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Research Article

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

Rocío S. Norman,[a] Manish N. Shah,[b] and Lyn S. Turkstra[a,c]

Purpose: The aim of this study was to characterize language comprehension in mild traumatic brain injury (mTBI) by testing a speed-based hypothesis. We hypothesized that adults with mTBI would perform worse than a group of adults with orthopedic injuries (OIs) on an experimental language comprehension task.
Method: The study employed a prospective experimental design. Participants were 19 adults with mTBI and 19 adults with OI ages 18–55 years. Participants completed the *Whatdunit* task, a sentence agent selection task in speeded and unspeeded conditions.
Results: In the unspeeded condition, the mTBI group performed with a marginally significant higher accuracy than the OI group. In the speeded condition, the mTBI group performed with lower accuracy than the OI group; however, this difference did not reach statistical significance. There was a marginally significant interaction of Sentence Type × Group for reaction time in the speeded condition.
Conclusions: 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. The similarities in performance between both groups have clinical implications for the treatment of not just brain-related trauma but also trauma in general.

Nearly 2.5 million individuals are affected by traumatic brain injury (TBI) in the United States annually, and 87% of these individuals are treated in and discharged from emergency departments (EDs; M. Faul, Xu, Wald, & Coronado, 2010). The vast majority of these injuries are mild, and in recent years, there has been an increased interest in characterizing the cognitive effects of these injuries. This interest is driven by studies showing that mild TBI (mTBI) is a risk factor for progressive diseases, such as dementia, also known as *concussion*, mild cognitive impairment, and chronic traumatic encephalopathy (Schneiderman, Braver, & Kang, 2008), and also by the need to identify clinical guidelines for returning to work, school, or athletics, all of which are significantly influenced by cognitive status postinjury (Iverson & Gioia, 2016; Lange et al., 2012).

[a]Department of Communication Sciences and Disorders, University of Wisconsin–Madison
[b]Berbee Walsh Department of Emergency Medicine, School of Medicine and Public Health, University of Wisconsin–Madison
[c]Neuroscience Training Program and Department of Surgery, University of Wisconsin–Madison
Correspondence to Rocío S. Norman: normanr@uthscsa.edu

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Most research on the cognitive effects of mTBI has focused in the acute to subacute stage after injury, that is, from about 3 weeks to 3 months (Karr, Arenshenkoff, & Garcia-Barrera, 2014; Raskin, Mateer, & Tweeten, 1998). Common cognitive complaints in this stage have been well described and include problems with attention, executive functions, and verbal and visual memory (Raskin et al., 1998). What has not been well studied is how these cognitive problems affect everyday communication functions, such as understanding spoken language, which are essential to all activities of daily living.

The lack of evidence on communication after mTBI stems from the current lack of valid instruments to assess and quantify communication problems after these injuries. Assessment of language problems after mTBI is a challenge for speech-language pathologists (SLPs), and communication disorders may be underdiagnosed in the acute stage of mTBI due to a lack of appropriate instruments (Blyth, Scott, Bond, & Paul, 2012; Duff, Proctor, & Haley, 2002; Stout, Yorkston, & Pimentel, 2000). Blyth et al.'s (2012) study on mTBI language assessment found that published measures such as the Cognistat (Kiernan, Mueller, Langston, & Van Dyke, 1987) and the Cognitive Linguistic Quick Test (Helm-Estabrooks, 2001) had a low predictive value for communication disorders, and tests used routinely by SLPs either lack specificity and sensitivity or have yet to be norm- or criterion-referenced on individuals with mTBI (Krug & Turkstra, 2015; Turkstra, Coelho, & Ylvisaker, 2005). There

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are also gaps in clinical training about mTBI: In a 2016 survey of certified SLPs in the state of Wisconsin (Riedeman & Turkstra, 2016), 30% of respondents reported being "not confident" to "somewhat confident" in treating individuals with communication symptoms related to TBI and reported that mTBI was a particular area of concern in clinical practice. This gap in knowledge and the lack of appropriate tools negatively impact clinical care and contribute to underrecognition of communication problems in the acute setting (Blyth et al., 2012).

