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Reaction time and cognitive-linguistic performance in adults with mild traumatic brain injury

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Abstract

Objective: The purpose of this study was to characterize cognitive-linguistic performance in adults with mTBI to advance assessment and treatment practices. We hypothesized that individuals with mild traumatic brain injury (mTBI) would demonstrate longer reaction times (RTs) and greater error rates when compared to an orthopedic injury (OI) group on a category-naming task.

Method: Participants were age and education-matched adults with mTBI (n=20; 12 females) and adults with OI (n=21; 5 females) who were discharged to home after an Emergency Department visit. Our primary task was a category-naming task shown to be sensitive to language deficits after mTBI. The task was adapted and administered under speeded and unspeeded conditions.

Results: There was a significant main effect of condition on RT (speeded faster than unspeeded) and accuracy (more errors in the speeded condition). There was a marginally significant effect of group on errors, with more errors in the mTBI group than the OI group. Naming RT and accuracy in both conditions were moderately correlated with injury variables and symptom burden.

Conclusions: Our data showed a marginal effect of group on accuracy of performance. Correlations found between naming and neurobehavioural symptoms, including sleep quality, suggest that the latter should be considered in future research.

Keywords

adult; brain injuries; cognitive-linguistic; mild traumatic brain injury

Introduction

Traumatic brain injury (TBI) has been associated with cognitive-linguistic performance deficits in both the acute and chronic stages of the injury (1). These deficits have been associated with negative long-term outcomes such as difficulty securing and maintaining employment (2), social interaction limitations (3), and reduced quality of life (4). Over the

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past three decades, there has been significant interest in characterizing cognitive-linguistic performance after moderate to severe TBI (5–7), but 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 (8, 9). Although most people recover fully from mTBI (10), 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 (10–13). Common symptoms after mTBI include headache, fatigue, forgetfulness, sleep problems, and cognitive dysfunction. Cognitive impairments are evident on both tests of global cognitive abilities (e.g. IQ) (14) and on tests of specific cognitive domains such as attention (15) and speed of information processing (16, 17). Stout and colleagues (18) found that when compared to healthy adults, individuals with mTBI showed impairments such as linguistic inefficiency, disorganization, and fewer meaningful content units per minute on experimental tasks, all of which hint at possible information processing deficits. Cognitive-linguistic 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 (19).

Guidelines for mTBI indicate that early education and treatment are critical for ensuring positive long-term outcomes (20, 21). 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 (22). Effective education and treatment cannot occur without early identification of problems; however, this identification is often difficult. The cognitive-linguistic performance deficits exhibited by patients with mTBI are so subtle that they are often overlooked in the acute care setting, which leads to under-identification of patients with language problems (23, 24). If individuals with mTBI miss this important window for receiving treatment, they may face challenges in cognitive-linguistic performance exchanges in the workplace, school settings, 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 (25). Therefore, identifying these deficits and intervening early may prove invaluable for both research and clinical outcomes.

Shortcomings in SLPs' assessment tools have contributed to the gap in knowledge about cognitive-linguistic performance problems after mTBI. Although patients report problems in their everyday lives and are often referred to SLPs for treatment, it has been a challenge to document these problems using standardized tests (26, 27). Although there have been some advances made in evaluating cognitive-linguistic performance skills for moderate to severe TBI using measures such as the Functional Assessment of Verbal Reasoning and Executive Strategies Test (28) and discourse assessment (29), overall standardized language tests lack sensitivity and specificity for detecting the mild deficits that are characteristic of mTBI (30, 31). Use of current published tests has been associated with under-diagnosing of patients with cognitive-linguistic impairments (24). Furthermore, additional sources of information, aside from standardized tests, are needed in order to gain an accurate understanding of an individual's communication performance. Cognitive-linguistic functioning is a critical part of everyday communication therefore, quantifying effects of mTBI on performance is critical for developing appropriate assessments and treatment (32).

The underlying mechanisms of cognitive-linguistic deficits in mTBI are unknown, but one promising area of study is speed of information processing, a domain known to be significantly affected in both the acute and chronic stages of recovery from mTBI (16, 17, 33–37). Speed of information processing has been generally regarded as a component of attention processes (38), and neuropsychological studies have operationalized speed using experimental measures of reaction time (RT) on tasks such as the symbol-digit test (39), the Stroop test (40) and tests of attention (41). RT measures are widely accepted as measures of cognitive processing time (42) and have consistently been shown as a reliable measure of differences in cognitive processing between individuals with and without TBI (43). 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 (37, 44, 45). Speed of information processing likely plays a critical role in everyday cognitive-linguistic 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 (23, 46, 47). Given the evidence that speed of processing is affected by mTBI, and the potential for slowed speed to affect performance, a promising approach to capturing mTBI effects is to measure RT on cognitive-linguistic tasks. 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 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. Researchers have characterized the effect of speed on language in mTBI by administering experimental spoken tasks under timed conditions (48, 49), or by including timed variables in narrative tasks (e.g., number of words per minute;(1, 18, 47)

In a 2003 study, Barrow et. al (49) explored speeded category naming in adults with mTBI and the authors argued that traditional neuropsychological tests were not sensitive enough to detect mild language impairments in the mTBI 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. The authors found main effects of group, vocabulary level, category, color, and speed. Barrow et al. (50) 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.

