Lieshout, 2011). Cognitive slowing has traditionally been operationalized as response times (RTs) on neuropsychological tests such as symbol-digit (Draper & Ponsford, 2008), the Stroop test (Ben-David, Nguyen, & van Lieshout, 2011), and tests of attention (Ríos et al., 2004). RT measures are widely accepted as measures of cognitive processing time (Grön, 1996) and consistently have been shown to be a reliable measure of differences in cognitive processing between individuals with TBI and those with no TBI (Ziino & Ponsford, 2006). Efficient and timely processing of information supports functions such as planning and organizing; sustained, alternating and divided attention; and verbal memory, all critical components of language use. In a meta-analysis by Frenchman et al (2005), which included 17 studies, speed of information processing and working memory had the largest effect size ($g = 0.47$, $p < .001$) when compared to other cognitive domains, suggesting that speeded information processing measures are most sensitive to deficits in neuropsychological performance in adults at any stage of recovery after mTBI. This finding replicated that of Binder et al (1997), considered the first meta-analysis of cognitive changes after mTBI.

Limited Resource vs. Resource Allocation Problems

There is considerable interest in the research community to determine the biological bases of cognitive impairments associated with mTBI, including speed of information processing. Research methods have included neuroimaging, electrophysiology, and pathology to characterize and identify brain abnormalities that might account for some of the deficits described above. Primarily mTBI is a white-matter injury, and the most common finding is diffuse axonal injury along areas of the brain responsible for information transmission. Abnormalities in prefrontal areas, corpus callosum, and subcortical white matter have been correlated with cognitive dysfunction (Lipton et al., 2008; Lipton et al., 2009). Mathias and colleagues (2004) found that the volume of the corpus callosum, a critical area for intra-hemispheric transmission, was 15-20% smaller in patients with mTBI. Niogi et al. (2008) has similar findings on their study of the corona radiata and the uncinate fasciculus, white matter tracts also vital for information transmission.

There is also evidence in the literature that individuals with mTBI may have problems at the level of resource allocation, which is defined as "a person's ability to divide mental resources between concurrent mental activities" (Montgomery & Evans, 2009). The electrophysiological literature, specifically studies of evoked potentials, has informed this thinking. Studies using evoked potentials (EPs) have addressed this question by describing involuntary cognitive responses to visual or auditory stimuli. Studies describing the P3 response, in particular, have been quite informative. The P3 response has been known to reflect a deficit in resource allocation (Polich, 2007). Broglio et al. (2009) and Kashluba et al. (2008) have found that young adults with three years post-injury demonstrated deficits in the P3b and the N2 responses, indicating depressed allocation resource capacity. The P3 response has been shown to index attention processing, and in adults with mTBI, longer latency times and decreased amplitudes have been found (Dupuis et al., 2000; Gaetz et al., 2000; Gosselin et al., 2012; Lavoie et al., 2004; Thériault et al., 2009), despite similar task performance. Ozen et al. (2013) found a significant difference between latency and amplitude on the P3 potential in individuals with mTBI and healthy controls using the oddball task and n-back task.

Diminished cognitive resources from abnormal white matter or [decreased] frontal lobe integrity, combined with reduced ability to allocate these cognitive resources, can potentially contribute to cognitive performance characterized by longer than average processing times. This cognitive slowing is particularly evident in timed contexts, which require efficient resource allocation within strict temporal demands. The result of this mismatch in skill and demand is therefore represented behaviorally as slow processing time. Deficits in speed can have a significant impact across many areas of functioning. Speed of information processing will likely play a role in everyday language functions such as auditory comprehension, particularly when there is time pressure to respond, so it is important to understand the effects of speed on language performance. Individuals with speed processing problems might encounter difficulties in everyday language comprehension performance. Auditory comprehension tasks will potentially be more effortful, require longer processing times, and may be executed with a greater number of errors.

To our knowledge, there are no experimental studies of language comprehension in adults with mTBI that have explored the role of a specific cognitive domain on language comprehension in mTBI. However, without identifying and understanding the cognitive deficits that underlie these functional problems, progress in developing effective assessments and treatments for communication problems after mTBI will remain static, and thus will prevent individuals with mTBI from returning to pre-injury levels of participation.

Our study is motivated by the pressing need to provide SLPs with sensitive instruments to quantify language comprehension problems in adults with mTBI. By interpreting reduced resource allocation as prolonged processing time, we tested our hypothesis behaviorally using measures of language. Experiments that manipulate the element of processing time encourage participants to perform as quickly as possible or to take their time, and these experiments allowed us to test the hypothesis that condition affects cognitive performance in mTBI. To increase the scientific rigor of these approaches, we validated the experimental language measure with a standardized and reliable neuropsychological test of speed of processing. Because there is evidence that language complexity affects efficient processing, we manipulated the complexity of the language task in our study using methods from the developmental literature. Specifically, we chose sentence constructs that vary in complexity defined by age of acquisition. That is, sentence constructs that are early developing in native English speakers, i.e., those constructs that follow canonical word order, are on the lower end of complexity, and those that are later developing, i.e., those that violate canonical word order, are on the higher end of complexity. By using sentences of varying complexity that are stripped of semantic plausibility and asking participants with and without mTBI to interpret the agent of the sentence ("who is doing the action?"), we are tested our study question: is speed a mechanism underlying language performance after mTBI?

We hypothesized that language problems after mTBI are consistent with reduced speed of information processing, and we proposed that the source of these deficits is limited resource capacity combined with a reduced ability to allocate attentional resources. Specifically, we proposed that adults with mTBI allocate resources less efficiently than their peers and that this contributes to overall longer sentence interpretation times and lower accuracy. We predicted that speed and sentence type would have a main effect on performance and that this effect would be more pronounced in the mTBI group. To add concurrent validity to our experimental measures, we also included a standardized neuropsychological measure of speed of information processing to our protocol and predicted that it would be correlated with speeded measures.

METHOD

Participants and Procedures

The study employed a prospective between group comparisons of adults with mTBI and OI. Participants in both groups had presented to the Emergency Medicine Department at the University of Wisconsin-Madison, and had been diagnosed with mTBI or a non-surgical OI by a physician, physician assistant, or nurse practitioner (Please see Appendix A for diagnostic codes). After initial evaluation and care for their injuries, both mTBI and OI participants were discharged to home, and they participated in the study 3-12 weeks after their injuries.

All procedures were approved by the Institutional Review Board at the University of Wisconsin-Madison. Potential participants were identified via a medical chart review by research personnel with valid clinical access. (Recruitment procedures are listed in Appendix B.) Participants were actively recruited from April 2016 to March 2017. Participants were mailed a letter indicating that they were being contacted because of their recent visit to the emergency department and stating their potential eligibility for the study. Two hundred and twelve individuals were identified as potential participants via the medical chart review. These potential participants were called by the first author for phone screening to determine eligibility for the study. The first author attempted to contact potential participants at least three times via telephone. If contact was made and potential participants expressed interest in participating, they were screened for the study inclusion criteria, and if criteria were met, a research appointment was scheduled no later than one month after the telephone screening. Participants provided oral consent for the telephone screening and written consent at the time the study was completed. Participants were compensated $25 per hour to complete the study tasks. On average, most participants completed the study in 2.5 hours.

Participants were included if they were ages 18-55 years and reported English as their primary language. We chose 55 years as a cut-off age to reduce age-related cognitive effects as a confounding variable. Individuals in the mTBI group were included if they were diagnosed with International classification of diseases and related health problems, 9th edition (ICD-9) Codes 850* and 10th edition (ICD-10) Codes S06.0*, which were confirmed during the in-person interview using the following definition of mTBI:

> A blunt injury to the head or to the body with impulsive force transmitted to the head that resulted in any of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, drowsiness, blurred vision, memory difficulty or difficulty concentrating. (Eisenberg et al., 2014)

Individuals in the OI group were diagnosed with non-surgical, traumatic OI as defined by ICD 9 Codes 800-829 and ICD 10 Codes S40-S49, S72, S82, and S92.

Exclusion criteria for all participants were: 1) history of pre-injury medical or neurological disease affecting the brain (other than concussion for the mTBI group), or language or learning disability; 2) indication of a health-care surrogate on the medical record; or 3) failure of a pure-tone hearing screening using an air conduction threshold of 30 dB or better in one ear (averaged across 500, 1000, and 2000 Hz). The hearing screening was completed at the time of the study by either a licensed SLP or a trained graduate assistant.

Participant Characteristics

Participants were 19 adults with mTBI (11 females), and 19 adults with OI (14 females). Table one lists demographic characteristics and descriptive data. Injury information is included in Table 2. There were no significant between-groups differences in neurobehavioral symptoms, or scores on standardized cognitive tests.

Primary Measures

Whadunit Sentence Task

Our primary outcome measure was an adaptation of the Whatdunit task (Montgomery et al., 2016). The Whatdunit task is an experimental sentence completion task comprised of sentences that use either canonical English word order (subject-verb object [SVO] and subject relative [SV]) or non-canonical word order (passive and object relative [OR]). There are 33 sentences of each of the four types, and they are presented via audio to a listener. After each sentence, the listener is asked to select the agent of the sentence ("the picture of the noun doing the action") from a group of four pictures displayed on the screen (Rossion & Pourtois, 2004). The methods for administering the task followed the original study by Montgomery and colleagues (2016), with the exception that we divided stimuli into two sets that were presented in two conditions: speeded and unspeeded. In the speeded condition, as in the original task, participants were told to select the agent "as quickly as possible." In the unspeeded condition, participants were instructed to "take your time" in selecting the agent of the sentence. E-prime software (Psychology Software Tools, 2012) captured accuracy, and response times were measured via touch screen monitor (Elo™ 1000 Series 1715L Touchscreen Display).

Each condition contained 66 sentences, presented in two blocks of 33 sentences. The unspeeded set was composed of 16 (SVO), 16 (SR), 17 (PAS), and 17 (OR) sentences. The speeded set contained 17 (SVO), 17 (SR), 16 (PAS), and 16 (OR) sentences. The sentences were randomized in each condition and the conditions were counterbalanced. All sentences were the same length (12 words) and the words had word frequency ratings of age 6 or younger (i.e., early acquired words are typically higher in frequency), age of acquisition of age 3.6 years or younger, with high imageability (>500) and concreteness ratings per previous research (Coltheart, 1981; Kuperman, Stadthagen-Gonzales, & Brysbaert, 2012; Storkel & Hoover, 2010; Vitevich & Luce, 2004). Sentences were spoken at a normal speaking rate (~4.4 syllables/second) in standard Midwestern English, and administered through professional over-the-ear headphones at a comfortable listening level for each participant.

The Whatdunit task is a validated language task originally developed for use with children with specific language impairment (SLI), children who, like individuals with mTBI, are thought to have resource capacity and allocation difficulties (Montgomery & Evans, 2009). The demands of the task require efficient resource allocation within a narrow response window. These high task demands, in combination with the documented limited cognitive resources available to individuals with mTBI, provided a high threshold for accuracy, which we believed would be sensitive to mTBI-related comprehension deficits. We predicted that, like children with SLI, our participants with mTBI would complete the task with less accuracy and longer reaction times than our participants in the OI group.

This task was piloted prior to launching the study with the participation of two individuals with mTBI and two individuals without mTBI who had participated in previous studies in the Communication and Cognition Laboratory at the University of Wisconsin-Madison. Preliminary data showed that the mTBI group completed the sentence task at a slower pace and with more errors than community controls, particularly in sentences that violated canonical word order (e.g., Passives and OR). Results supported the feasibility of the study and were used to calculate sample size. (Please see Table 8 for examples of sentence stimuli used.)