mTBI and Language Comprehension

A communication function that is critical for return to work and school is language comprehension. There is some evidence that adults with mTBI report problems in this domain (Ransom et al., 2015; Wasserman, Bazarian, Mapstone, Block, & van Winjngaarden, 2016). Wasserman et al. (2016) reported that high school and college students with concussion took longer to return to school when compared to a group with isolated musculoskeletal injuries. A larger proportion of students with mTBI reported an increase in academic problems postinjury and a greater need for academic accommodations (e.g., extra time on tests) than the musculoskeletal injury group. The primary symptom measure, the Academic Dysfunction Questionnaire, included items regarding language comprehension, 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," but scores for these individual items were not reported. In Ransom et al.'s (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. While these findings are suggestive, they are based on self-report rather than objective measures. They are also not based on any comprehension theory or framework and so do not advance our understanding of the nature of comprehension problems, which is necessary for treatment. There is a need for a well-designed prospective study that employs both objective and subjective measures of language comprehension and tests a theory-driven hypothesis that will help translate findings into clinical intervention.

Cognition and mTBI

The neuropsychological literature in mTBI provides a framework for studying language comprehension. Unlike language comprehension, cognition is well studied in mTBI research (Karr et al., 2014), and cognitive skills are known to affect communication (Chabok, Kapourchali, Leili, Saberi, & Mohtasham-Amiri, 2012). 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 (Chabok et al., 2012; Coelho, 2007; Youse & Coelho, 2005); thus, an understanding of cognitive impairments can help us generate hypotheses about communication impairments.

The most commonly reported sequela of mTBI is reduced speed of information processing (Dean & Sterr, 2013; Frencham, Fox, & Maybery, 2005; Kashluba, Hanks, Casey, & Millis, 2008; Ponsford, Draper, & Schönberger, 2008; Zwaagstra, Schmidt, & Vanier, 1996). Speed consistently has been found impaired in individuals with acute (Ponsford et al., 2000) or remote (Dymowski, Owens, Ponsford, & Willmott, 2015; Miotto et al., 2010) mTBI. This work spans several decades and aligns with the idea that TBI induces cognitive slowing (Ben-David, Nguyen, & van Lieshout, 2011). Cognitive slowing has traditionally been operationalized as reaction time (RT) on neuropsychological tests, such as the symbol digit test (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 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 Frencham et al. (2005), 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 Rohling et al. (2011), considered the first meta-analysis of cognitive changes after mTBI. Because of the compelling evidence demonstrating chronic deficits in speed of processing after mTBI and research supporting the effect of cognition on language after TBI, speed of information processing is worthy of exploring as a significant problem underlying efficient language performance.

Limited Resource Versus Resource Allocation Problems

There is considerable interest among researchers in determining the biological bases of cognitive impairments associated with mTBI, including speed of information processing. Researchers have used methods from neuroimaging, electrophysiology, and pathology to characterize brain abnormalities that might account for some of the deficits described above. mTBI is primarily a white matter injury, and the most common neuropathological finding is diffuse axonal injury in cortical regions. Abnormalities in prefrontal cortex, corpus callosum, and subcortical white matter have been correlated with cognitive dysfunction (Lipton et al., 2008, 2009). Mathias et al. (2004) found that the volume of the corpus callosum, a critical area for intrahemispheric transmission, was 15%–20% smaller in patients with mTBI. Niogi et al. (2008) reported similar findings in corona radiata, corpus callosum, superior longitudinal fasciculus, and uncinate fasciculus, and structural integrity in these pathways was correlated with RTs. There is evidence 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. For example, Broglio, Pontifex, O'Connor, and Hillman (2009) and Kashluba et al. (2008) found that the P300 response, which has been linked to resource allocation (Polich, 2007), was abnormal in young adults 3 years postinjury and who demonstrated deficits. Adults with mTBI also have shown longer P300 latencies and decreased amplitudes than their uninjured peers, despite similar performance (Dupuis, Johnston, Lavoie, Lepore, & Lassonde, 2000; Gaetz & Weinberg, 2000; Gosselin et al., 2012; Lavoie, Dupuis, Johnston, Leclerc, & Lassonde, 2004; Ozen, Itier, Preston, & Fernandes, 2013; Thériault, De Beaumont, Gosselin, Filipinni, & Lassonde, 2009).

