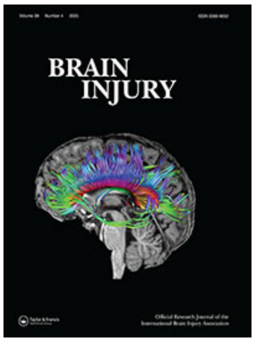

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Relationship between language comprehension and chronic neurobehavioral symptoms in adults with mild traumatic brain injury

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ABSTRACT

Primary objectives: Annually, millions of Americans sustain mild traumatic brain injuries (mTBI), and some may experience neurobehavioral symptoms (NBS), like slow processing speed that persist chronically or longer than 6 months post injury. In turn, cognitive processes like language comprehension may be compromised. This study investigates the relationship between NBS and language comprehension in individuals with mTBI history and low or high NBS.

Methods & procedures: Thirty-one adults with mTBI and high ($n = 13$; female = 11) and low ($n = 18$; female = 10) NBS completed a language comprehension task in speeded and unspeeded conditions. Reduced language comprehension, as measured by slower response times (RTs) and reduced accuracy, was expected to be high compared to low NBS group, regardless of condition. Language comprehension correlates (e.g. cognition and general processing speed) were also measured.

Main outcomes & results: Adults with high NBS showed reduced comprehension, measured by slower RTs in the unspeeded condition compared to low NBS. No difference in accuracy or errors produced was observed. Cognitive skills and processing speed are negatively correlated and predicted language comprehension task performance.

Conclusions: NBS and predictive factors specific to the individual are important to monitor post-mTBI, as they may affect language functioning.

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Concussion; language; mild traumatic brain injury; communication; symptoms; cognition

Introduction

Mild traumatic brain injury (mTBI), or concussion, is a prevalent health issue that accounts for 70% to 90% (1,2) of the total 2.8 million annual United States cases (3). Further, the global burden of TBI echoes that of the U.S., with approximately 55.9 million of the 69 million annual new cases classified as mTBIs (4).

Despite the high incidence of mTBI, long-term implications experienced in the chronic recovery stage (6 months or more post injury) are unclear. Most adults will recover within a few weeks to 6 months after injury (5,6), but some may experience persistent 'post-concussion' or neurobehavioral symptoms (NBS). Persistent NBS, defined as symptoms lasting 3 months or more (7), are presumed to have a brain and behavioral basis that may or may not relate to the injury. These symptoms can be measured via the Neurobehavioral Symptom Inventory (NSI). The NSI measures three NBS categories: 1) cognitive – concentration, memory, and processing speed; 2) affective – fatigue, sleep, anxiety, depression, and irritability; and 3) somatic/vestibular factors – nausea, headaches, vision sensitivity, hearing issues, taste/smell changes, dizziness, balance, and coordination (8). While remote or chronic mTBI history alone, even if repetitive, is not causal for cognitive problems (9), emerging evidence suggests that mTBI recovery is heterogeneous (10), with a minority of individuals experiencing persistent NBS that may lead to poor cognitive outcomes (11) beyond 3 months (9–12). Thus, in cases where individuals experience persistent NBS post-mTBI, a link between the NBS and cognitive impairments may exist. While the direct link between NBS and cognitive impairments is unclear, these symptoms may underlie some common cognitive impairments post-mTBI that span several cognitive domains, including problems with processing speed (12,13), memory (14), attention (15,16) and executive function (17). Importantly, cognitive impairments within these domains all play an essential role in communication – a complex, multi-faceted human function involving an interplay of cognitive, linguistic, emotional, physical, personal, and contextual factors (18). Further, research is needed to understand the interplay of cognitive (e.g., processing speed) and communication (e.g., language comprehension) impairments post-mTBI. These impairments can reduce communication competence or the ability to use communication to achieve community and societal integration goals (18), and ultimately result in poorer outcomes post-mTBI.

Evidence suggests that language comprehension, a key component of communication, may be compromised after mTBI. One study has shown young adults with an mTBI history perceive difficulties in understanding complex materials as quickly and efficiently as peers (19). Similarly, a qualitative study of 30 adults with mTBI history further

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supports perceived language comprehension difficulties post-mTBI, as 84% of the sample reported language comprehension problems (20). However, due to the subjective nature, it is unclear if these findings generalize to the mTBI population and underscore the need for an objective measure. Further, it is unclear if language comprehension difficulties are limited to semantic (meaning) or syntactic (grammar) processing. These studies also do not connect language comprehension difficulties to the common and well-studied cognitive symptom post-mTBI that has been consistently observed across individuals with acute (21) or remote/chronic (12,13) mTBI history: slow processing speed (22–26).