Baseline Motor Speed Task

To control for potential individual differences in motor planning and execution time within and between groups, all participants completed a simple motor speed task prior to completing the experimental language task. The structure of this task was identical to the Whatdunit task. Displayed along the bottom of the touch screen were three empty boxes arranged horizontally. Participants were told that they would first hear a tone (2kHz, 500ms) and then see a cross appear in one of the boxes. They were instructed to reach out and touch the cross as quickly as possible as soon as it appeared. E-Prime derived a motor reaction time (in ms) from this act. The tone and cross were separated by an inter-stimulus interval of 500ms and 1.5 s.

Across the trials, the cross appeared randomly in each box an equal number of times. The task consisted of 30 trials which were averaged out to attain an average motor RT for each participant. The motor RT was used in analysis of the sentence interpretation time (Please see Statistical Analysis).

Other Measures

Medical Record Review

In order to accurately characterize the sample, the following information was extracted from participants' medical records: mechanism of injury, medical diagnoses, psychiatric diagnoses, medication use, dates of service in the UW Emergency Medicine Department, referral to other providers upon discharge from the hospital, and medical lab/test results related to the ED visit. Demographic information such as date of birth, sex, race/ethnicity, and primary language was also collected for all participants.

Case History

A case history form was completed in face-to-face interview format after completion of written consent by the participant. This form solicited information regarding demographic characteristics; health, education, and vocational history; current employment or academic performance; and medical and neuropsychological history related to the injury. Medical records were reviewed when deemed necessary, for example, when ruling out neurological conditions that would exclude participation in the study.

Neurobehavioral Symptom Inventory (NSI)

The Neurobehavioral Symptom Inventory (NSI) is a self-report measure of symptoms commonly associated with Post-Concussion Syndrome (PCS) that may emerge after mTBI. There are three scales based on the type of symptom: cognitive, somatic/sensory, and affective.

Symptoms such as hearing difficulty and change in taste or smell would be considered somatic, slowed thinking or forgetfulness would be considered cognitive, and feeling anxious or depressed would be considered affective. The NSI is widely used in civilian and military clinical and research settings (Belanger, Kretzmer, Vanderploeg, & French, 2010; Soble et al., 2014). Soble et al. (2014) found that an average score in a non-deployed, non-clinical sample (n = 1453) was 3.0, with a standard deviation of 5.7.

Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) As cognition is affected by sleep and sleep quality (Wiseman-Hakes et al., 2013), we were interested in the amount and quality of sleep our participants endorsed. On the PSQI higher scores indicate poorer sleep quality over the preceding month. The results include subtotals in seven categories: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction.

Speech-Language and Cognitive Tests

WAIS Processing Speed Index (Wechsler, 2008). To describe general speed of information processing skills (non-verbal), we administered the WAIS-symbol search (WAIS-ss) and coding (WAIS-dsc) subtests. These two subtests comprise the WAIS Processing Speed Index (WAIS-PSI).

NIH Toolbox Cognition Battery (Gershon et al., 2013). To characterize participants' general cognitive and language abilities, all subtests of the NIH Cognition Battery were administered. Cognitive domains assessed were executive function (including inhibitory control), attention, episodic memory, language (Picture Vocabulary Test, Oral Word Recognition Test) and processing speed. Fully corrected scores were used for all analyses. The NIH Toolbox is included in the National Institute of Neurological Disorders and Stroke (NINDS) common data elements recommendations, which allow comparison across studies in TBI (Wilde et al., 2010).

Sentence Comprehension Test, Adapted from Philadelphia Comprehension Battery, (MacWhinney, Fromm, Forbes, & Holland, 2011), the Sentence Comprehension Test was administered to control for general sentence comprehension abilities. It is part of the TBI TalkBank study protocol, a shared database and longitudinal project regarding language recovery after TBI (www.talkbank.org).

Statistical Analysis

Main statistical analyses were conducted in SPSS Version 23.0 with criterion level set at $p < .05$. Post-hoc power analyses were conducted using G*Power Program (F. Faul et al., 2007). Scaled demographic variables were tested with independent samples t-tests, and categorical variables (e.g., sex, race, employment) were tested using the chi-square statistic or a Fisher's exact test. Average motor reaction times were compared using independent samples t-tests.

To test our main study hypothesis regarding overall sentence interpretation accuracy and overall sentence interpretation time, we used a repeated measures ANOVA with group (mTBI or OI) as the between-groups factor and a within-group factor of condition (speeded vs. unspeeded). To derive a sentence interpretation time for each participant, we followed the subtraction method explained in (Montgomery et al., 2016). Mean motor RT's were subtracted from each correct sentence trial and these numbers were averaged to derive an overall sentence interpretation average score. Items answered incorrectly were excluded from this calculation, and thus, there were fewer items in the sentence interpretation analysis when compared to the accuracy analysis.

To test our second hypotheses regarding the effect of sentence type, we conducted a repeated measures ANOVA with sentence type (SVO, SR, OR and PAS) as a within-group factor and group as the between-groups factor. Planned pair-wise comparisons were conducted using t-tests, with a Bonferroni correction for multiple comparisons.

To ensure that the manipulation of the speed condition was valid, we used Pearson correlations to compare WAIS-PSI scores to Whatdunit task dependent variables (accuracy or sentence interpretation time in speeded and unspeeded conditions).

Results

Demographic characteristic of the sample are shown in Table 1. There were no significant between-groups differences on any variable. Injury characteristics for the two groups are shown in Table 2. Participants with mTBI were, on average, further post-injury than OI participants (65 vs. 57 days post-injury) and this difference was marginally significant, χ^2 (2, N=38) =3.66, *p*=.08. Results of relevant questionnaires and tests are shown in Table 3. The two groups did not differ on NIH Toolbox scores, sentence comprehension, sleep quality or neurobehavioral symptoms as measured by the NSI. However, NSI scores were elevated for both groups as average scores for both were more than two standard deviations beyond the normal range (Soble et al., 2014).

Motor Speed

There was no statistically significant difference in mean motor reaction between the mTBI group (M=719.33 ms, SD= 88.94) and the OI group (M=748.94 ms, SD=102.14), t(36)=.953, p=.17, although the OI group tended to be slower.

Sentence Interpretation Accuracy

Table 4 lists overall sentence accuracy for speeded and unspeeded conditions by group. In the unspeeded condition, the mTBI group had a higher mean accuracy (M=89.46, SD=11.93) than the OI group (M=82.49, SD=19.15). Levene's test demonstrated that the assumption of homogeneity of variances was not met (*p*=.006), therefore the Welch test was conducted and this test showed a marginally significant difference (*p*=.09) between groups. In the speeded condition, the TBI group performed with lower accuracy (M=79.80, SD=20.60) than the OI group (M=83.55, SD=16.17), however this difference did not reach statistical significance F(1,36)=.391, *p*=.268. There was no significant effect of condition on accuracy scores, Lambda= .96 F(1,36)=1.656, *p*=.10.

Sentence Interpretation Speed

There was no significant effect of group on sentence interpretation speed in the speeded condition, F(1, 36)=.005, *p*=.47; or the unspeeded condition F(1,36)=.755, *p*=.195; although participants with mTBI tended to take longer than OI participants to interpret the sentences in the speeded condition (M=468 ms, SD=403 ms vs M=459.04 ms, SD=428 ms) and in the unspeeded condition (M=1140.04 ms, SD=1230.80 vs M=834.35, SD=914). There was a statistically significant effect of condition, Lambda= .726 F(1,36)=13.56, *p*=.001 whereby both groups decreased their interpretation time in the speeded condition; and the group by condition interaction was not statistically significant Lambda= .971 F(1,36)=1.086, *p*=.152.

Accuracy and Sentence Interpretation Speed by Sentence Type Accuracy

See table 5 for summary of accuracy scores by sentence type and group in both conditions. In the speeded condition, a repeated measures ANOVA showed that the effect of sentence type (OR, PAS, SR or SVO) was significant in the speeded condition, Lambda = .56 *F*(1,36)=8.89, *p*=.00, η^2 = .44; with no significant interaction of group by sentence type, Lambda = .969 F(1,36)=3.65, p=.389, . η^2 = .03. Accuracy on OR sentences was significantly lower from accuracy on PAS (*p*=.009), SR (*p* < 000) and SVO (*p* <.001); PAS accuracy was significantly higher from accuracy on OR (*p*<.01) SR (*p*=.011) and lower than SVO sentences (*p*=.007); and

SR accuracy was significantly higher from OR (*p*=.00) and PAS (*p*=.01) but not significantly different from SVO accuracy (*p*=.50).

In the unspeeded condition, there also was a statistically significant effect of sentence type, Lambda =.71 $F(1,36)=4.53$, $p=.0004$, $\eta^2 = .29$; but no group by sentence type interaction, Lambda =.97 $F(1,36)=3.38$, $p=.40$, $\eta^2 = .03$. Planned pairwise comparisons with Bonferroni correction revealed significantly higher accuracy for performance on the OR sentences compared to SR sentences (*p*=.002) and lower accuracy when compared to SVO sentences (*p*=.002), and higher accuracy for PAS sentences compared to SR sentences (*p*=.009) and lower accuracy for PAS compared to SVO sentences (*p*=.0075); and no statistically significant differences in accuracy between OR and PAS.

Sentence Interpretation Time

For sentence interpretation time, there was a statistically significant effect of sentence type in the speeded condition Lambda= .798 $F(1,36)=2.7$, $p=.03$, $\eta^2 = .20$; and a marginally significant interaction of sentence type by group, Lambda= .833 $F(1,36)=2.14$, $p=.08$, $\eta^2 = 17$. Planned pairwise comparisons with Bonferroni correction revealed statistically significant differences in sentence interpretation time in the speeded condition between OR and SVO sentence types (*p*=.029), and between OR and SR sentences (*p*=.06), with OR sentences on average, taking longer to interpret than SVO and SR sentences.

In the unspeeded condition, there was a statistically significant effect of sentence type on interpretation time, Lambda = .587 $F(1,36)=7.5$, $p=.0005$, $\eta^2 = .41$; and no statistically significant effect of sentence type by group, Lambda= .951 $F(1,36)= .55$, $p=.33$, $\eta^2 = .04$. Pairwise comparisons revealed significantly longer sentence interpretation time for OR sentences in comparison to SVO (p=.026) and longer interpretation times for SR sentences compared to SVO (p=.02).

WAIS-IV Processing Speed Index

WAIS-PSI differed significantly by group, *F* (1,36) =2.94, *p*=.04; with lower scores in the TBI group compared to the OI group (M=103.16 , SD=11.37 vs. M=110.73, SD=15.56). The effect of group approached significance in the WAIS-dsc F(1,36)=2.6, *p*=.058 and in the WAISss F(1,36)=2.34, *p*=.06. Both groups' WAIS scores were within the range of normal. Correlations between WAIS-PSI scores and the Whatdunit task variables are listed on Table 7. Positive correlations were found between WAIS-PSI and accuracy in the speeded condition (*p*=.022) indicating that higher scores on the WAIS-PSI (indicating better performance on speeded tasks) test was associated with higher accuracy on the Whatdunit task. Negative correlations were found between WAIS-PSI scores and sentence interpretation time in both speeded (*p*=.001) and unspeeded condition (*p*=.013) indicating that higher scores on the WAIS-PSI was associated with lower sentence interpretation time as measured in milliseconds.

DISCUSSION

The current study aimed to characterize language after mTBI by investigating the role of speed on language comprehension in a group of adults with mTBI and a comparison group of adults with OI, during the sub-acute stage of recovery. In the next sections, we consider results for each of the study aims, and what our study adds to the literature on language functioning in adults with mTBI.