Diminished cognitive resources from abnormal white matter or reduced frontal network integrity, combined with reduced ability to allocate these cognitive resources, may underlie the longer-than-average RTs of individuals with TBI. This cognitive slowing is particularly evident in timed contexts, which require efficient resource allocation within strict temporal constraints. The result of this mismatch in skill and demand may be represented behaviorally as slow processing time.

Speed of information processing is likely to 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. To our knowledge, no experimental studies of language comprehension in adults with mTBI have considered the role of speed. Identifying and understanding the cognitive mechanisms underlying functional problems are an important step in developing effective assessments and treatments for communication problems after mTBI and supporting individuals with mTBI in returning to pre-injury levels of participation.

Our study was motivated by the pressing need to provide SLPs with sensitive instruments to quantify language comprehension problems in adults with mTBI. By operationalizing resource allocation as RT, we tested our hypothesis behaviorally using measures of language. We manipulated speed by encouraging participants to perform as quickly as possible versus to take their time, which allowed us to test the hypothesis that condition (speeded vs. unspeeded) affects cognitive performance in mTBI. To increase the scientific rigor of our approach, 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 complexity of the language task using methods from developmental language literature. Specifically, we chose sentence constructs that varied in complexity, as defined by age of acquisition. That is, sentence constructs that are early developing in native English speakers (i.e., that follow canonical word order) are on the lower end of complexity, and those that are later developing (i.e., that violate canonical word order) are on the higher end of complexity and thus would require longer RTs. 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 tested our study question: Is speed of information processing 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.

Our first aim was to determine whether adults with mTBI exhibit longer sentence RTs and lower accuracy than controls with orthopedic injury (OI). We predicted that, because adults with mTBI potentially process less efficiently than controls with OI, this would contribute to overall longer sentence RTs and lower accuracy levels on our experimental task. Our second aim was to determine if syntactic complexity would influence sentence RT and accuracy. We predicted that speed and syntactic complexity would have a main effect on performance and that this effect would be higher 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 positively correlated with speeded measures.

Method

Participants and Procedure

The study employed prospective group comparisons of adults with mTBI and OI. Participants in both groups had presented to the ED affiliated with the University of Wisconsin–Madison and had been diagnosed with mTBI or a nonsurgical OI by a physician, physician assistant, or nurse practitioner. After initial evaluation and care for their injuries, both participants with mTBI and participants with OI 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. Participants were 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 ED and stating their potential eligibility for the study. Two hundred 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. 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

1 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 hr.

Participants were included if they were ages 18–55 years and reported English as their primary language. We chose 55 years as a cutoff 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, Ninth Revision* (ICD-9) Codes 850* or *10th Revision* (ICD-10) Codes S06.0* (World Health Organization, 1977, 2007), which were confirmed during the in-person interview using Eisenberg's definition of mTBI (Eisenberg, Meehan, & Mannix, 2014). Individuals in the OI group were diagnosed with nonsurgical, 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 (a) history of a pre-injury medical or neurological disease affecting the brain (other than concussion for the mTBI group) or language or learning disability, (b) indication of a health care proxy on the medical record, or (c) 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 either by a licensed SLP or a trained graduate assistant. Participants were screened for active moderate-to-severe depression symptoms during the study visit. If the participant indicated symptoms of moderate-to-severe depression (a score of 3 or more on the Neurobehavioral Symptom Inventory [NSI] Scale), the study visit was terminated, and steps were taken to locate behavioral services for the participant. Participants reporting mild depression symptoms were not excluded from the study.

Table 1. Demographic characteristics of participants.

Variable	mTBI (n = 19)	OI (n = 19)
Age, years, *M* (*SD*)	27.17 (6.08)	28 (9.91)
Age range	18.5–37	19.5–51
Female, *n* (%)	14 (74)	11 (58)
Male, *n* (%)	5 (26)	8 (42)
Caucasian	17 (89.5)	12 (63.2)
African American	1 (5.3)	3 (15.8)
Other race	1 (5.3)	4 (21.1)
Highest level of education		
High school/GED	0	2 (10.5)
Some college/associate/ tech degree	11 (57.9)	8 (42.1)
Bachelor's degree	7 (36.8)	6 (31.6)
Postgraduate	1 (5.3)	3 (15.8)
Employment		
Unemployed	2 (10.5)	1 (5.3)
Part-time employment	1 (5.3)	7 (36.8)
Full-time employment	16 (84.2)	10 (52.6)
Student	5 (26.3)	8 (42.1)

Note. mTBI = mild traumatic brain injury; OI = orthopedic injury; GED = general education diploma.