Studies exploring cognitive-linguistic function after mTBI have had 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 and use of standardized tests that lack sensitivity and specificity. This area of research lacks a well-designed study of cognitive-linguistic performance under timed and untimed conditions with a demographically similar control group. To address the gap in knowledge about cognitive-linguistic performance after mTBI during the acute time period, we designed a prospective cohort study of adults with mTBI and a comparison group of OI peers. This study was designed to avoid potential confounds and biases which have been reported in the mTBI literature and may impact cognitive outcomes (10). These include variability in age, education level, time post-injury, injury type, history of learning disability or neurological disorder and level of medical care.

In summary, mTBI is common in the US and can affect cognitive and cognitive-linguistic performance function in both the acute and chronic stages of recovery. Research in mTBI has focused primarily on cognitive impairments after injury without full consideration of how these cognitive changes affect language performance and everyday cognitive-linguistic performance (51). Because of the pressing need to capture cognitive-linguistic performance problems that can affect outcome, it is necessary to characterize language problems that occur in the early stage after injury so we can develop effective diagnostic tools and evidence-based treatments. To address the gap in knowledge about language performance early after mTBI, the present study characterized language problems using time-based measures of spoken language performance and manipulated demands for speed. In addition, individuals with mTBI commonly endorse neurobehavioral symptoms such as difficulties with maintaining sleep-quality, anxiety, and other somatic symptoms. These symptoms could potentially impact cognitive-linguistic performance, therefore in order to provide further insight into this relationship and to control for a spurious relationship between them, measures of these neurobehavioral symptoms were collected using validated questionnaires.

Participants were tested in the sub-acute stage of recovery from mTBI (3–12 weeks 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 (52). 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 3–12 weeks 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 (53). Furthermore, researchers have argued that OI comparison groups are valid because they likely share demographic, pre-injury characteristics (e.g. risk-taking behaviour) 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 (54, 55). 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 (18, 49, 50, 56, 57). We hypothesized that individuals with mTBI would demonstrate longer RTs and higher error rates when compared to the OI group, particularly on speeded tasks. Research in this area would add to knowledge about this complex clinical group and inform the development of appropriate cognitive-linguistic performance assessments and interventions, which are currently lacking in the field of SLP. Our main study aims were to: 1) compare cognitive-linguistic performance between individuals with mTBI and OI in speeded and unspeeded conditions and 2) as an exploratory aim, determine whether neurobehavioral symptoms and sleep quality were correlated with accuracy and RT on the naming task, our primary measure.

Methods

Participants and Procedures

The study was a prospective comparison between groups of adults with mTBI vs. OI. Participants in both groups had presented to the Emergency Department (ED) affiliated with the University of Wisconsin-Madison and had been diagnosed with mTBI or a non-surgical OI by a physician, physician assistant, or nurse practitioner. After initial evaluation and care for their injuries, patients with either mTBI or OI were discharged to home and were invited to participate 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. Participants were actively recruited from April 2016 to March 2017. 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. If 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, participants completed study tasks in two to two and a half hours, earning between $50 to $63 in total for their participation.

Participants were included if they were 1) ages 18–55 years; 2) reported English as their primary language; and 3) were either diagnosed with TBI [ICD9 Codes 850* and ICD10 Codes S06.0*], with diagnosis confirmed using a published definition of mTBI (58); or 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) a 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 which would indicate limited capacity to consent to research participation; or 3) failure of a pure-tone hearing screening using an air conduction threshold of 30 decibels.

Primary Measures

Category Naming Task—Our primary experimental task was a category-naming task adapted from previous studies (48, 49). 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 novel source (59), to improve image quality; and we used different criteria for categorization of the picture stimuli. Details are provided below.

Participants were asked to view 120 randomized pictures, displayed individually on a computer monitor, and name one other item belonging to the same category as the picture in view (e.g. picture of a dog → naming a cat). 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 (60) and was classified as <3 years, 3–4 years, 4–5 years, and 5+ years. All words were familiar to native English speakers per Rossion (59) criteria: over 80% agreement and a score of 3 or more on a familiarity scale of 1–5, with 5 being most familiar. The task used the elements of category level and speed to impose a cognitive load on naming under experimental conditions (48). 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 (61) 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 (49) 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).

Response accuracy was measured used the Battig & Montague (62) corpus of validated noun categorization as a guide. For items not contained in the selected corpus, we used the taxonomic feature type classification from the McRae, Cree (63) corpus, as these were the largest and most recent categorization norms. 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. (49), error types were categorized as perseveration, semantic, visual, non-response, or other (out-of-category response). 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. Responses vocalized outside of the response window (3500 ms) were scored and, as in the Barrow et al. 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'. (49) (p. 890).

Secondary 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—Participants completed a case history form that solicited information regarding demographic characteristics; health, education, and vocational history; current employment or academic status; and medical and neuropsychological history related to the injury.

Neurobehavioral Symptom Inventory (NSI) (64).—The NSI is a self-report measure of symptoms commonly associated with Post-Concussion Syndrome (PCS) that may emerge after mTBI. This measure was included to better characterize symptoms that could potentially affect cognitive-linguistic function.