Aim One

The results of our study did not support our hypothesis regarding overall sentence interpretation accuracy and overall sentence interpretation time. We hypothesized that the mTBI group would perform with lower accuracy levels and with longer interpretation times; however, the mTBI group had significantly higher scores than the OI group and although the mTBI group tended to have longer interpretation times, this difference did not reach statistical significance. The combination of higher accuracy levels and longer processing times hints at the possible use of a speed-accuracy trade off in the mTBI group. Speed-accuracy tradeoff is a strategy whereby an individual prioritizes accuracy at the expense of reaction time, particularly in instances with a temporal response window (Wickelgren, 1977). The use of this strategy has been documented in the study of cognition in moderate to severe TBI (Battistone et al., 2008; Madigan et al., 2000), and to our knowledge this is the first study to investigate speed effects in adults with mTBI. The use of a speed-accuracy tradeoff is a potential indicator that if indeed individuals with mTBI have limited cognitive resources combined with reduced allocation abilities they may attempt to compensate for these limitations (consciously or unconsciously) by using self-generated cognitive strategies such as speed-accuracy trade-off. Modeling of speed-accuracy tradeoff was not a primary aim of this study; therefore, formal statistical modeling of this relationship awaits future analyses of the data.

One important element to consider when discussing this methodology is the role of each participant's motor reaction time. Although there were no significant group differences in motor reaction time, the OI group tended to be slower. Although the motor component of the sentence task required minimal movement, it is worthwhile to consider that a large proportion of the OI group had been diagnosed with shoulder and upper arm orthopedic injuries and these injuries could negatively impact the biomechanics of their reaching motion to touch the stimuli on the touchscreen monitor used in our study (P. McCrea, Eng, & Hodgson, 2002). Conducting speed-accuracy tradeoff modeling would need to consider the fact that participants in the OI group may be using slower movements not only to gain additional thinking time and thus increase accuracy, but also to gain additional motor planning time. Our study aimed to address this confound by using the subtraction method described earlier in the methods section to control for each individuals' motor reaction time.

Aim Two

Our second aim was partially supported by our findings. To test our participants' comprehension at varying levels of syntactic complexity, we included sentence stimuli of varying complexity (SVO, SR, OR and PAS). We predicted that sentence type would affect speed and accuracy, whereby sentences that violate canonical word order and are later-developing (OR and PAS) would be interpreted with lower accuracy levels and longer processing times. Our experiment demanded efficient allocation of resources, as participants are required to manipulate verbal information while retaining language comprehension in speeded and unspeeded conditions, thus the demands are potentially high and the task complex enough to capture subtle deficits, which are characteristic of mTBI.

In both the speeded and unspeeded condition, this manipulation of sentence type yielded medium (unspeeded condition) to large (speeded condition) effects on accuracy. In regard to sentence interpretation time, our findings again indicated an effect of sentence type in both conditions. Our pairwise comparisons in both conditions supported the second part of our hypothesis, i.e., that the PAS and OR sentences would be processed with lower accuracy levels and prolonged interpretation times overall. These results are in concordance with the literature on syntactic complexity in the normal population (Wells, Christiansen, Race, Acheson, & McDonald, 2009). PAS and OR sentences are not only less frequent in occurrence than SVO and SR sentences in written and spoken English but their word order is also less frequent and their sentence construction (noun-noun-verb and object-verb-object) requires considerably more effortful processing (Montgomery et al., 2016).

We reported a marginally significant group X sentence type interaction, but only in the speeded condition. This finding demonstrates that perhaps the combination of syntactic complexity combined with strict temporal response windows can be a potential method for further study. Comeford, Geffen, May, Medland, and Geffen (2002) compared a large sample of adults with mTBI to OI and community controls, and found that the TBI group produced fewer sentences on the Speed and Capacity of Language Processing Test (Baddeley, Emslie, & Nimmo-Smith, 1992) in a two-minute time window compared to both of the other groups. The authors found a significant difference in reaction times among the female participants but not in the male participants. While the participant groups share some similarities with our study's participants, participants in the Comeford et al. study were all evaluated within 24 hours of admission to the emergency department at a large metropolitan hospital, in contrast to our participants who had been discharged home and had weeks and, for some, months of recovery time. Their study also did not exclude participants under the influence of alcohol, which is likely a confounding variable in measures of reaction time (Maylor & Rabbitt, 1993).

The lack of a robust group interaction with our variables of interest (accuracy and sentence interpretation time) reflects the challenge of developing appropriate language tasks to test hypotheses in the mTBI population. While our task might have been sensitive to cognitive processing abilities in both groups (as evidenced by the main effects of condition and sentence type) the task was not specific enough to capture mTBI-related deficits. Indeed, this is an issue that has been observed in other populations in which the degree of cognitive impairment is mild, such as mild cognitive impairment, multiple sclerosis and chemotherapy-related cognitive disorder. Nevertheless, this lack of an association expanded the current knowledge regarding processing speed abilities in mTBI within the context of the experience of trauma in general. Our use of a comparison group with a mild bodily injury during the same temporal window of recovery guides our interpretation of cognitive performance after mTBI. The use of OI controls is critical in the study of mTBI, as they allow researchers to control for the effect of trauma on participants, recognizing that a traumatic event in of itself will change performance. Furthermore, researchers have argued that OI comparison groups are valid because they likely share demographic, pre-injury characteristics (e.g., risk-taking behavior) with participants with TBI, and if recruited from the same medical facility, as our participants were, they have had comparable levels of medical care for their injuries (Landre et al., 2006; Troyanskaya et al., 2016). Further research in this area is needed to determine whether communication changes are more likely to surface as a result of experiencing trauma, regardless of etiology.

Limitations

Because there were limitations, the results of our study should be interpreted with caution. The most significant limitation was our small sample size. Although our study's recruitment period was one year in duration, we experienced difficulties contacting potential participants as well as enrolling participants who fit our narrow exclusion criteria. We used our data to complete post-hoc sample-size estimations. These analyses revealed a need for sample sizes of 96 to 456 adults per group to observe differences in our variables of interest (accuracy and sentence-interpretation time). Because differences between individuals with mTBI and typical comparison groups are small (in our case, the differences in performance were either a few percentage points in accuracy or several milliseconds in interpretation time), we need very large samples to detect these subtle differences. Recruitment for these large sample sizes is not always feasible or practical, and the question remains as to whether such small effects are clinically meaningful.

A second limitation stems from the fact that we recruited all patients discharged with mTBI rather than just those who reported cognitive symptoms. The probability of cognitive deficits at more than one month post-mTBI has been estimated to be less than 5% (Binder et al., 1997). If we assume individuals with persistent cognitive symptoms are those who would likely experience problems with cognitive-communication, the number of adults with cognitive-communication symptoms in our group would be as low as one. The results of our symptom report measure, the NSI, revealed that over 6 people in our sample (4 mTBI and 2 OI) reported symptoms over 5, which is significantly higher than the mean for the non-deployed, uninjured sample in Soble et. al. A visual inspection of NSI means demonstrates three outlying scores, two of which are in the OI group, which could significantly have affected the central tendency of the sample.

A future study might recruit a clinical sample of individuals with mTBI symptoms, or screen for cognitive-communication problems prior to enrolling in the study to increase the likelihood of detecting comprehension deficits in the included mTBI sample. This future recruitment approach also would more closely match clinical samples seen by SLPs most likely to see patients with lasting and disabling problems. In addition, our study may have suffered from a sampling bias, as we enrolled people who were not only invested in participating in research (often they were invested months after their injuries) but had flexibility in their employment and other life activities to do so. These limitations make the ability to generalize and apply our results to other mTBI populations tenuous at best.

Conclusions and Further Directions

The results of our study can help inform the development of sensitive and specific measures of language performance after mTBI. Although the effects of sentence type on performance under speeded conditions were only marginally significant, perhaps the inclusion of this manipulation can inform future studies. The correlation between WAIS-PSI scores and speeded measures provides some validation for the use of this measure with mTBI, so it might be beneficial to use this measure in future studies.

Because there is a pressing need to improve assessment and treatment for mTBI-related symptoms and strong evidence that communication supports long-term outcomes such as social integration and employment, more research that characterizes communication after mTBI is warranted. Further directions for research include the continued investigation of differences in language performance between adults with mTBI and OI controls on measures of expressive language, including word, sentence, and discourse under speeded conditions. Tasks that are valid and reflect everyday communication demands are worthy candidates for further study. Studies in this realm are critically needed in order to develop measures with ecological validity. Investigating the effect of cognitive effort on language performance outcomes promises to be an important direction for further study. While studies of language performance such as the current study traditionally have focused on accuracy or reaction time outcomes, the role of elements such as mental effort should also be considered. Evidence of high effort could potentially affect cognitive capacity and resource allocation and consequently speed of information processing.

Table 1

Demographic Characteristics of Participants

	mTBI (n=19)	**OI (n=19)**
Age, y, mean (SD)	28 (9.91)	27.17 (6.08)
Age, range	19.5-51	18.5-37
Female, n (%)	11 (58)	14 (74)
African American	3 (15.8)	1 (5.3)
Other race	4 (21.1)	1 (5.3)
Highest level of education		
High School/GED	2 (10.5)	0
Some College/Associates/Tech Degree	8 (42.1)	11 (57.9)
Bachelor’s Degree	6 (31.6)	7 (36.8)
Post-Graduate	3 (15.8)	1 (5.3)
Employment		
Unemployed	1 (5.3)	2 (10.5)
Part-Time Employment	7 (36.8)	1 (5.3)
Full-Time Employment	10 (52.6)	16 (84.2)
Student	8 (42.1)	5 (26.3)

Table 2

Injury Characteristics of the Sample

mTBI (=19)		OI (n=19)	
Time post injury, d, mean (SD)	65.26 (18.54)	Time post injury, d, mean (SD)	57.5 (13.18)
Participants with history of previous mTBI, n (%)	8 (42)	Participants with history of previous mTBI, n (%)	4 (21)[a]
Mechanism of Injury, n, (%)		Mechanism of Injury, n, (%)	
Moving Vehicle Accident	3	Moving Vehicle Accident	1
Fall	6	Fracture	9
Assault	3	Dislocation	5
Sports-related	4	Sprain	1
Hit head on structure	3	Contusion	1
Hit by cow	1	Inflammation	1
		Unknown	1

[a] reported injuries in group occurred > 2 years prior to date of study participation

Table 3

Scores on NIH Toolbox Tests, Neurobehavioral Symptom Inventory (NSI), and Pittsburgh Sleep Quality Index (PSQI). Data are means (SD).

	mTBI (n = 17)	OI (n = 19)
NIH Toolbox Composite Score	52.75 (9.49)	56.35 (10.42)
NIH Toolbox Working Memory	45.93 (11.60)	49.71 (10.48)
NIH Toolbox Processing Speed	36.45 (7.55)	34.82 (9.03)
NIH Toolbox Vocabulary	55.05 (8.66)	57.65 (10.20)
Sentence Comprehension Test	18.66 (1.68)	18.63 (1.42)
NSI Total Score	16.31 (10.58)	14.15 (11.70)
NSI Affective Score	7.44 (3.71)	5.94 (5.69)
NSI Cognitive Score	3.42 (2.47)	3 (3.33)
NSI Somatic Score	5.23 (4.85)	5.21 (3.99)
PSQI Global Score	7.15 (4.05)	6.21 (3.66)

Table 4 ***Overall Sentence Interpretation Accuracy (percentage correct) and Sentence Interpretation Time[a] (in msecs) by group and condition***

	Acc-s	Acc-u	Time-s	Time-u
mTBI (n=19)				
Mean	79.80	89.46	468.52	1140.04
SD	20.60	11.93	403.90	1230.80
Range				
OI (n=19)				
Mean	83.55	82.49	459.04	914.44
SD	16.17	19.15	428.50	209.78
Range				

[a] Time is adjusted for baseline motor speed
Abbreviations:

Table 5 ***Sentence Interpretation Accuracy (percentage correct) by sentence type and group in both speeded and unspeeded conditions***

	Sentence Type							
	SVOs	*SVOu*	*SRs*	*SRu*	*PASs*	*PASu*	*ORs*	*ORu*
mTBI (n=19)								
Mean	95.04	95.72	94.11	95.72	77.30	84.21	72	84.41
SD	6.60	6.26	7.33	6.60	29.84	21.57	31.16	17.69
OI (n=19)								
Mean	94.80	97.03	93.80	96.38	80.59	78.94	70.07	77.71
SD	10.13	4.35	10.10	4.80	29.75	34.48	29.72	31.28

Table 6 Sentence Interpretation Time (in msecs) by sentence type and group in speeded and unspeeded conditions

	Sentence Type							
	SVOs	*SVOu*	*SRs*	*SRu*	*PASs*	*PASu*	*ORs*	*ORu*
mTBI (n=19)								
Mean	335.43	942.96	474.82	1177.94	612.12	1104.14	741.26	1342.64
SD	357.27	1107.60	489.05	1331.81	758.99	1304.19	1096.95	1582.24
OI (n=19)								
Mean	454.10	735.57	479.52	857.72	373.72	917.19	713.19	1225.41
SD	479.19	771.70	434.07	915.34	363.71	1188.87	812.97	1701.27

Table 7 ***Pearson Correlations between WAIS performance and Whatdunit Task Performance for sample (n=38)***

	Acc-s	**Acc-u**	**Time-s**	**Time-u**
WAIS-psi	.328*	.192	-.501**	-.360*

*Correlation is significant at the 0.05 level (1-tailed).
** Correlation is significant at the 0.01 level (1-tailed).