Typically, slow general processing speed and language comprehension are linked (27–29). However, few studies have investigated the link between language comprehension problems and persistent NBS, even though clinicians often under-recognize these problems (30,31). Only one study has investigated this link (32), hypothesizing that those with subacute (3–6 months post injury) mTBI history would have slower and less accurate comprehension speed compared to orthopedic controls (OIs) on a language comprehension task called the *Whatdunit*. The *Whatdunit* task was selected since it previously revealed subtle language processing differences in those with specific language impairment by requiring participants to select an agent or object completing actions in sentences with varied syntactic complexity (33), unimpaired adults perform this task with high accuracy (34), and previous study measured a neural index of syntactic processing in a small TBI sample, hinted that syntactic processing may be severely compromised after TBI (35). Contrary to predictions, those with mTBI were not slower or less accurate than orthopedic controls (OIs) on the comprehension task. Heterogeneity in NBS was proposed to underlie the lack of differences, as a closer investigation of NBS revealed six individuals (four mTBI, two OIs) in the sample ($n = 36$ overall; $n = 18$ mTBI; $n = 18$ OIs; 16% of the sample) that had NSI total scores greater than or equal to 5, which was higher than a normative non-injured sample (36) that had an NSI total score mean of 3 (SD = 5.7, 75%ile rank = 4.0).

A study investigating another aspect of language comprehension and semantics also hints at a link between language comprehension and persistent NBS after mTBI. When the N400, a neural index of semantic processing, was measured in adults with acute (up to 3 months post injury) mTBI history, the difference between the brain response to reading semantically correct and incorrect sentences (N400 effect) was significantly weakened by more symptoms (37). In contrast, fewer perceived mTBI symptoms were associated with larger N400 effects, similar to a healthy adult response where semantically incorrect stimuli yield a larger (more negative) N400 compared to correct. The study also found that when mTBI severity and recovery status were more controlled, those in the mTBI group showed lower memory, language, and executive function scores on the standardized Cognitive-Linguistic Quick Test (CLQT) (38). However, the CLQT primarily reflects expressive, not receptive language abilities, which highlights a weakness of using this cognitive-linguistic measure in clinical practice overall and reduces relevance to the current study. Additionally, it remains unclear whether these results extend to chronic mTBI and if NBS impacts syntactic processing.

In conclusion, literature suggests that some individuals experience persistent NBS after mTBI, which may contribute to cognitive deficits that may reduce language comprehension. While language comprehension difficulties after mTBI are subjectively described, quantitative studies have struggled due to methodological weaknesses and the challenge of measuring subtle deficits in a heterogeneous population.

Present study

The relationship between processing speed, language comprehension, and persistent NBS in individuals within the chronic mTBI recovery stage has not been thoroughly explored. To address this gap, we conducted an exploratory pilot study, where we employed a previously validated objective (33) sentence comprehension task called the *Whatdunit* with speeded and unspeeded conditions (32) to measure response times, accuracy, and errors in mTBI adults in the chronic stage recovery with varying levels of NBS.

Using this approach, we first aimed to determine how the level of persistent neurobehavioral symptoms (NBS) affects language comprehension in individuals with persistent symptoms and mTBI history. Since heterogeneity in NBS has been observed in a study investigating language comprehension in a mTBI sample and may have contributed to reduced differences between groups (32), we expected language comprehension to differ by NBS. Specifically, we hypothesized that individuals with high NBS would demonstrate decreased or poorer language comprehension, regardless of condition, as measured by increased errors, slower RTs, and lower accuracy on the *Whatdunit*, compared to those with low NBS. Since no prior research is available to suggest that NBS leads to increased language comprehension difficulties in tasks requiring speeded comprehension, a between-group difference, irrespective of condition was anticipated. Further, no between-group differences in baseline motor planning or execution speed were anticipated because between-group differences were not previously observed when individuals with mTBI history and orthopedic controls were previously compared using the *Whatdunit* (32).

Specific cognitive skills, measured via standardized assessments for cognition (NIH Toolbox Cognitive Total Score) and processing speed (WAIS PSI), were also expected to be correlated with language comprehension. We predicted that low standardized processing speed and cognitive scores would show a strong negative correlation with *Whatdunit* accuracy, RTs, and errors, indicating that similar constructs were measured in the *Whatdunit*. We also expected NBS, processing speed, and cognitive total scores to predict *Whatdunit* RTs.

Additionally, due to the exploratory nature of this study, a number of language comprehension variables were analyzed to determine if they affected language comprehension in individuals with chronic mTBI history. Measurement of these variables was essential because data were collected from an inherently heterogenous sample community-dwelling individuals with mTBI history. Specifically, language performance variables like sleep quality, perceived communication abilities, processing speed, cognitive abilities, and sentence comprehension were measured, but only sleep quality and processing speed were expected to be different between groups and related to comprehension. Since sleep and sleep quality can impact cognition (39) and sleep quality has been associated with poor expressive language task performance in an mTBI sample (40), we expect the high NBS group to have poor sleep quality scores that are associated with slower RTs and lower accuracy, compared to low NBS. Between-group processing speed differences were also expected. Specifically, the high NBS group was expected to have slower processing speed (lower WAIS PSI scores) compared to the low NBS group. Furthermore, the WAIS PSI scores were expected to be associated with poor accuracy and slower RTs as observed in (32). The standardized assessments and additional measures were administered to describe the sample, so no group differences in perceived communication, cognitive abilities, or sentence comprehension were expected.