Pittsburgh Sleep Quality Index (PSQI) (65).—As cognition can be affected by sleep and sleep quality (66), 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.

Speech, Language, and Cognitive Measures

WAIS Processing Speed Index (67).—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 (68).—All subtests of the Cognition Battery (Working Memory, Processing Speed, and Vocabulary) were administered to characterize participants' general cognitive and language ability. Fully corrected scores were used for all analyses.

Speech Rate.—To rule out group differences in motor speech function that could influence performance on the primary cognitive-linguistic task, we assessed speech rate using stimuli from the Assessment of Intelligibility of Dysarthic Speech (69), a widely used measure of motor speech performance. Speech rate was defined as average syllables per minute.

Rapid Naming Task (RAN).—To rule out group differences in general naming ability, we administered the Rapid Naming Test (RAN), developed by Montgomery et al. (70) using (59) 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.

Statistical Analyses

Main statistical analyses were conducted in SPSS Version 23.0 (71) with the significance level set at $p < .05$. Post-hoc power analyses were conducted using G*Power Program (72). 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 study was powered using the findings of Barrow, which suggested that our sample size was adequate.

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. This was tested using repeated measures 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

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, including employment and student-status. Eighteen out of 20 participants in the TBI group were employed either full or part time and nineteen out of twenty-one participants in the OI groups were employed either full or part-time. Injury information is included in Table 2. Out of 20 participants in the mTBI group, eight had a previous history of mTBI and in the OI group, four out of 21 participants had a history of previous mTBI. The reported previous injuries were remote in nature; they occurred over two years prior to the date of study participation.

There were no significant between-groups differences in neurobehavioural symptoms or scores on standardized cognitive tests, including the speeded cognitive tests (NIH Toolbox Processing Speed subtest and the WAIS Processing Speed Index). There was a significant difference in employment status between the two groups χ^2 (8, N = 41) = 40.69, $p < 0.001$; with more full-time employees in the mTBI group and more part-time employees in the OI group. 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, $p = 0.07$, with longer times post-injury in the mTBI group.

Questionnaires

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, $p = 0.08$; and in speaking rate, t (30) = −1.42, $p = 0.08$, with faster speaking rate in the mTBI group. The two groups did not differ on NIH Toolbox Subtest scores, sleep quality, or neurobehavioural symptoms as measured by the NSI. Of note, there were no significant differences on performance on the NIH toolbox processing speed subtest score nor the WAIS PSI.

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), F (1, 39) = 58.05, $p = 0.00$, $\eta^2 = .04$; 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 showed no statistically main effect of condition, 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, F (1, 39) = .011, $p = .46$, $\eta^2 = .003$.

Correlations

Time Post-Injury.—Correlation results are shown in table 5. 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; i.e. better sleep quality was associated with lower accuracy and slower RT.

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 neurobehavioural 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 shows error types by group and condition. In both the unspeeded and speeded conditions, both groups made more semantic errors than any other type of error in both the speeded and unspeeded conditions. In the unspeeded conditions the “out of category” error pattern was the second most prevalent followed by perseveration. In the speeded condition, perseverative errors were the second most prevalent followed by “out of category” errors. In both groups, most errors occurred in the unspeeded condition.

Discussion

The aim of this study was to begin 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 language task, which was shown to be sensitive to naming deficits after mTBI (49), Barrow, Hough (50) was adapted to be administered under speeded and unspeeded conditions, to test our hypothesis that reduced processing speed is a cognitive mechanism underlying mTBI-related cognitive-linguistic performance problems.

Our data showed a marginal effect of group on accuracy of performance and our results should be interpreted with caution. Overall, individuals with mTBI performed with lower accuracy in both conditions; however, this difference did not reach statistical significance. This lack of statistical significance was likely a result of limited statistical power. 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 reaction time) at 80% statistical power. This finding illustrates a unique issue related specifically to mTBI research and one which diverges from work in moderate to severe TBI. In moderate to severe TBI research, it is common to have small sample sizes with large 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.

Inspection of errors indicated that accuracy for both groups was affected primarily by semantic errors, i.e. responses were associated with the pictured stimuli but did not satisfy criterion for correctness (e.g. “wine” for a picture of “grapes”). The performance of the mTBI group was particularly affected by more semantic errors than that of the OI group. Given that the majority of our normative data was from Battig and Montague’s norms, which were developed in 1969, our participants’ ‘errors’ may have reflected changes in mainstream vocabulary in the U.S. since that time. For example, when shown a picture of a stool, one participant responded ‘bartop’, a response that was considered inaccurate per the Battig and Montague norms but is arguably in line with contemporary U.S. vernacular.

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

(73) 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, Periáñez (41) 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. Rather, 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. Further, between-groups comparisons revealed the opposite trend in the reaction time variable from what we predicted: the mTBI group responded faster than the OI group, albeit not significantly. 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-severe TBI (33, 74), but to our knowledge has not been documented in adults with mTBI. Modeling of speed-accuracy tradeoff and which is limited with the design of the current experiment, 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. Another possible method of interpreting this lack of difference between groups is by perhaps interpreting both the mTBI and OI injuries as similar "mild" traumas, both likely to induce cognitive-linguistic deficits of the same degree. Perhaps mild brain trauma and mild body trauma are more similar than expected when interpreting language and cognitive outcomes.