Table 8

Whatdunit sample sentences

Subject–Verb–Object

The hat had hugged the belt behind the very bright new sock.

The ring had moved the square behind the very bright cold bed.

The square had changed the bed under the very new dry key.

The shoe had bumped the fork near the very bright new wheel.

The knife had watched the ball near the very bright hot square.

Subject Relative

The watch that had hugged the truck behind the kite was bright.

The train that had helped the knife under the square was cold.

The boot that had fixed the shoe behind the drum was new.

The cake that had cleaned the bed near the train was bright.

The spoon that had licked the book near the watch was bright.

Passive

The train was watched by the bed behind the very cold cake.

The watch was bumped by the wheel near the very bright clock.

The key was changed by the chair behind the very bright square.

The belt was pulled by the book near the very new bowl.

The clock was rubbed by the shirt behind the very new door.

Object Relative

The truck that the clock had pressed near the door was bright.

The chair that the bread had splashed under the square was new.

The kite that the dress had pressed near the book was hot.

The watch that the sock had wiped near the shirt was dry.

The box that the kite had splashed behind the shoe was dry.

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CHAPTER 4

Manuscript 3

Self-perception of Communication Competence in Adults with Mild TBI, Moderate to Severe TBI, and Orthopedic Injuries

Rocío S. Norman[1], Melissa C. Duff[3], Bilge Mutlu[4] and Lyn S. Turkstra[1,2],

1 Department of Communication Sciences and Disorders, University of Wisconsin-Madison

2 Neuroscience Training Program and Department of Surgery, University of Wisconsin-Madison

3 Department of Hearing and Speech Sciences, Vanderbilt University

4 Department of Computer Sciences, University of Wisconsin-Madison

Corresponding Author:

Rocío S. Norman

University of Wisconsin-Madison

Department of Communication Science and Disorders

1975 Willow Drive

Madison, WI 53706

Email: rocio.norman@wisc.edu

Phone: 210-367-1600

Abstract

Objective: The aim of the study was to characterize communication in adults with mTBI by measuring self-perception of communication problems in everyday life. A second aim of the study was to compare the responses of the mTBI group with a group of moderate to severe TBI and a community based comparison (CC) group.

Method: 19 adults with mTBI (13 females), 20 adults with OI (11 females), 31 adults with moderate to severe TBI (12 females), and 29 CC peers (15 females) participated in the study. Participants completed the LaTrobe Communication Questionnaire-Self, the WAIS-IV Processing Speed Index, and the Neurobehavioral Symptom Inventory (NSI).

Results: Our analysis of mean scores on the LCQ-self revealed a statistically significant main effect of group, F (3,45) =8.1, $p < .001$. Planned post-hoc comparisons indicated no differences among the mTBI, OI, and CC groups, and a statistically significant difference between the CC and moderate to severe TBI groups ($p <.001$), indicating that the moderate to severe TBI group reported significantly more communication problems than the CC group.

Conclusions: The mTBI group identified fewer areas of deficit in communication competence than any of the study groups. There were only significant differences between groups at the opposite ends of the injury spectrum: the moderate to severe TBI group and the CC group. Our findings for the mTBI group can be attributed to the presence of post-concussive symptoms in adults with general trauma and adults with TBI or the potentially limited sensitivity of the LCQ-self for mTBI.

Keywords: adult, brain injuries, communication, mild traumatic brain injury

Traumatic brain injury (TBI) is defined by the American Congress of Rehabilitation Medicine as a "traumatically induced physiological disruption of brain function" (American Congress of Rehabilitative Medicine, 1993b). Nearly 2.5 million individuals are affected by TBI in the United States each year, and 87 percent of these individuals are treated in and discharged from Emergency Medicine departments (Centers for Disease Control and Prevention, 2015; M. Faul, Xu, Wald, & Coronado, 2010b). Most of these injuries are mild, and in recent years, there has been an increased interest in characterizing the effects of these mild injuries. MTBI is associated with a constellation of symptoms resulting from both mechanical and metabolic changes after injury (Giza & Hovda, 2001). Physical symptoms include headaches, photophobia, hearing loss, sleep disturbances, and vestibular problems. Psychological symptoms include post-traumatic stress disorder, anxiety, and depression. Cognitive symptoms include slowed speed of information processing and impairments in executive functions and memory (Iverson, 2016). Most people fully recover from these symptoms between three weeks to three months post-injury (Bernstein, 2002; L. Carroll et al., 2004; Iverson, 2005; Makdissi et al., 2015), but a small percentage report persistent physical, psychological, and cognitive symptoms for months or even years after injury (Alves, Macciocchi, & Barth, 1993; Ponsford et al., 2000).

In addition to symptoms in the domains described above, preliminary evidence shows that individuals with mTBI are at risk for communication problems (Crewe-Brown, Stipinovich, & Zsilavecz, 2011; Norman et al., 2013; Parrish et al., 2009). Studies have established that communication problems after moderate to severe TBI are commonly a result of underlying cognitive difficulties (Chabok et al., 2012a; Coelho, 2007; Youse & Coelho, 2005), but because the cognitive sequelae of mTBI are less severe, it is unclear whether they might contribute to communication problems. Early experimental studies suggest that adults with mTBI have deficits in expressive communication, including effortful naming, fewer content words in discourse, and less efficient processing in connected speech (Barrow et al., 2003, 2006; Blyth et al., 2012; Stout et al., 2000). Descriptive studies have described deficits in word finding, self-correction of errors, verbal initiative, and speech rate in mTBI (LeBlanc et al., 2014). These studies have provided the foundation for describing language problems associated with mTBI, but their designs did not account for how cognition contributes to communication problems; therefore, further studies are needed in this area.

Another reason for studying communication in this clinical population stems from the fact that adults with mTBI are seeking speech-language pathology treatment at higher rates than previously reported (Parrish et al., 2009; Salvatore, 2011; Sohlberg & Ledbetter, 2016). Patients with mTBI report functional problems such as difficulties communicating with multiple conversational partners simultaneously, producing fluent speech, and expressing themselves adequately (Cornis-Pop, Mashima, Roth, MacLennan, Picon, Hammond, Isaki, et al., 2012). However, current standardized tools lack sensitivity and specificity to adequately diagnose cognitive-communication problems resulting from mTBI. Blyth et al.'s 2012 study on mTBI language assessment found that published tests such as the Cognistat (Kiernan et al., 1987) and the Cognitive Linguistic Quick Test (CLQT;(Helm-Estabrooks, 2001) missed high-level communication deficits in adults with mTBI at a large trauma center in Australia. A survey by Duff et al. (2002) found that SLPs providing care to adults with mTBI often relied on standardized tests not validated on the TBI population. These inadequate testing materials have led to an under-diagnosis of patients with mTBI-related communication disorders and have created an inaccurate perception of patients' communication competence (Blyth et al., 2012). A patient may present significant subjective complaints and with reports of functional problems at home, school, and the workplace, yet the tools available to providers cannot quantify these limitations. There is a need for studies that characterize mTBI-related communication functions and for studies that propose new methods of capturing everyday communication problems in this group, as this is a growing area of rehabilitation and research (Anderson-Barnes, Weeks and Tsao, 2010; Arciniegas, Anderson, Topkoff and McAllister, 2005).

Self-report questionnaires, an alternative to standardized tests, are specifically designed to capture TBI-related communication deficits. For patients who eventually participate in therapy, self-report measures can have more clinical relevance than standardized tests because they identify problems at a functional and individual level. Self-report questionnaires can help identify treatment goals, as they often reflect communication problems the client perceives as salient to his or her life; therefore, clients are more motivated to address those problems in treatment (Douglas, Bracy, & Snow, 2007). Areas in which clients perceive a problem are typically considered a good starting point for treatment (Douglas & O'Flaherty, 2000).

Among scales of communication skills, the Latrobe Communication Questionnaire (LCQ; Douglas, Bracy, & Snow, 2007; Douglas & O'Flaherty, 2000) has been reliably used in TBI research and in clinical settings for almost 20 years. The LCQ has high internal and external validity, a stable factor structure, and high inter-rater reliability (Hoepner & Turkstra, 2013; Rietdijk et al., 2013; Struchen, Pappadis, Mazzei, Davis, & Sander, 2008). The LCQ was developed with the purpose of capturing everyday communication performance in adolescents and adults with TBI (Douglas et al., 2007). Items are based on Grice's maxims and the literature on communication problems in TBI as well as on communication competence of typical adults. The LCQ includes a self-report measure, the LCQ-self, and a caregiver report form, the LCQ-Other (Douglas & O'Flaherty, 2000). The LCQ has primarily been used in studies of moderate to severe TBI, including studies of adolescents with TBI and married couples (Douglas, 2010b; Struchen et al., 2008), and significant differences have been found between individuals with TBI and their "close others" (i.e. familiar communication partners) and between participants without TBI and their peers.

The first aim of the current study is to characterize communication in adults with mTBI by measuring self-perception of communication problems in everyday life. To control for general effects of a traumatic injury, we compared adults with mTBI to adults with orthopedic injuries (OI). The use of OI controls is critical in the study of mTBI, as they allow researchers to control for the effect of trauma on participants. In addition, researchers have argued that OI comparison groups are valid because they likely share demographic, pre-injury characteristics (e.g., risk-taking behavior) with participants with TBI, and comparable levels of medical care for their injuries (Landre et al., 2006; Troyanskaya et al., 2016), which could affect overall outcomes. Furthermore, the inclusion of an injury group without TBI adds scientific rigor to study design (Troyanskaya et al., 2016).

The second aim of the study was to place mTBI data within the context of the existing literature on moderate to severe TBI because the LCQ traditionally has not been developed for an mTBI participant group. All prior published studies employed the 30-item version of the LCQ. Douglas has since expanded the questionnaire to include four questions related to social communication and social cognition, and we included this updated version (Douglas, personal communication, October 15, 2012). Thus, we compared our mTBI and OI groups to data from new community controls (CC) and moderate to severe TBI groups who also completed the 34-item version. We predicted a graded effect of injury severity on LCQ scores: participants with moderate to severe TBI would report the highest scores (indicating more communication problems), followed by the mTBI group, the OI group, and finally, the CC group, who we predicted would report the lowest number of communication problems.