Participant Characteristics

Participants were 19 adults with mTBI (five men, 14 women) and 19 adults with OI (eight men, 11 women). Table 1 lists demographic characteristics and descriptive data. Injury information is included in Table 2. Two participants in the OI group reported remote history of one mTBI, and two participants in the OI group reported remote history of two mTBIs. OI participants with history of mTBI were ultimately not excluded from the study because of the remote nature of their injuries (all occurred 2 years or more prior to study participation). There were no significant between-groups differences in neurobehavioral symptoms or scores on standardized cognitive tests.

Primary Measures

***Whatdunit* Sentence Task**

Our primary outcome measure was an adaptation of the *Whatdunit* task (Montgomery, Evans, Gillam, Sergeev, & Finney, 2016). The *Whatdunit* task is an experimental sentence completion task composed of sentences that use either canonical English word order (subject–verb–object [SVO] and subject relative [SR]) or noncanonical word order (passive [PAS] 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 et al. (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 RTs were measured via touchscreen monitor (Elo 1000 Series 1715L touchscreen display).

Each condition (speeded/unspeeded) contained 66 sentences, presented in two blocks of 33 sentences. The sentences types were randomized in each condition (speeded/ unspeeded), and the conditions (speeded/unspeeded) were counterbalanced. All sentences were of the same length (12 words), and the words had word frequency ratings of age 6 years or younger (i.e., early acquired words are typically higher in frequency), age of acquisition of 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/s) in standard Midwestern English and administered through professional over-the-ear headphones at a comfortable listening level for each participant.

Table 2. Injury characteristics of the sample.

Characteristic	mTBI (n = 19)	Characteristic	OI (n = 19)
Time postinjury, days, *M* (*SD*)	65.26 (18.54)	Time postinjury, days, *M* (*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

Note. mTBI = mild traumatic brain injury; OI = orthopedic injury.

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

The *Whatdunit* task is a validated language task originally developed for use with children with specific language impairment—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. We predicted that, like children with specific language impairment, our participants with mTBI would complete the task with less accuracy and longer RTs than our participants in the OI group (please see Appendix A of Montgomery et al., 2016, for examples of sentence stimuli used).

Baseline Motor RT Task

To control for potential individual differences in baseline motor planning (RT) within and between groups, all participants completed a simple motor speed task with identical structure prior to completing the *Whatdunit* task. Consistent with the methods described in Montgomery et al. (2016), participants heard a tone and saw a cross displayed on one of three boxes on touchscreen. Participants were asked to touch the cross as quickly as possible and to rest their finger on a dot in front of them between trials. The task consisted of 30 trials, which were averaged out to attain an average baseline motor RT for each participant. The motor RT was used in analysis of the sentence RT (please see the Statistical Analysis section).

Other Measures

Medical Chart Review

The following information was extracted from participants' medical records: mechanism of injury, medical diagnoses, psychiatric diagnoses, medication use, dates of service in the ED, referral to other providers upon discharge from the hospital, and medical lab/test results related to the ED visit.

Case History

A case history form was used that solicited information regarding demographic characteristics, health education, and vocational history; current employment or academic performance; and medical and neuropsychological history related to the injury.

NSI

The NSI is a 22-item self-report measure of symptoms commonly associated with postconcussion syndrome that may emerge after mTBI. Individuals rate their current symptoms on a scale from 0 to 4 (0 = *symptom is rarely present or not a symptom at all*, 4 = *symptom is very severe and almost always present*). 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. 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 nondeployed, nonclinical sample (n = 1453) was 3.0, with an *SD* of 5.7.