Our findings were in contrast to those of Barrow (49) 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. Our study had more stringent recruitment and scoring criteria than those in previous research, including use of a comparison group that was more comparable to the mTBI group and enforcing a strict temporal study window (3–12 weeks after injury). Significant group differences in previous studies may be attributable to these differences in study design. Barrow and colleagues (49, 50) tested their mTBI participants 1–7 days after injury, during a hospital admission and acute management of symptoms. The mTBI groups were compared to community-based controls who had not experienced neurological or psychological trauma; therefore, it is problematic 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 been discharged home and experienced several weeks of recovery time. This time allowed for recovery from the initial insult, 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 likely excluded individuals with pronounced symptoms after TBI. The decision to include patients without a loss of consciousness was motivated by our quest to avoid heterogeneity in the mTBI group and the possibility of including participants with more severe injuries. This strict characterization of participants is supported by recommendations by the American Congress of Rehabilitative Medicine (75). Indeed, most of our participants endorsed full recoveries, with the majority of them 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. The comparable performance of adults with orthopedic injuries and adults with mTBI could potentially highlight a misattribution of symptoms to mTBI specifically. Perhaps group differences observed in studies with community based control groups (49, 50) simply reflect effects of general trauma rather than mTBI. There is evidence that trauma in general can confound scores on neuropsychological tests (76) and general trauma can induce psychological and somatic symptoms similar to those of mTBI (55). Understanding that the experience of trauma, regardless whether it is brain-based or body-specific, impacts everyday thinking is important as we attempt to characterize mTBI-related problems. 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 potentially confounding psychological 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 for the TBI group, 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. Future studies in language performance after mTBI would benefit from strict sampling procedures using smaller recovery windows as well as a thorough characterization of study participants to better understand this important and often understudied variable (time-post injury). Our findings contribute to the literature in that they underscore the complexity of investigating language in mTBI and delineate 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.

In Barrow (49) a greater number of errors in relation to other error categories were deemed to be semantic in origin and in a later study, they (48) replicated their initial findings. Participants in the current study also reported a larger proportion of semantic errors rather than other types of errors. This finding is consistent with preliminary studies of mTBI using electrophysiological methods to elucidate different aspects of semantic processing. One study (77) posited that during picture naming tasks, semantic information needs to be available before phonological information about a word to ensure accuracy. Another (78) case study provided evidence that an individual with mTBI takes longer to process sentences and demonstrates lower accuracy when compared to an unimpaired group. The Barrow studies also found a main effect of group that was magnified by an increase in vocabulary difficulty level in the stimuli, that is as items increased in difficulty level more semantic errors were demonstrated by individuals with mTBI. Therefore, in order to develop instruments that are sensitive and specific to mTBI language performance, testing under time constraints as well as manipulating variables such as semantic difficulty appear to be promising areas of future research. The current study expands the knowledge we have about cognitive-linguistic performance after mTBI and distinguishes itself from previous studies by including a comparison group that is demographically similar in order to determine whether the problems observed in the population are consistent with mTBI or trauma in general.

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. Furthermore, unlike previous studies, our study did not recruit a clinical sample of individuals with mTBI symptoms nor did we screen for language-related mTBI deficits prior to enrolling in the study; therefore, the likelihood of detecting expressive language deficits in the included mTBI sample was low, which limited statistical power. In addition, our experiment potentially suffered from limited sensitivity and specificity to language-related mTBI deficits on account of low probability of these problems in the general mTBI population. Our study may have additionally 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 and perhaps fewer problems and symptoms that enabled them to do so. In addition, our study participants were compensated between $50-$63 per hour which could contribute to potential volunteer bias. These limitations makes generalization of our results to other, more diverse mTBI populations tenuous.

The category-naming task utilized in the current study, while useful for capturing word-level language performance has potentially limited ecological validity for capturing the everyday cognitive-linguistic challenges people with mTBI might report. However, the novel conditions (speeded vs. unspeeded) under which we administered this cognitive-linguistic task can potentially be utilized in future studies to shed light into possible underlying mechanisms of deficits in communication. Findings in the speeded condition in particular can be extended to potential cognitive-linguistic performance in natural conversation, which is inherently a speeded task. Additionally, timed cognitive tests have been used routinely in neuropsychological evaluations to determine functional recovery after TBI so the use of a timed cognitive-linguistic task could potentially be used in the acute and subacute setting to capture individuals at risk of cognitive-communication disorders after mTBI. We acknowledge that such information is a first step in determining an individual’s communication skills and that multiple sources of information including other standardized approaches as well as communication partner report are needed to obtain a comprehensive view of performance.

The limitations our current experimental task presented also highlight the difficult task of finding a sensitive and specific language task that captures the subtle deficits in performance after mTBI. This shortcoming in assessments tools is shared by other areas of research and clinical practice such as mild cognitive impairment, multiple sclerosis and chemotherapy-related cognitive disorder.