Methods

Participants

Sample. Participants were 19 adults with mTBI (13 females), 20 adults with OI (11 females), 31 adults with moderate to severe TBI (12 females), and 29 CC peers (15 females). All participants lived in the Midwest. Table 1 lists demographic characteristics and descriptive data. Injury information is included in Table 2.

Inclusion criteria. Participants were included if they were ages 18-55 years (to avoid potential age-related effects on cognitive-communication functions); reported English as their primary language; had normal or corrected vision; passed a hearing screening; and had no self-reported history of neurological or psychiatric condition affecting language or thinking (pre-morbidly for the moderate to severe TBI group). Participants in the mTBI and OI groups were not excluded if they reported a history of previous mTBI. Three participants in the OI group reported a history of mTBI over 2 years prior to participation in the study. In order to keep inclusion consistent for both groups, these participants were not excluded from study and reported no symptoms related to their remote mTBI injuries.

Participants with mTBI were included if they were diagnosed with ICD9 Codes 850* and ICD10 Codes S06.0*, which we confirmed during the in-person interview using the following definition of mTBI:

> A blunt injury to the head or to the body with impulsive force transmitted to the head that resulted in any of the following symptoms: headache, nausea, vomiting,

dizziness/balance problems, fatigue, drowsiness, blurred vision, memory difficulty or difficulty concentrating (Eisenberg et al., 2014).

Participants with OI were included if they were diagnosed with non-surgical, traumatic orthopedic injuries as defined by the International Classification of Diseases (ICD-9) Codes 800-829 and International Classification of Diseases (ICD-10) Codes S40-S49, S72, S82, and S92. Participants with moderate to severe TBI were included if they had sustained a moderate to severe TBI, defined using the Mayo Classification System (Malec et al., 2007), and were in the chronic post-injury phase (i.e., > 6 months post-injury).

Exclusion criteria for all participants were: 1) history of pre-injury medical or neurological disease affecting the brain (other than concussion for the mTBI group), or language or learning disability; 2) indication of a health-care surrogate on the medical record; or 3) failure of a pure-tone hearing screening using an air conduction threshold of 30 dB or better in one ear (averaged across 500, 1000, and 2000 Hz). The hearing screening was completed at the time the study was completed by either a licensed speech-language pathologist or a trained graduate assistant.

Recruitment. Participants in the mTBI and OI groups had presented to the Emergency Medicine Department at the University of Wisconsin-Madison and had been diagnosed with mTBI or a non-surgical orthopedic injury by a physician, physician assistant, or nurse practitioner. After initial evaluation and care for their injuries, both mTBI and OI participants were discharged to home, and they participated in the study 3-12 weeks after their injuries. Potential participants were identified via a medical chart review by research personnel with valid clinical access. Participants were mailed a letter describing the study and stating that they were being contacted for potential participation because of their recent visit to the emergency department. Potential participants were called by the first author for phone screening to determine eligibility for the study. If participants met inclusion criteria, a research appointment was scheduled no later than one month after the telephone screening.

Participants with TBI and the CC group were recruited as part of a larger study of social cognition and communication in adults with TBI. We chose a subset of participants from that study who matched the mTBI and OI groups for age and sex. Participants were recruited through a variety of community resources, including local TBI support groups and service organizations.

All participants provided oral consent for the telephone screening and written consent at the time the study was completed. Participants were compensated $25 per hour to complete the study. On average, most participants completed the study tasks in 2.5 hours. All procedures were approved by the relevant institutional review boards.

Measures

LCQ

The LCQ is a 34-item questionnaire in which respondents answer questions about communication difficulties in everyday situations over the preceding six months, such as “When talking to others, do you leave out important details?”; “Do you have difficulty thinking of the particular word you want?”; or “Do you give people information that is correct?” Participants answer using a Likert-type scale that rates the frequency of occurrence of the behavior described in each item (1=never/rarely, 2=sometimes, 3=often, 4=usually/always). The respondent is asked to consider the variety of communication contexts he or she might encounter in routinely, e.g., home, work, or school. Item ratings are summed, and total scores range from 30 to 136, with higher scores indicating more frequent communication problems. The first dependent variable for analyses was the number of items rated more than "2" on the LCQ, and the second dependent variable was the LCQ-self total score.

WAIS Processing Speed Index (Wechsler, 2008). To describe general speed of information processing skills (non-verbal), we administered the WAIS-symbol search and coding subtests. These two subtests comprise the WAIS Processing Speed Index (WAIS-PSI).

Neurobehavioral Symptom Inventory (NSI) (Soble et al., 2014). The NSI is a self-report measure of symptoms commonly associated with Post-Concussion Syndrome (PCS) that may emerge after mTBI. There are three scales included, based on the type of symptom: cognitive, somatic/sensory, and affective. Symptoms such as hearing difficulty and change in taste/smell would be considered "somatic," slowed thinking or forgetfulness would be considered "cognitive," and feeling anxious or depressed would fall under "affective." This measure is widely used in civilian and military clinical and research settings (Belanger et al., 2010; Soble et al., 2014). Soble et al. (2014) found that in a non-deployed, non-clinical sample, scores on this measure averaged 3.0, with a standard deviation of 5.7.

Statistical analysis

For our first aim, we analyzed data descriptively by reporting item responses. We inspected group responses to individual LCQ items where the modal value was "2" or more, indicating situations that the participant deemed to be a problem. For our second aim, we planned a one-way analysis of variance (ANOVA) to compare total LCQ-self scores across the four participant groups. Levene's F test revealed that the homogeneity of variance assumption was not met, $F\ (3,95)=5.9$, p-=.001, so we used a Welch's ANOVA. Statistical analyses were performed using SPSS software version 23 (IBM Corp., Armonk, NY), and the alpha level was set at .05.

Results

Demographic variables. There were significant between-groups differences in years of education and scores on the WAIS-IV Processing Speed Index (WAIS-PSI), with lower education level F (3,95)=2.9, *p*=.04 and lower PSI scores F (3,94)=2.7, *p*=.05) attained by the moderate to severe TBI group (see Table 1).

Aim 1: An analysis of modal values revealed that as a group, participants with moderate to severe TBI perceived communication problems on 15/34 (79%) questions on the LCQ. Participants with mTBI endorsed problems on 2/15 (13%) questions, participants with OI reported problems on 9/34 (26%) questions, and the CC group reported problems on 9/34 (26%). The most common value was "2" for all items for all groups, except for question number 2 for the mTBI group, for which the modal value was 3. See Table 3 for specific communication problems endorsed by the participants.

Aim 2: Table Four shows LCQ means and deviations for the four groups. Our analysis revealed a statistically significant main effect of group, F (3,45) =8.1, *p* < .001. Games-Howell procedure was used for planned post-hoc comparisons since our homogeneity of variance assumption was not met, and these indicated no differences among the mTBI, OI, and CC groups, and a statistically significant difference between the CC and moderate to severe TBI groups (*p* <.001), indicating that the moderate to severe TBI group reported significantly more communication problems than the CC group. See Figure 1.

Discussion

Our findings indicate that self-perception of communication competence as measured by the LCQ-self total score was not significantly different between adults with mTBI and age-matched adults with OI. In addition, when total LCQ scores were compared to scores from an age-matched group of adults with moderate to severe TBI and a CC group, there were only significant differences between groups at the opposite ends of the injury spectrum: the moderate to severe TBI group and the CC group. Although differences among the CC, OI, and mTBI groups did not reach statistical significance, visual inspection of means indicated that the CC group (i.e., the group without any history of injury) tended to have lower total LCQ scores, indicating that they perceived fewer communication problems in their day-to-day exchanges.

Our main results for the differences between the moderate to severe TBI and CC group are consistent with previous findings for this population. Because our study used the 34-item LCQ, an updated version of the original 30-item questionnaire, we compared our relative differences between our TBI and control groups to those in previous studies. Despins, Turkstra, Struchen, and Clark (2016) reported an average 4.5 point difference between the TBI group LCQ-self score mean of 63.86 and the control group mean of 59.48. Douglas (2010a) reported a mean of 59.7 (SD=15.51) for the TBI group and 48.42 (SD=9.58) for their control group. Ryan et al. (2013) study on young adults with a history of TBI reported the following LCQ scores: control group mean: 44.86 (5.76) , mild-mod TBI = 50.43 (12.18), and severe = 60.00 (15.26). Similar to our study, Ryan et al (2013) found a significant difference (p<.01) between the severe TBI group and the control group on LCQ-self scores, but no significant differences in the mild to moderate TBI group, in either control, or in severe TBI groups. Struchen, Pappadis, Sander, Burrows, and Myska (2011) study of 184 adults with medically documented TBI recruited from a trauma center reported a mean of 51.26 (13.82). In summary, the 11-point difference between our moderate to severe TBI group and CC group is consistent with what other studies have reported. To our knowledge, the LCQ-self has not been used in a strictly mTBI group but our scores were within the range of Ryan et al. (2013) who included mild to moderate TBI participants.

Our main study aim was to characterize and possibly identify communication problems individuals with mTBI report in their everyday experiences. We hypothesized that we would see a graded effect among the groups, with means for the mTBI group closely following those of the moderate to severe TBI group, followed by the OI and CC groups. We observed that not only did the mTBI group have lower overall LCQ-self scores, they also identified fewer areas of deficit than did the OI and CC groups. Indeed, the OI and CC groups reported four times as many problems as did the mTBI group. The problems reported by the mTBI group were characterized by repeating or needing repetition of information, whereas the OI group reported a variety of communication problems such as giving inaccurate responses, needing a long time to think about responses, and not knowing how to conclude a conversation.

Because this study to our knowledge is the first to use the LCQ-self in subacute mTBI, the comparably fewer reports of communication symptoms by the mTBI group warrants closer inspection. One interpretation is that the LCQ-self may be insensitive to the communication difficulties experienced by adults with mTBI. While the LQC-self items reflect predominantly expressive communication problems, research has shown that adults with mTBI also experience significant communication problems in comprehension, particularly in contexts where the demands require understanding complex language, such as in the academic setting. The sports literature has shown that college students with mTBI frequently report comprehension problems such as difficulty with understanding material (Ransom et al., 2015; Wasserman et al., 2016). Perhaps the items contained in the LCQ-self do not reflect the everyday communication experiences of adults with mTBI.

On the other hand, perhaps a sampling bias was inherent in our study design. Our participants were symptomatic per NSI scores, so they did reflect the mTBI population, but we did not aim to recruit a clinical sample of individuals with communication problems, nor did we screen for cognitive-communication problems prior to enrolling in the study. The probability of cognitive-communication symptoms 1-3 months after mTBI is unknown, as prior studies recruited patients either very early post-injury, in the chronic stage; or for symptomatic patients, in the chronic stage. Thus, we do not know if we recruited a representative sample of that population. It may be that because the percentage of patients with residual communication problems is low, the likelihood of detecting self-identified communication deficits in our small sample was also low.

An alternative explanation is related to the temporal course of recovery from injury and whether we assessed for communication problems at the optimal time. Preliminary studies of trauma patients (both with and without mTBI) have hinted at the contribution of symptoms such as headache, pain, and psychological distress to cognitive outcomes. Landre et al. (2006) study of cognitive symptoms in admitted trauma patients with and without mTBI (including OI, stab wounds, lacerations, spinal cord injuries, and other bodily injuries) found that measures of post-concussive symptoms (including cognitive, somatic and emotional symptoms) were not significantly different among these two groups and moreover were not particularly high or significantly associated with cognitive performance. The study team suggested that this low report of symptoms in the acute setting was because many mTBI patients do not fully endorse symptoms early in the recovery course, and that the onset of symptomatology begins outside the medical setting as the individual attempts to return to normal activities.