Pittsburgh Sleep Quality Index

As cognition can be affected by sleep and sleep quality, we were interested in the amount and quality of sleep our participants reported. On the Pittsburgh Sleep Quality Index, participants rate sleep quality over the past month, and higher scores indicate poorer sleep quality.

Speech-Language and Cognitive Tests

Wechsler Adult Intelligence Scale–Fourth Edition Processing Speed Index

To describe general speed of information-processing skills (nonverbal), we administered the Wechsler Adult Intelligence Scale–Fourth Edition (WAIS-IV; Wechsler, 2008) Symbol Search and Coding subtests. These two subtests comprise the WAIS-IV Processing Speed Index (WAIS-IV PSI).

NIH Toolbox Cognition Battery

To characterize participants' general cognitive and language abilities, all subtests of the NIH Toolbox Cognition

Battery (Gershon et al., 2013) were administered. The NIH Toolbox is included in the National Institute of Neurological Disorders and Stroke 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 was selected because it assesses the same sentence constructs as the experimental task (PAS, OR, SR, SVO).

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, Erdfelder, Lang, & Buchner, 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. Baseline motor RTs were compared using independent-samples *t* tests.

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

To test our second hypothesis 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 pairwise comparisons were conducted using *t* tests, with a Bonferroni correction for multiple comparisons. To ensure that the manipulation of the speed versus unspeeded administration condition was valid, we used Pearson correlations to compare WAIS-IV PSI scores to *Whatdunit* task-dependent variables (accuracy or sentence RT in speeded and unspeeded conditions).

Results

Demographic characteristics 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 postinjury than participants with OI (65 vs. 57 days postinjury), and this difference was marginally significant, $\chi^2(2, N = 38) = 3.66$, $p = .08$. 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 2 *SD*s beyond the normal range (Soble et al., 2014). Because four participants in the OI group had a remote history of mTBI, the measures of interest (language measures, descriptive measures, and questionnaires) were analyzed with and without them, and no differences were found.

Baseline Motor RT

There was no statistically significant difference in average baseline motor RT between the mTBI group (M = 719.33 ms, SD = 88.94) and the OI group (M = 748.94 ms, SD = 102.14), $t(36) = 0.953$, $p = .17$, although the OI group tended to be slower.

Accuracy

Table 4 lists overall sentence accuracy for speeded and unspeeded conditions by group. In the speeded condition, the TBI group performed with lower mean 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, $F(1, 36) = 0.391$, $p = .268$. 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. There was no significant effect of condition (speeded or unspeeded administration) on accuracy scores, $\lambda = .96$, $F(1, 36) = 1.656$, $p = .10$.

Table 3. Scores on NIH Toolbox tests, Sentence Comprehension Test, Neurobehavioral Symptom Inventory (NSI), and Pittsburgh Sleep Quality Index (PSQI).

Test	mTBI (*n* = 19)	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)

Note. Data are means (*SD*). mTBI = mild traumatic brain injury; OI = orthopedic injury.

Table 4. Overall sentence interpretation accuracy (% correct) and sentence interpretation reaction time[a] (in milliseconds) by group and speeded/unspeeded condition.

Group	Acc-s	Acc-u	RT-s	RT-u
mTBI (*n* = 19)				
M	79.80	89.46	468.52	1,140.04
SD	20.60	11.93	403.90	1,230.80
Range	36–100	55–100	99–1,438	207–5,081
OI (*n* = 19)				
M	83.55	82.49	459.04	914.44
SD	16.17	19.15	428.50	209.78
Range	52–100	48–100	–25 to 1,477	77–3,581

Note. Acc-s = accuracy–speeded condition; Acc-u = accuracy–unspeeded condition; RT-s = reaction time–speeded condition; RT-u= reaction time–unspeeded condition; mTBI = mild traumatic brain injury; OI = orthopedic injury.

[a]Time is adjusted for baseline motor speed.