Further directions for research include investigating differences in 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 cognitive-linguistic function and both of which naturally occur under speeded conditions within the context of everyday conversation. The correlations between language task performance and neurobehavioural symptoms, including sleep quality, suggest that symptom-based factors should also be considered in future research.

Conclusions

In summary, results of our study supported our hypothesis by indicating practical differences between adults with mTBI and OI controls in cognitive-linguistic performance, particularly in accuracy of responses. And in interpreting our subtle group differences, it is imperative to consider our narrow sampling approach. In direct contrast to previous studies, the mTBI group included in the current study did not experience loss of consciousness, nor were they hospitalized for their injuries, therefore it is worthwhile to consider that they represent the 'mildest' of a mTBI group population. Our study and particularly the limited group differences on the language-task also advances and enriches our understanding of the effects of generalized trauma on language performance. In addition, the associations we found between secondary symptoms and language performance indicate that including a careful characterization and measure of secondary symptoms with tools such as the NSI is valid and necessary. Our findings highlight the complexity of investigating cognitive-linguistic function in mTBI and the important role of task selection, appropriate comparison groups and consideration of the effect of neurobehavioural symptoms and this will inform future research efforts.

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Declaration of Interest:

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References

1. LeBlanc J, de Guise E, Champoux MC, Couturier C, Lamoureux J, Marcoux J, et al. Acute evaluation of conversational discourse skills in traumatic brain injury. Int J Speech Lang Pathol. 2014;16(6):582–93. [PubMed: 24447162]
2. Rietdijk R, Simpson S, Togher L, Power E, Gillett L. An exploratory prospective study of the association between communication skills and employment outcomes after severe traumatic brain injury. Brain Inury. 2013;27(7–8):812–8.

3. McDonald S Impairments in social cognition following severe traumatic brain injury. J Int Neuropsychol Soc. 2013;19(3):231–46. [PubMed: 23351330]
4. Galski T, Tomkins C, Johnston MV. Competence in discourse as a measure of social integration and quality of life in persons with traumatic brain injury. Brain Injury. 1998;12(9):769–82. [PubMed: 9755368]
5. Mozeiko J, Le K, Coelho C, Krueger F, Grafman J. The relationship of story grammar and executive functioning following TBI. Aphasiology. 2011;25(6–7):826–35.
6. Coelho C, Lê K, Mozeiko J, Hamilton M, Tyler E, Krueger F, et al. Characterizing discourse deficits following penetrating head injury: a preliminary model. Am J Speech Lang Pathol. 2013;22(2):S438–48. [PubMed: 23695915]
7. Yang FG, Fuller J, Khodaparast N, Krawczyk DC. Figurative language processing after traumatic brain injury in adults: a preliminary study. Neuropsychologia. 2010;48(7):1923–9. [PubMed: 20230844]
8. Kraus J, Arthur DL, Silverman TA, Jayaraman M, Naravan RK, Wilberger JE, et al. Epidemiology of brain injury. New York: McGraw-Hill; 1996.
9. Cassidy J, Carroll L, Peloso P, Borg J, Von Holst H, Holm L, et al. Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. 2004. 2004;36:28–60.
10. Carroll L, Cassidy J, Peloso P, Borg J, Von Holst H, Holm L, et al. Prognosis for mild traumatic brain injury: Results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. Journal of Rehabiliation Medicine. 2004;43:84–105.
11. Bernstein DM. Information processing difficulty long after self-reported concussion. J Int Neuropsychol Soc. 2002;8(5):673–82. [PubMed: 12164676]
12. Makdissi M, Davis G, McCrory P. Clinical Challenges in the diagnosis and assessment of sports-related concussion. Neurology: Clinical Practice. 2015;5(1):2–5.
13. Iverson GL. Outcome from mild traumatic brain injury. Current Opinion in Psychiatry. 2005;18(3): 301–17. [PubMed: 16639155]
14. Belanger HG, Vanderploeg RD. The neuropsychological impact of sports-related concussion: a meta-analysis. J Int Neuropsychol Soc. 2005;11(4):345–57. [PubMed: 16209414]
15. Broglio S, Pontifex M, O'Connor P, Hillman C. The persistent effects of concussion on neuroelectric indices of attention. Journal of Neurotrauma. 2009;26:1463–70. [PubMed: 19331519]
16. Frencham KA, Fox AM, Maybery MT. Neuropsychological studies of mild traumatic brain injury: a meta-analytic review of research since 1995. J Clin Exp Neuropsychol. 2005;27(3):334–51. [PubMed: 15969356]
17. Dean PJ, Sterr A. Long-term effects of mild traumatic brain injury on cognitive performance. Front Hum Neurosci. 2013;7(30):1–11. [PubMed: 23355817]
18. Stout CE, Yorkston KM, Pimentel JI. Discourse production following mild, moderate, and severe traumatic brain injury: A comparison of two tasks. Journal of Medical Speech-Language Pathology. 2000;8(1):15–25.
19. Cornis-Pop M, Mashima PA, Roth CR, MacLennan DL, Picon LM, Hammond CS, et al. Guest editorial: Cognitive-communication rehabilitation for combat-related mild traumatic brain injury. J Rehabil Res Dev. 2012;49(7):xi–xxxii. [PubMed: 23341288]
20. Lundin A, de Boussard C, Edman G, Borg J. Symptoms and disability until 3 months after mild TBI. Brain Inj. 2006;20(8):799–806. [PubMed: 17060147]
21. Ponsford J, Draper K, Schönberger M. Functional outcome 10 years after traumatic brain injury: its relationship with demographic, injury severity, and cognitive and emotional status. J Int Neuropsychol Soc. 2008;14(2):233–42. [PubMed: 18282321]
22. Wright J Medical Treatment of Concussion. Seminars in Speech and Language. 2014;3:155–8.
23. Stout CE, Yorkston KM, Pimentel JI. Discourse production following mild, moderate, and severe traumatic brain injury: A comparison of two tasks. 2000 p. 15–25.
24. Blyth T, Scott A, Bond A, Paul E. A comparison of two assessments of high level cognitive communication disorders in mild traumatic brain injury. Brain Inj. 2012;26(3):234–40. [PubMed: 22372411]