The mTBI and OI groups who participated in the current study were at a very early stage of their recovery (within 3 months of injury). Hence, our study may have been too early in the recovery process for patients to adequately self-identify communication problems. Douglas (2010) suggested that for adults with TBI, “full awareness of deficits develops with the passage of time and repeated experience of difficulty” (p.173). Although this statement referred to moderate to severe TBI, it may also apply to any injury that disrupts cognitive functioning. However, because of the variability in symptomatology in mTBI, patients may present with a variety of risk factors that might make them predisposed to poor outcomes; it is advisable that communication skills be monitored along the trajectory of recovery from the acute to subacute stages, and until well into the chronic stages.

Finally, our findings suggest that that communication problems, not unlike post-concussive symptoms, may exist in non-neurological populations such as those with OI. In the current study, LCQ scores were elevated for both the OI and mTBI group. Perhaps clinicians should exercise caution when attributing symptomatology exclusively to a neurological event such as mTBI (Hoge, Goldberg, & Castro, 2009). Potential underlying participant factors (such as history or presence of mental health disorders) should be considered in future studies of communication in mTBI. Indeed, a study of combat soldiers with and without mTBI (Hoge et al. (2008) found that when analysis controlled for stress disorders in soldiers with mTBI, all of their reported physical and cognitive symptoms with the exception of headache were no longer associated with their mTBI.

Limitations

Results of our study should be interpreted with caution, as there were limitations. The most significant of these was our small sample size, particularly for our primary aim of investigating differences between mTBI and OI. Although our study recruitment period was one year, we had difficulty contacting potential participants (i.e., a large percentage of potential participants did not answer the phone despite multiple attempts), and we had difficulty enrolling participants who fit our narrow exclusion criteria. We used our data to complete post-hoc sample-size estimations, which revealed that we would need a sample size of 1,352 to observe differences in LCQ-self scores. Because differences between individuals with mTBI and typical comparison groups are small (in our case, the difference between the OI group and the mTBI group LCQ score was one point), we need large samples to detect these subtle differences. Recruitment of these large samples is not always feasible, and it is difficult to translate small differences into clinically meaningful terms. A possible shortcoming of the LCQ is that items are weighed equally, despite the fact that some items might have more impact on everyday communication. The combination of these variables could have affected the results of our study.

Another limitation in our study was the use of a self-report questionnaire as a primary outcome measure, as this prevents the ability to compare our findings to an objective, biological measure as Rigon et al. (2016) did by comparing LCQ scores with neuroimaging data. However, in mTBI, clinical neuroimaging is typically normal, and most objective “bio-markers” are insensitive and currently not a standard operating procedure in medical facilities. In addition, both diagnosing and treating mTBI-related symptoms involve a significant amount of subjective report. Future studies could control for this confound by using the LCQ-other in conjunction with the LCQ-self. The LCQ-other has been found to be a reliable and valid tool for comparing perceptions of communication among close communication partners, particularly for those with moderate to severe injuries. The present study did not include this measure, and therefore it is difficult to confirm whether the self-perception scores reported by participants would have matched their communication partners' scores, which we would expect to be more objective. On the other hand, Hoepner and Turkstra (2013) and Despins et al. (2016) found high agreement between LCQ-self and LCQ-other scores.

Using this measure in the subacute time period of mTBI was a novel approach, as most studies have used the LCQ-self to measure communication perceptions in chronic stages of recovery after moderate to severe TBI. Measuring the LCQ-self closer to the time of injury could potentially control for possible confounding variables, among them the "good-old days" bias (Iverson, Lange, Brooks, & Rennison, 2010) in which a person perceives his or her pre-injury functioning as above average and overestimates the degree of impairment. Validating the LCQ tool for adults with mTBI and their close others as well as determining an optimal time period for administration would benefit future studies of communication after mTBI.

Finally, our study sample was culturally homogenous; all participants were from the same geographical area, which limits the ability to generalize results to other populations. However, our geographical area of recruitment was fairly large and the racial and ethnic make-up of our sample was representative of the area of the US where the study took place. For our study purposes, the four groups were evenly matched on race and ethnicity and this limited potential bias.

Future Directions

Future studies investigating self-perception of communication skills in adults with mTBI would benefit from larger, more diverse samples, and from control for individual pre-morbid factors such as anxiety or depression that can confound interpretation of cognitive test results (Bonhnen & Jolles, 1992). It would also be worthwhile to include groups who report communication symptoms and to determine potential risk factors for communication.

Conclusions

Previous studies on communication competence after TBI have predominantly relied on groups with moderate to severe TBI in the chronic stages of recovery. The current study aimed at describing these skills along the continuum on injury by presenting scores on a communication measure from a community-based group, an orthopedically injured group, an mTBI group, and a group with moderate to severe TBI. Our findings, when compared to the existing literature, revealed elevated scores for all groups, with the exception of the uninjured group. However, at present, the LCQ-self does not have a standard cut-off score for clinically significant communication problems, so it is difficult to interpret the functional impact of the scores reported here. While not every communication problem may warrant intervention, communication is a critical aspect of many activities of daily living, and thus tracking recovery, particularly in highly symptomatic patients, may be a good use of clinical resources. Although injuries of this nature are considered “mild,” the issues surrounding appropriate assessment, treatment, and recovery are complex and should be regarded in research.

Table 1
Participant Demographic Characteristics

	CC (n=29)	OI (n=20)	mTBI (n=19)	Mod-Sev. TBI (n=31)
Age, y, mean (SD)	27.14 (5.33)	28.1 (9.77)	26.78 (6.41)	27.72 (5.79)
Age, range	18-40	19.5-52	18.4-37.8	19.3-42.9
Female, n (%)	15 (51.7)	11 (55)	13 (68.4)	12 (38.7)
African-American, n (%)	3 (10.3)	0	2 (10.5)	2 (10)
Education, y, mean (SD)*	15.63 (1.58)	16.2 (1.9)	15.92 (1.45)	14.72 (2.39)
WAIS-PSI *	109.17 (17.82)	108.80 (16.5)	102.5 (11.07)	98.86 (15.73)
NSI Total Score	---	14.15 (11.43)	17.93 (13.06)	---

Note. WAIS-PSI= Wechsler IV Processing Speed Index; NSI=Neurobehavioral Symptom Inventory
*sig at $p<.05$

Table 2
Injury Characteristics of OI, mTBI, and TBI Groups

	OI (n=20)		mTBI (n=19)	Mod.-Sev. TBI (n=31)
Time post-injury, d, mean (SD)	57.95 (12.64)	Time post-injury, d, mean (SD)	65.10 (18.06)	80.2 (57.1)
Mechanism of Injury, n, (%)		Mechanism of Injury, n, (%)		
Moving Vehicle Accident	1	Moving Vehicle Accident	2	18
Fracture	9	Fall	6	7
Dislocation	5	Assault	3	1
Sprain	1	Sports-related	4	5
Contusion	1	Hit head on structure	3	0
Dog Bite	1			
Inflammation	1	Hit by cow	1	0
Unknown	1			

Table 3
Communication Problems Endorsed by Participants with OI, mTBI, and Mod.-Sev. TBI

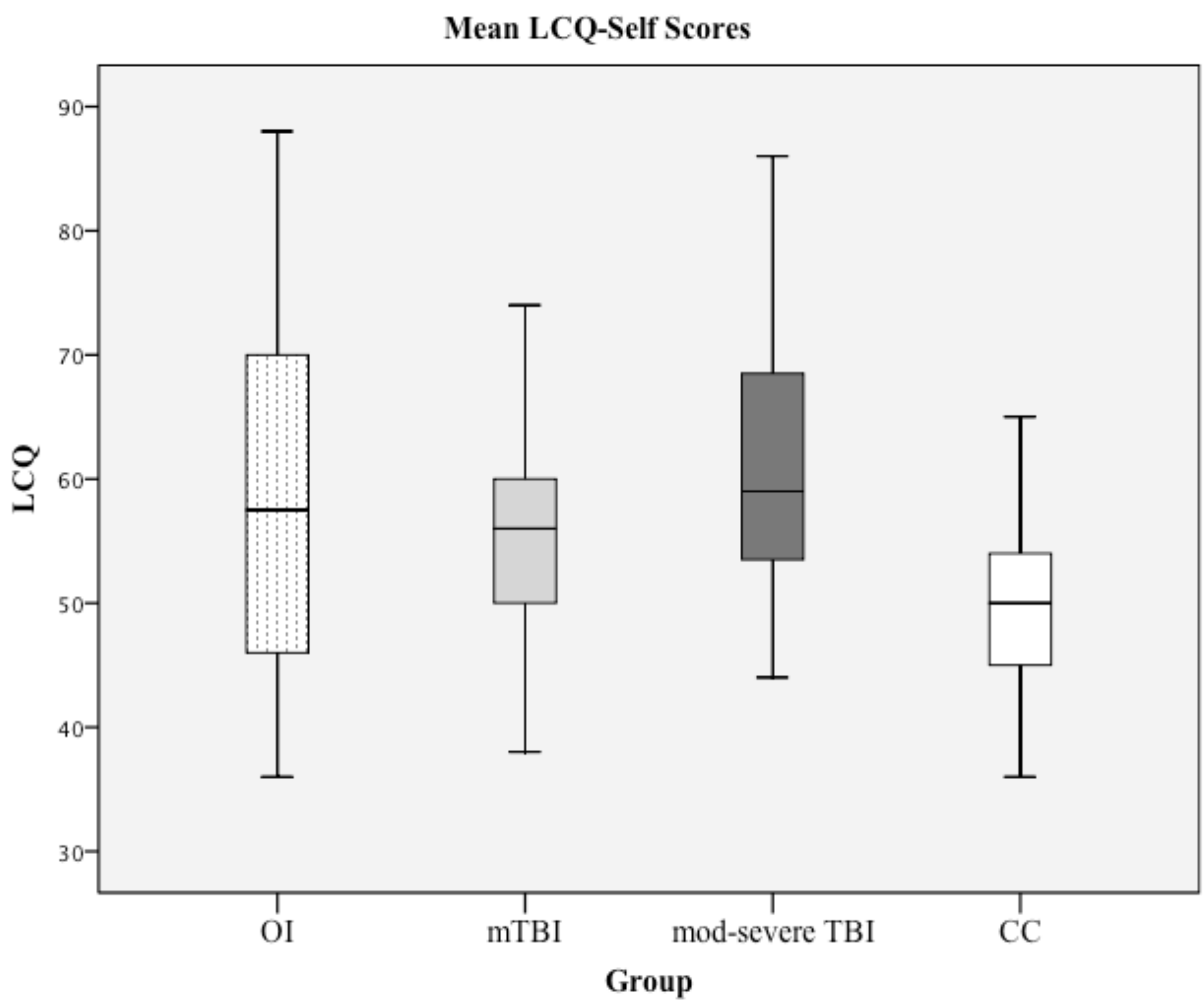
	LCQ Item **"When talking to others do you…"**
CC	4. Switch to a different topic of conversation too quickly?
	8. Have difficulty thinking of the word you want?
	11. Hesitate, pause or repeat yourself?
	13. Get side-tracked by irrelevant parts of conversation?
	25. Speak too quickly?
	29. Carry on talking about things for too long in your conversation?
	20. Have difficulty getting conversations started?
	31. Answer without taking time to think about that the other person has said?
	33. Lose track of conversations in noisy paces?
OI	3. Go over the same ground over and over in conversation?
	5. Need a long time to think before answering the other person?
	8. Have difficulty thinking of the word you want?
	29. Carry on talking about things for too long in conversations?
	30. Have difficulty thinking of things to say to carry on the conversation?
	31. Answer without taking time to think about what the other person has said?
	32. Give information that is completely inaccurate?
	33. Lose track of conversations in noisy places?
	34. Have difficulty bringing conversations to a close?
mTBI	11. Hesitate, pause of repeat yourself?
	16. Need the other person to repeat what they said before being able to answer?
TBI	1. Leave out important details?
	2. Use a lot of vague or empty words such as "you know what I mean?"
	3. Go over and over the same ground in conversation?
	4. Switch to a different conversation topic too quickly?
	5. Need a long time to think before answering the other person?
	8. Have difficulty thinking of the word you want?
	10. Say or do things others might consider rude or embarrassing?
	13. Get side-tracked by irrelevant parts of conversations?
	16. Need the other person to repeat what they said before being able to answer?
	20. Have difficulty getting conversation started?
	29. Carry on talking about things for too long in conversation?
	30. Have difficulty thinking of things to say to keep the conversation going?
	31. Answer without taking the time to think about what the other person has said?
	33. Lose track of conversations in noisy places?
	34. Have difficulty bringing conversations to a close?