Sentence RT

There was no significant effect of group on sentence RT in the speeded condition, $F(1, 36) = 0.005$, $p = .47$, or the unspeeded condition, $F(1, 36) = 0.755$, $p = .195$, although participants with mTBI tended to take longer than participants with OI to interpret the sentences in the speeded condition ($M = 468$ ms, $SD = 403$ vs. $M = 459.04$ ms, $SD = 428$) and in the unspeeded condition ($M = 1140.04$ ms, $SD = 1230.80$ vs. $M = 834.35$ ms, $SD = 914$). There was a statistically significant effect of speeded versus unspeeded condition, $\lambda = .726$, $F(1, 36) = 13.56$, $p = .001$, whereby both groups decreased their RT in the speeded condition. The Group × Condition (speeded vs. unspeeded) interaction was not statistically significant, $\lambda = .971$, $F(1, 36) = 1.086$, $p = .152$.

Accuracy by Sentence Type

See Table 5 for the summary of accuracy and RT by sentence type and group in both conditions. A repeated-measures ANOVA showed that the effect of sentence type (SVO, SR, PAS, OR) was significant in the speeded condition for both groups, $\lambda = .56$, $F(1, 36) = 8.89$, $p = .00$, $\eta^2 = .44$, but no significant interaction of group by sentence type, $\lambda = .969$, $F(1, 36) = 3.65$, $p = .389$, $\eta^2 = .03$. 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 ($p < .01$) and 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 was also a statistically significant effect of sentence type, $\lambda = .71$, $F(1, 36) = 4.53$, $p = .0004$, $\eta^2 = .29$, but no Group × 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 ($p = .002$), lower accuracy when compared to SVO sentences ($p = .002$), higher accuracy for PAS sentences compared to SR sentences ($p = .009$), lower accuracy for PAS compared to SVO sentences ($p = .0075$), and no statistically significant differences in accuracy between OR and PAS.

Sentence RT by Sentence Type

Sentence RT results demonstrated 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 × Group, $\lambda = .833$, $F(1, 36) = 2.14$, $p = .08$, $\eta^2 = 17$. Planned pairwise comparisons with Bonferroni correction revealed statistically significant differences in RT 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 sentence RT, $\lambda = .587$, $F(1, 36) = 7.5$, $p = .0005$, $\eta^2 = .41$, and no statistically significant effect of Sentence Type × Group, $\lambda = .951$, $F(1, 36) = 0.55$, $p = .33$, $\eta^2 = .04$. Pairwise comparisons revealed a significantly longer sentence RT for OR sentences in comparison to SVO ($p = .026$) and a longer sentence RT for SR sentences compared to SVO ($p = .02$).

WAIS-IV PSI

WAIS-IV PSI scores 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-IV Coding task, $F(1, 36) = 2.6$, $p = .058$, and in the WAIS-IV Symbol Search task, $F(1, 36) = 2.34$, $p = .06$. Both groups' WAIS-IV scores were within the normal range. Correlations between WAIS-IV PSI scores and the *Whatdunit* task variables are listed on Table 6. Positive correlations were found between WAIS-IV PSI and accuracy in the speeded condition ($p = .022$), indicating that higher scores on the WAIS-IV PSI (indicating better performance on speeded tasks) test were associated with higher accuracy on the *Whatdunit* task. Negative correlations were found between WAIS-IV PSI scores and sentence RT in both speeded ($p = .001$) and unspeeded ($p = .013$) conditions, indicating that higher scores on the WAIS-IV PSI were associated with a lower sentence RT 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 subacute stage of recovery. The results of our study did not fully support our hypothesis regarding overall sentence interpretation

Table 5. Sentence accuracy (percentage correct) and sentence reaction time[a] (in milliseconds) by group, sentence type, and condition.

Sentence type	mTBI (n = 19) M (SD)	OI (n = 19) M (SD)
Subject–verb–object		
Accuracy, speeded	95.04 (6.60)	94.80 (10.13)
Accuracy, unspeeded	95.72 (6.26)	97.03 (4.35)
Interpretation time, speeded	335.43 (357.27)	454.10 (479.19)
Interpretation time, unspeeded	942.96 (1,107.60)	735.57 (771.70)
Subject relative		
Accuracy, speeded	94.11 (7.33)	93.80 (10.10)
Accuracy, unspeeded	95.72 (6.60)	96.38 (4.80)
Interpretation time, speeded	474.82 (489.05)	479.52 (434.07)
Interpretation time, unspeeded	1,177.94 (1,331.81)	857.72 (915.34)
Passive		
Accuracy, speeded	77.30 (29.84)	80.59 (29.75)
Accuracy, unspeeded	84.21 (21.57)	78.94 (34.48)
Interpretation time, speeded	612.12 (758.99)	373.72 (363.71)
Interpretation time, unspeeded	1,104.14 (1,304.19)	917.19 (1,188.87)
Object relative		
Accuracy, speeded	72.00 (31.16)	70.07 (29.72)
Accuracy, unspeeded	84.41 (17.69)	77.71 (31.28)
Interpretation time, speeded	741.26 (1,096.95)	713.19 (812.97)
Interpretation time, unspeeded	1,342.64 (1,582.24)	1,225.41 (1,701.27)