25. Leblanc J, De Guise E, Feyz M, Lamoureux J. Early prediction of language impairment following traumatic brain injury. Brain Inj. 2006;20(13–14):1391–401. [PubMed: 17378231]
26. Parrish C, Roth C, Roberts B, Davie G. Assessment of Cognitive-Communication Disorders of Mild Traumatic Brain Injury Sustained in Combat. SIG 2 Perspectives on Neurophysiology and Neurogenic Speech and Language Disorders. 2009;192:47–57.
27. Tucker FM, Hanlon RE. Effects of mild traumatic brain injury on narrative discourse production. Brain Inj. 1998;12(9):783–92. [PubMed: 9755369]
28. MacDonald S, Johnson CJ. Assessment of subtle cognitive-communication deficits following acquired brain injury: A normative study of the Functional Assessment of Verbal Reasoning and Executive Strategies (FAVRES). Brain Injury. 2005;19(11):895–902. [PubMed: 16299932]
29. Coelho C, Ylvisaker M, Turkstra LS. Nonstandardized assessment approaches for individuals with traumatic brain injuries. Semin Speech Lang. 2005;26(4):223–41. [PubMed: 16278795]
30. Krug H, Turkstra LS. Assessment of Cognitive-Communication Disorders in Adults with Mild Traumatic Brain Injury. SIG 2 Perspectives on Neurophysiology and Neurogenic Speech and Language Disorders. 2015;25(1):17–35.
31. Turkstra LS, Coelho C, Ylvisaker M. The use of standardized tests for individuals with cogntive-communication disorders. Semin Speech Lang. 2005;26(4):215–22. [PubMed: 16278794]
32. Worrall L, McCooey R, Davidson B, Larkins BM, Hickson L. The validity of fucntional assessments of communication and the Activity/Participation components of the ICIDH-2: do they reflect waht really happens in real-life? Journal of Communication Disoders. 2002;35:107–37.
33. Madigan NK, DeLuca J, Diamond BJ, Tramontano G, Averill A. Speed of information processing in traumatic brain injury: modality-specific factors. J Head Trauma Rehabil. 2000;15(3):943–56. [PubMed: 10785624]
34. Tombaugh TN. A comprehensive review of the Paced Auditory Serial Addition Test (PASAT). Arch Clin Neuropsychol. 2006;21(1):53–76. [PubMed: 16290063]
35. Tombaugh TN, Rees L, Stormer P, Harrison AG, Smith A. The effects of mild and severe traumatic brain injury on speed of information processing as measured by the computerized tests of information processing (CTIP). Arch Clin Neuropsychol. 2007;22(1):25–36. [PubMed: 17071052]
36. Lovell MR, Iverson GL, Collins MW, McKeag D, Maroon JC. Does loss of consciousness predict neuropschological decrements after concussion? Clinical Journal of Sports Medicine. 1999;9(4): 193–8.
37. Dymowski AR, Owens JA, Ponsford JL, Willmott C. Speed of processing and strategic control of attention after traumatic brain injury. J Clin Exp Neuropsychol. 2015;37(10):1–12. [PubMed: 25493696]
38. Willmott C, Ponsford J, Hocking C, Schönberger M. Factors contributing to attentional impairments after traumatic brain injury. Neuropsychology. 2009;23(4):424–32. [PubMed: 19586207]
39. Draper K, Ponsford J. Cognitive functioning ten years following traumatic brain injury and rehabilitation. Neuropsychology. 2008;22(5):618–25. [PubMed: 18763881]
40. Ben-David BM, Nguyen LL, van Lieshout PH. Stroop effects in persons with traumatic brain injury: selective attention, speed of processing, or color-naming? A meta-analysis. J Int Neuropsychol Soc. 2011;17(2):354–63. [PubMed: 21320377]
41. Ríos M, Periáñez JA, Muñoz-Céspedes JM. Attentional control and slowness of information processing after severe traumatic brain injury. Brain Inj. 2004;18(3):257–72. [PubMed: 14726285]
42. Grön G Cognitive slowing in patients with acquired brain damage: an experimental approach. J Clin Exp Neuropsychol. 1996;18(3):406–15. [PubMed: 8877624]
43. Ziino C, Ponsford J. Selective attention deficits and subjective fatigue following traumatic brain injury. Neuropsychology. 2006;20(3):383–90. [PubMed: 16719631]
44. Woods DL, Yund EW, Wyma JM, Ruff R, Herron TJ. Measuring executive function in control subjects and TBI patients with question completion time (QCT). Front Hum Neurosci. 2015;9:288. [PubMed: 26042021]
45. Miotto EC, Cinalli FZ, Serrao VT, Benute GG, Lucia MC, Scaff M. Cognitive deficits in patients with mild to moderate traumatic brain injury. Arq Neuropsiquiatr. 2010;68(6):862–8. [PubMed: 21243242]