Table 4
Mean LCQ Scores Across Groups

	CC (n=29)	OI (n=20)	mTBI (n=19)	TBI (n=31)
Mean (SD)	50.21 (7.04) *	57.80 (16.23)	56 (9.78)	61.39 (10.22) *
Range	36-65	36-88	38-74	44-86

LCQ: LaTrobe Communication Questionnaire
*the mean difference is significant at the 0.05 level

Figure 1: Mean LCQ-Self Scores



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CHAPTER 5

Conclusion

Conclusion

Adults with mild traumatic brain injury (mTBI) are at risk for developing persistent cognitive, physical, and psychological symptoms after their injuries. There is considerable interest in improving treatment and long-term outcomes in this population, both from the scientific world and the general public. Although a strong association has been established between communication and cognition after moderate to severe TBI, little is known about the effect of cognition on the communication skills of adults with mTBI.

Reduced speed of information processing has been identified as a common sequela of mTBI. Speed of information processing has been well studied in the literature and identified as an area of concern in both the acute and chronic stages of recovery from mTBI. Speed of information processing is expected to affect communication because of the speeded nature of conversation. Although individuals who seek speech-language therapy often report difficulties meeting the demands of everyday communication, the effect of speed of information processing on communication has not been studied.

In this dissertation, we reported data from three studies designed to characterize language performance in mTBI. For two studies, we tested a speed-based hypothesis based on the evidence that speed of information processing is an area of cognitive impairment for many people after mTBI. We compared performance to an OI group to discriminate the effects of brain versus general trauma in the subacute stage of recovery from mTBI.

Study One

Our first study explored expressive language after mTBI by comparing performance on a category naming task. Results indicated that the mTBI group made more overall errors than the OI group in both conditions, and both groups made more errors in the unspeeded condition than in the speeded condition, but this effect did not reach significance. The effect of speed was statistically significant for the group but differences could not be attributed to mTBI specifically. Our between-groups comparisons revealed the opposite trend from what we predicted; the mTBI group responded faster than the OI group, but this trend was offset by the greater number of errors on the task. Naming accuracy and RT in speeded and unspeeded conditions were correlated with injury and symptom variables of interest by group. Although this study did not demonstrate a robust group effect, our findings contributed to the literature in that they underscored the complexity of investigating language in mTBI and delineated some avenues for future research such as exploring the role of neurobehavioral symptoms, calculating mental effort, and continuing to refine research methods that require timely accuracy.

Study Two

The second study explored language comprehension performance after mTBI. We compared accuracy and sentence interpretation time on the Whatdunit Task (Montgomery et. al. 2016). We manipulated task conditions by administering the task in speeded and unspeeded conditions and by varying the sentence type using canonical and non-canonical sentence constructs. We predicted that adults with mTBI would have longer interpretation times and lower accuracy than would the OI group. Our study results did not support our hypothesis, although there was a marginal group by sentence interaction in the speeded condition, and we correlated our study task with the WAIS-PSI, a clinically valid test for speed of information processing. These results inform future study design by underscoring the need for manipulating language complexity in combination with strict response windows. The challenge in this study area is determining what level of comprehension is most affected by mTBI and using this knowledge to create sensitive and specific research stimuli.

Study Three

Study three aimed to characterize communication after mTBI using a more holistic approach. Our main study variable was a self-report questionnaire, the LaTrobe Communication Questionnaire, which has been used in many studies of moderate to severe TBI. Our main study aim was to compare the self-report of communication problems between a group with TBI and a group with OI. As a secondary aim, we compared these scores to scores of a group with moderate to severe TBI and to those of a community-based control group. We predicted a graded effect of injury severity on LCQ scores: participants with moderate to severe TBI at the high end (indicating more communication problems), and participants in the CC group at the other end. Results indicated no significant differences between mTBI and any other study group, and moreover, the mTBI group reported the lowest number of communication problems. We found significant differences only for moderate to severe TBI scores and CC scores, which is consistent with results from previous studies. We attributed these unexpected findings to our timing of the measure, recognizing that awareness of communication and cognitive problems potentially does not occur until later in the recovery process for adults with TBI. Results of this study emphasize the need for a clinically valid self-report measure of communication problems after mTBI, one that is sensitive and specific enough to be used along the continuum of recovery not only by speech-pathologists but by other health professions. Communication and cognition impact most facets of everyday living and should be monitored by all involved in post-injury care.

Motivation

The research studies that were completed for this dissertation were motivated by my experiences as a speech-language pathologist at the Polytrauma Rehabilitation Center in San Antonio, Texas. During this time, I provided cognitive-communication therapy to adults with persistent symptoms after mTBI, veterans who had served in the U.S. Wars in Iraq and Afghanistan. My patients sought my help when plans for reintegrating into their former lives did not go as expected. I witnessed first-hand how frustrated these individuals were when they could not meet the cognitive and communication demands of their work, school, and home environments. On many occasions, they described situations in which they could not efficiently process and produce the information needed to function at their pre-injury levels. They described being unable to “put thoughts into words” or to “find the right words,” and they reported that they could not communicate how they felt to their loved ones. These difficulties had an enormous impact on the success of their employment, their education, and their relationships. Despite such functional complaints, we were often unable to quantify these problems using standardized speech-language assessments. My patients and I understood the limits of these published assessments; we knew they did not capture the difficulties of everyday experience. To date, no standardized language test for mTBI exists, and there are no universal guidelines or established treatments for cognitive-communication disorders. My hope is that what I have learned from designing and conducting these studies will serve as the foundation for future research to inform clinical practice in mTBI.

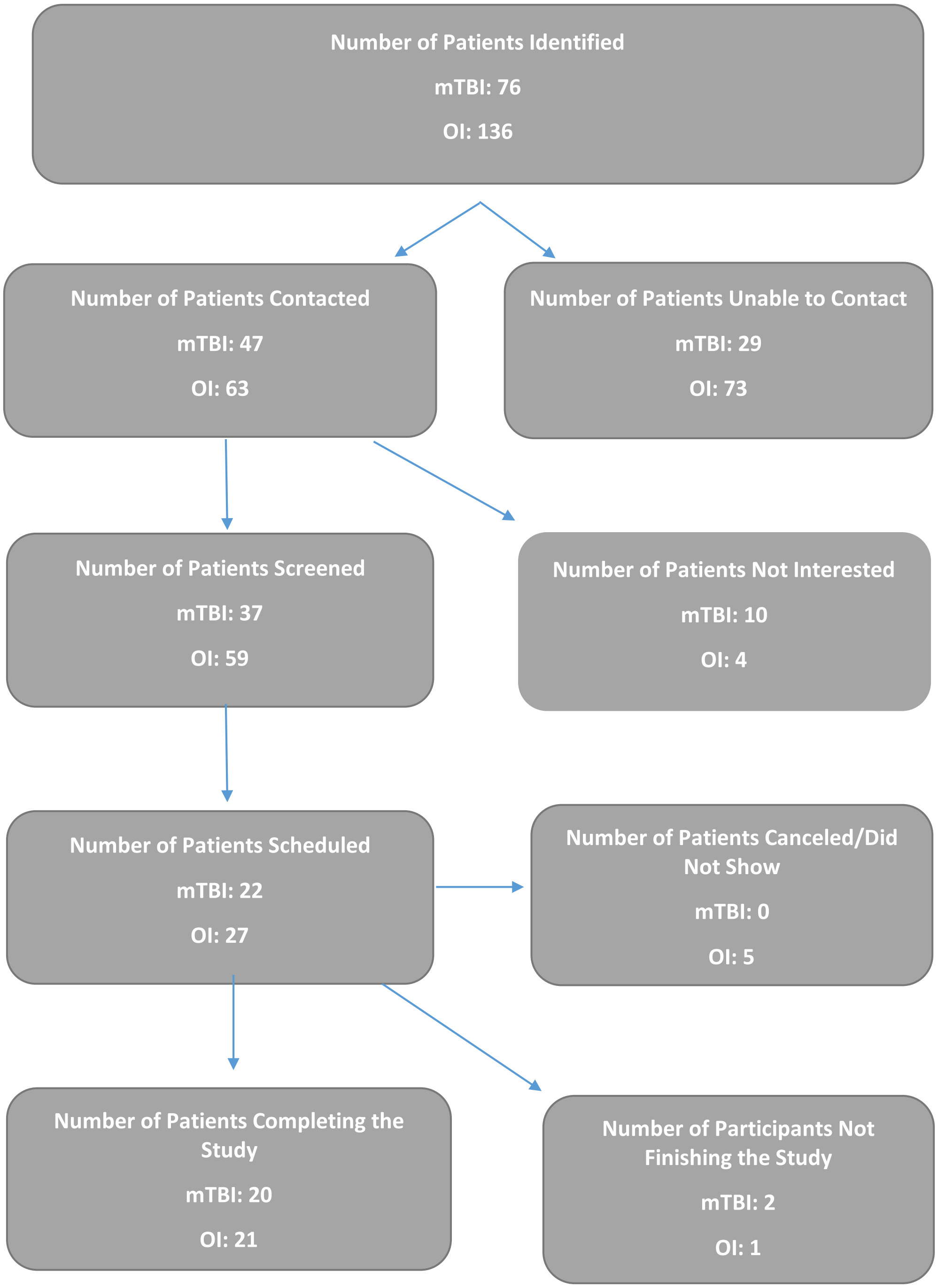
APPENDICES

Appendix A

Table A1*: ICD9 & ICD10 Codes**

mTBI Codes	OI Codes
ICD9	
850: Concussion with no loss of consciousness	820: Fracture of neck of femur
	821: Fracture of other parts of femur
	822: Fracture of patella
	823: Fracture of tibia and fibula
	824: Fracture of ankle
	825: Fracture of tarsal and metatarsal bones
	826: Fracture of phalanges of foot
	827: Other multiple fractures of lower limb
	828: Multiple fractures involving both lower limbs
	829: Fracture of unspecified bones
ICD10	
S06.0: Concussion	S40: Superficial injury of shoulder and upper arm
	S41: Open wound of shoulder and upper arm
	S42: Fracture of shoulder and upper arm
	S43: Dislocation and sprain of shoulder girdle
	S44: Injury of nerves at shoulder and upper arm
	S45: Injury of blood vessels at shoulder and upper arm
	S46: Injury of muscle at shoulder and upper arm
	S47: Crushing injury of shoulder and upper arm
	S48: Traumatic amputation of shoulder and upper arm
	S49: Other injuries of shoulder and upper arm

Table A2.
Recruitment Flow chart



Appendix B

Figure B1: ***Distribution of Data and Scatterplot for Barrow Category Naming Task***