Note. mTBI = mild traumatic brain injury; OI = orthopedic injury.

[a]Time is adjusted for baseline motor speed.

accuracy and overall sentence RT. We hypothesized that the mTBI group would perform with lower accuracy levels and with longer sentence RTs. Results showed that our hypothesis was partially supported by trends in the data; although the mTBI group had higher accuracy scores than the OI group, the mTBI group tended to have longer sentence RTs; however, this difference did not reach statistical significance.

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 sentence RT 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 RTs, and this hypothesis was partially supported by our findings, particularly when sentences were administered in a speeded condition. In both the speeded and unspeeded conditions, this manipulation of sentence type yielded medium (unspeeded condition) to large (speeded condition) effects on accuracy. With regard to RT, our findings again indicated an effect of sentence type in both speeded and unspeeded conditions. Our pairwise comparisons in both conditions supported the second part of our hypothesis, that is, that the PAS and OR sentences would be processed with lower accuracy levels and prolonged sentence RTs overall. These results are in concordance with the literature on syntactic complexity in the healthy 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).

Table 6. Pearson correlations between Wechsler Adult Intelligence Scale–Fourth Edition Processing Speed Index (WAIS-IV PSI) performance and *Whatdunit* task performance for sample (n = 38).

Test	Acc-s	Acc-u	Time-s	Time-u
WAIS-IV PSI	.328*	.192	–.501**	–.360*

Note. Acc-s = accuracy–speeded condition; Acc-u = accuracy–unspeeded condition; Time-s = time–speeded condition; Time-u= time–unspeeded condition.

*p = .05 (one-tailed). **p = .01 (one-tailed).

We reported a marginally significant Group × Sentence Type interaction, but only in the speeded condition. Our participants' performance was negatively impacted when interpretation of noncanonical sentences was presented in the speeded condition and improved when the condition was not speeded. This finding demonstrates that the combination of syntactic complexity and strict temporal response windows can be a potential method for further study. Perhaps, combining behavioral measures such as RT with biological measures such as evoked response potentials can shed light on whether differences in behavior are attributable to diminished resources or a potential resource allocation problem after injury. Exploring these phenomena in mTBI requires the use of sensitive measures and precise statistical approaches beyond the use of means and group averages. Given that everyday communication often requires efficient and timely processing, perhaps experimental manipulation in both content and condition can potentially shed light on the everyday, subtle communication problems that can arise after mTBI. The strong correlation found between our variables of interest (accuracy and sentence RT on the *Whatdunit* task) and the WAIS-IV PSI indicates a high degree of concurrent validity, which also indicates that it is potentially a viable method to predict speed changes related to language performance after mTBI.

The lack of a robust group interaction with our variables of interest (accuracy and sentence RT) 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 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 expands 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 controls with OI 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 and 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, Poppe, Davis, Schmaus, & Hobbs, 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 1 year in duration, we experienced difficulties contacting potential participants and enrolling participants who fit our narrow exclusion criteria. 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 sentence RT), we need very large samples to detect these subtle differences. Furthermore, 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 3 months post-mTBI has been estimated to be significantly low (McInnes, Friesen, MacKenzie, Westwood, & Boe, 2017). 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 six people in our sample (four with mTBI and two with OI) reported symptoms over five, which is significantly higher than the mean for the nondeployed, uninjured sample reported by Soble et al. (2014). 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 also 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-IV PSI scores and speeded measures provides some validation for the use of our experimental 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 controls with OI 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.

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