46. King KA, Hough MS, Vos P, Walker MM, Givens G. Word retrieval following mild TBI: Implications for categorical deficits. Aphasiology. 2006;20(2–4):233–45.
47. Galetto V, Andreetta S, Zettin M, Marini A. Patterns of impairment of narrative language in mild traumatic brain injury. J Neurolinguistics. 2013;26(6):649–61.
48. Barrow IM, Hough M, Rastatter MP, Walker M, Holbert D, Rotondo MF. The effects of mild traumatic brain injury on confrontation naming in adults. Brain Inj. 2006;20(8):845–55. [PubMed: 17060151]
49. Barrow IM, Hough M, Rastatter MP, Walker M, Holbert D, Rotondo MF. Can within-category naming identify subtle cognitive deficits in the mild traumatic brain-injured patient? J Trauma. 2003;54(5):888–95; discussion 95–7. [PubMed: 12777901]
50. Barrow I, Hough M, Rastatter M, Walker M, Holbert D, Rotondo M. The effects of mild traumatic brain injury on confrontation naming in adults. Brain Inj. 2006;20(8):845–55. [PubMed: 17060151]
51. Raskin S, Mateer C, Tweeten R. Neuropsychological assessment of individuals with mild traumatic brain injury. The Clinical Neuropsychologist. 1998;12(1):21–30.
52. Bonhnen N, Jolles J. Neurobehavioral aspects of postconcussive symptoms after mild head injury. The Journal of Nervous and Mental Disease. 1992;180(11):683–92. [PubMed: 1431820]
53. De Koning ME, Gareb B, El Moumni M, Scheenen ME, van der Horn HJ, Timmerman ME, et al. Subacute posttraumatic complaints and psychological distress in trauma patients with or without mild traumatic brain injury. Injury. 2016;47(9):2041–7. [PubMed: 27297705]
54. Troyanskaya M, Pastorek N, Scheibel R, Petersen N, Walder A, Henson H, et al. Choosing appropriate comparison group participants in studies of veterans: Characteristics of orthopedically injured and uninjured Operation Enduring Freedom/Operation Iraqi Freedom/Operation New Dawn veterans. Journal of Clinical and Experimental Neuropsychology. 2016;38(7):811–9. [PubMed: 27171190]
55. Landre N, Poppe CJ, Davis N, Schmaus B, Hobbs SE. Cognitive functioning and postconcussive symptoms in trauma patients with and without mild TBI. Arch Clin Neuropsychol. 2006;21(4): 255–73. [PubMed: 16716563]
56. King KA, Hough MS, Walker MM, Rastatter M, Holbert D. Mild traumatic brain injury: effects on naming in word retrieval and discourse. Brain Inj. 2006;20(7):725–32. [PubMed: 16809205]
57. Crawford MA, Knight RG, Alsop BL. Speed of word retrieval in postconcussion syndrome. J Int Neuropsychol Soc. 2007;13(1):178–82. [PubMed: 17166317]
58. Eisenberg J, Meehan WP, Mannix R. Duration and course of post-concussive symptoms. Pediatrics. 2014;133(6):999–1066. [PubMed: 24819569]
59. Rossion B, Pourtois G. Revisiting Snodgrass and Vanderwart's object pictorial set: the role of surface detail in basic-level object recognition. Perception. 2004;33(2):217–36. [PubMed: 15109163]
60. Carroll J, White M. Age of acquisition norms for 220 picturable nouns. Journal of Verbal Learning and Verbal Behavior. 1973;125:563–76.
61. E-Prime Pittsburgh PA: Psychology Software Tools; 2012.
62. Battig W, Montague W. Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. Journal of Experimental Psychology. 1969;80(3):1–46.
63. McRae K, Cree G, Seidenberg M, McNorgan C. Semantic Feature Production Norms for a Large Set of Living and Nonliving things. Behavior Research Method, Instruments and Computers. 2005;37(4):547–59.
64. Soble J, Silva M, Vandeploeg R, Curtiss G, Belanger H, Donnell A, et al. Normative Data for the Neurobehavioral Symptom Inventory (NSI) and Post-Concussion Symptom Profiles among TBI, PTSD and Nonclinical Samples. The Clinical Neuropsychologist. 2014;28(14):614–32. [PubMed: 24625213]
65. Buysse D, Reynolds C, Monk T, Berman S, Kupfer D. The Pittsburgh Sleep Quality Index: An new instrument for psychiatric practice and research. Psychiatry Res. 1989;28(2).