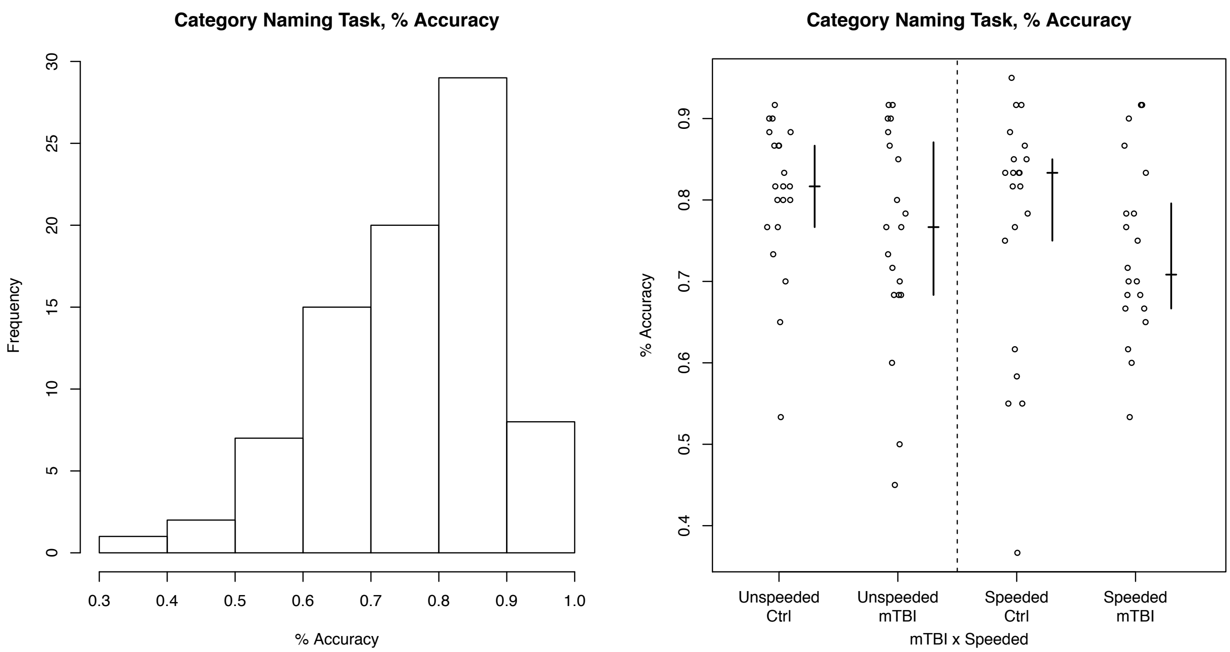
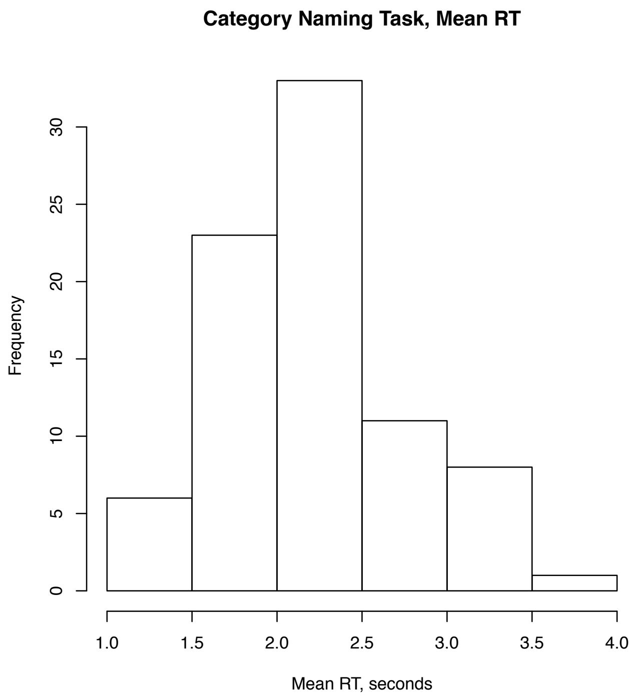
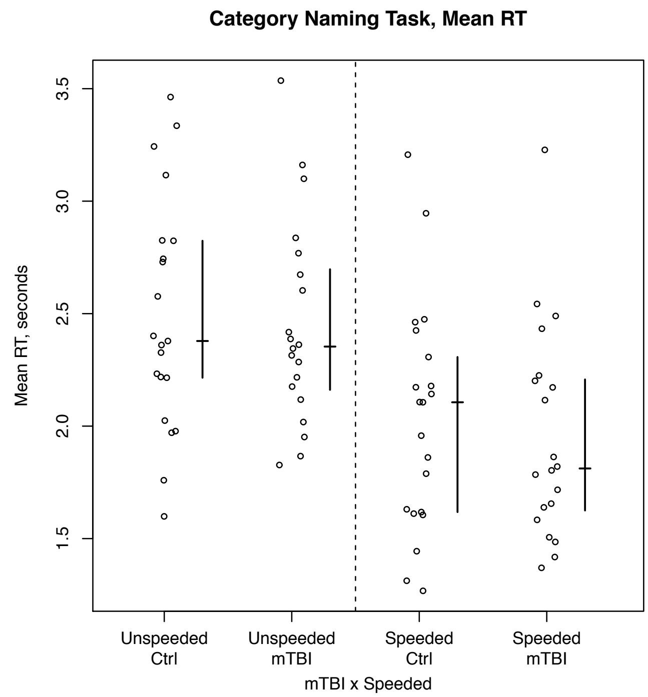


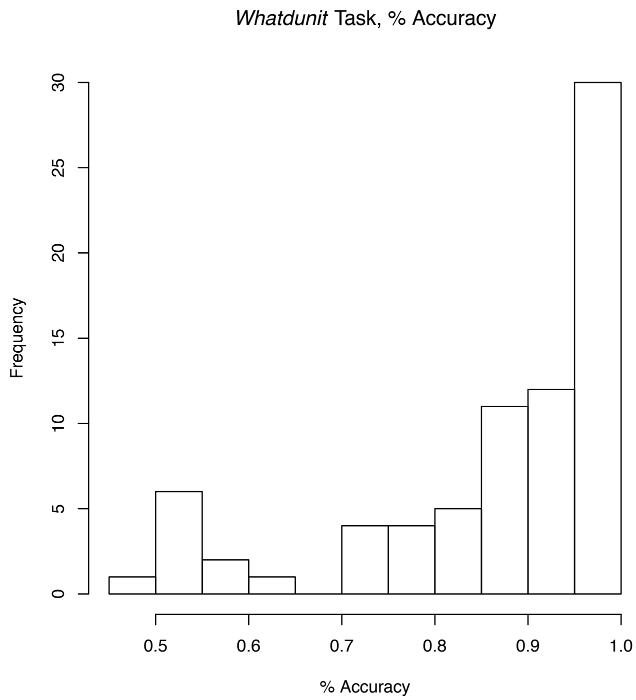
Figure B2: ***Distribution of Data and Scatterplot of RT (in secs) for Category Naming Task***





Appendix C

Figure C1: *Distribution of Data and Scatterplot for Whatdunit Task Accuracy*



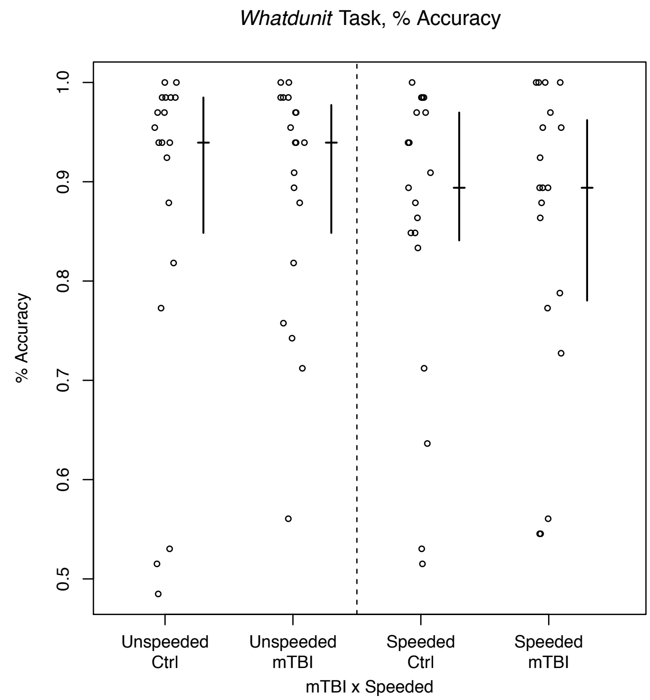


Figure C2:

Distribution of data and scatterplot of Sentence Interpretation Time (in secs) for Whatdunit Task

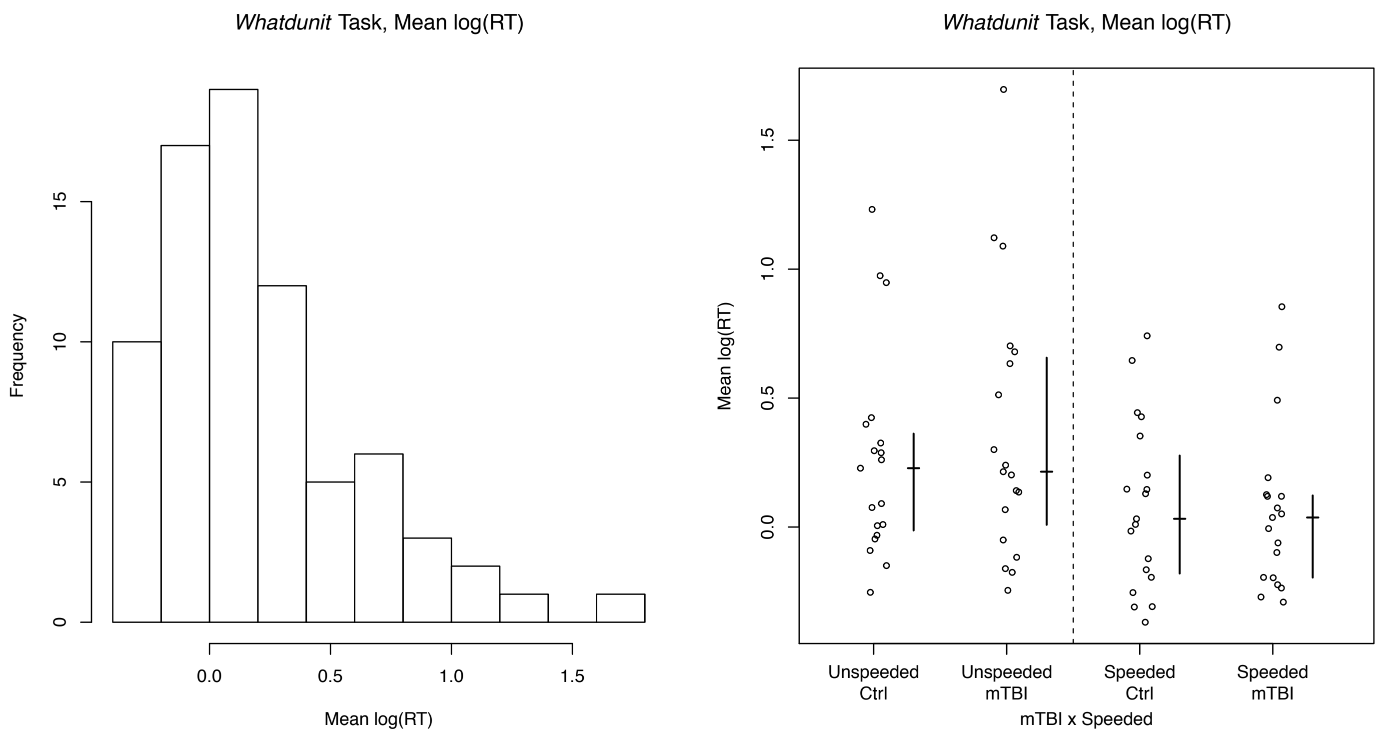


Figure C3:

Distribution of data and scatterplot of Sentence Interpretation Time (in secs) for Whatdunit Task, correct responses