66. Wisseman-Hakes C, Colantino A, Gargaro J. Sleep and wake disorders following traumatic brain injury: a systematic review of the literature. Critical Reviews in Physical and Rehabilitation Medicine. 2009;21:3–4.

67. Wechsler D Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV), Processing Speed Index. San Antonio, TX: Pearson; 2008.

68. Gershon R, Wagster M, Hendrie H, Fox N, Cook K, Nowinski C. NIH Toolbox for assessment of neurological and behavioral function. Neurology. 2013;80(Supp 3):S2–6. [PubMed: 23479538]

69. Yorkston KM, Beukkelman DR. Assessment of intelligibility of dysarthric speech: Pro-ed; 1984.

70. Montgomery J, Evans J, Gillam R, Sergeev A, Finney M. “Whatdunit?” Developmental changes in children’s syntactically based sentence interpretation abilities and sensitivity to word order. Applied Psycholinguistics. 2016;37:1281–309.

71. Corp I IBM SPSS Statistics for Macintosh. 23 ed2015.

72. Faul F, Erdfelder E, Lang A, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Method, Instruments and Computers. 2007;39:175–91.

73. Spikman JM, van Zomeren AH, Deelman BG. Deficits of attention after closed-head injury: slowness only? J Clin Exp Neuropsychol. 1996;18(5):755–67. [PubMed: 8941860]

74. Battistone M, Woltz D, Clark E. Processing speed deficits associated with traumatic brain injury: processing inefficiency or cautiousness? Appl Neuropsychol. 2008;15(1):69–78. [PubMed: 18443943]

75. Maas AI, Harrison-Felix C, Menon DK, Adelson PD, Balkin T, Bullock R, et al. Common Data Elements for Traumatic Brain Injury: Recommendations from the Interagency Working Group on Demographics and Clinical Assessment. Archives of Physical Medicine and Rehabilitation. 2010;91(11):1641–9. [PubMed: 21044707]

76. Meares S, Shores EA, Batchelor J, Baguley IJ. The relationship of psychcological and cognitive factors and opiods in the develpment of the postconcussion syndrome in general trauma patients with mild traumatic brain injury. Journal of the International Neuropsychological Society. 2006;12(6):792–801. [PubMed: 17064443]

77. Schmitt BM, Münte TF, Kutas M. Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. Psychophysiology. 2000;37(4):473–84. [PubMed: 10934906]

78. Key-DeLyria SE Sentence Processing in Traumatic Brain Injury: Evidence from the P600. Journal of Speech, Language and Hearing Research. 2016;59:759–71.

Table 1.

Participant demographic characteristics

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

Note: mTBI = mild traumatic brain injury, OI = orthopedic injury

Table 2.

Injury characteristics of the study sample

Injury Characteristics	mTBI (n=20)	Injury Characteristics	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

Note: mTBI = mild traumatic brain injury, OI = orthopedic injury

[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)

Tests/Questionnaires	mTBI (n = 20)	OI (n = 21)
NIH Toolbox Cognition Battery	52.63 (9.31)	57.14 (10.72)
sNIH 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: mTBI = mild traumatic brain injury, OI = orthopedic injury, NIH=National Institutes of Health, NSI=Neurobehavioral Symptom Inventory, PSQI=Pittsburgh Sleep Quality Index

Table 4.

Overall accuracy (percentage correct) and reaction time (in milliseconds) by group and condition. Data are means (SD)

Variable-Condition	**mTBI (n = 20)**	**OI (n = 21)**
Accuracy- Speeded	73.66 (10.84)	77.21 (15.13)
Reaction Time-Speeded	1952.64 (470.34)	2006.64 (471.42)
Accuracy- Unspeeded	75.49 (13.33)	80.47 (9.22)
Reaction Time- Unspeeded	2451.23 (451.16)	2491.44 (516.21)

Note: mTBI = mild traumatic brain injury, OI = orthopedic injury

Table 5.

Pearson Correlations with significant values between naming task dependent variables and participant characteristics

Group	Variable-Condition	Time Post	Speech Rate	Sleep Quality	NSI Total[a]
mTBI n=20					
	Accuracy-speeded	.15 .27	−.03 .47	24 .17	−.38 .07
	Accuracy-unspeeded	−.36* .06	.07 .40	−.53* .01	−.47* .03
	Reaction Time-speeded	−.11 .32	−.37 .09	.55** .01	.17 .25
	Reaction Time-unspeeded	−.13 .30	−.39 .08	.44* .03	.24 .18
OI n=21					
	Accuracy-speeded	.18 .22	−.39 .06	−.03 .45	−.69** .00
	Accuracy-unspeeded	−.06 .41	−.11 .34	.21 .18	−.51** .01
	Reaction Time-speeded	−.31 .09	−.42* .05	.27 .12	.11 .32
	Reaction Time-unspeeded	−.40* .04	−.54 .01	.19 .21	.11 .32

Note: mTBI = mild traumatic brain injury, OI = orthopedic injury,

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 % of all responses in parentheses

Error Types	**mTBI (n=20)**	**OI (n=21)**
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)

Note: mTBI = mild traumatic brain injury, OI = orthopedic injury