Methods

Participants

The study sample was comprised of 31 community-dwelling adults with self-reported mTBI history (see section 2.3 for participant eligibility details). After study completion, the sample was stratified into two groups: low ($n = 18$; Female = 10) and high ($n = 13$; Female = 11) NBS. The groups were stratified using the median Neurobehavioral Symptom Inventory Score (NSI) score of 16. The high NBS group had NSI scores greater than 16, and the low NBS group had scores less than or equal to 16. To eliminate systematic bias, stratification was performed after study completion. High or low on the NSI has not been established in the field, so the median was used. In clinical research, the median split approach may be used since clinical populations exhibit varying degrees of symptomatology, and the question is whether the symptoms exceed a threshold that would warrant treatment (41). Median split usage is also valid here because non-injured controls lack the lived experience of mTBI (42). Furthermore, studies that have split their data by post-mTBI symptoms have shown more consistent findings related to cognitive deficits (43).

Questionnaires & assessments

Experimental measure: Whatdunit task

The main measure is an adapted version of the *Whatdunit* (33), an experimental task that assesses English language comprehension in sentences without semantic cues. The task consists of 66 sentences (see **A1**) that are either syntactically simple (subject – verb – object [SVO] and subject relative [SR]) or complex, passive [PAS] and object relative [OR]). Our methods followed the original study (33), except our stimuli were divided into two sets and presented in two conditions (speeded/unspeeded, following a more recent investigation using the *Whatdunit* after mTBI (32)). Each participant listened to all 66 sentences divided equally into two blocks (33 speeded/33 unspeeded). In each condition, sentence types were randomized and counterbalanced. To complete the task, participants heard a sentence, viewed four pictures on the screen, and were instructed to select the image of the agent in the sentence or the object in the sentence that was doing the action, with their dominant hand index finger 'quickly as possible' in the speeded condition and to 'take their time' in the unspeeded condition. Participants had an unlimited response window in both conditions. Accuracy and RTs were captured using E-Prime software (44) and a touch screen monitor (Elo 1000 Series 1715 L touchscreen display). See appendix for sample stimuli.

Primary questionnaire: NSI

The NSI is widely used in clinical and military settings (36,45) and consists of 22 items to measure NBS over a retrospective 2-week interval. Items cover somatosensory (e.g., 'sensitivity to light" or 'numbness or tingling on parts of my body'), cognitive (e.g., 'slowed thinking, difficulty getting organized, can't finish things' or 'forgetfulness, can't remember things') and affective (e.g., 'feeling anxious or tense' or 'feeling depressed or sad') symptoms. See (49) for full NSI checklist. Respondents rate each item on a 5-point scale ranging from 0 (None – Rarely if ever present) to 4 (Very Severe – Almost always present). Total scores range from 0 to 88 and are calculated by adding all item scores. Three subscales can be calculated: Cognitive (0–16), Affective (0–28), and Somatosensory (0–44). Higher scores indicate more frequent and severe NBS.

Baseline motor task

A baseline task is controlled for individual differences in *Whatdunit* motor planning and execution speed (33). Thirty trials were administered, in which participants heard a single tone, saw four boxes, and were instructed to select the cross in one of the boxes and return their finger to a dot on the table after responding. Once baseline motor planning and execution speed RT (referred to as baseline motor RT hereafter) are subtracted from the *Whatdunit* RTs (interpretation RT), the remaining RT values are representative of language processing or more specifically sentence interpretation speed. The appendix (**A2**) includes uncorrected *Whatdunit* RTs and statistical results.

Case history form

To characterize the sample, a case history form was used to collect background and health information.

La Trobe communication questionnaire (LCQ-30-S)

The LCQ-30-S (46) measures self-perceived communication abilities. Respondents rate each item on a 4-point frequency scale: 1 (never or rarely), 2 (sometimes), 3 (often), 4 (usually or always). Total score ranges from 30 to 120, with higher scores indicating greater communication difficulties.

Pittsburgh sleep quality index (PSQI)

The PSQI subjectively measures sleep quality over a retrospective one-month period (47). Higher scores suggest poorer sleep quality.

Wechsler adult intelligence scale – fourth edition (WAIS-IV)

The WAIS Symbol Search and Coding subtests were administered to measure non-verbal information processing speed. Subtest scores were used to calculate a Processing Speed Index (PSI). Higher PSI scores indicate a faster processing speed (48).

NIH toolbox cognition battery

All standardized NIH Toolbox Cognition Battery subtests (49) were administered via an iPad to characterize cognition and obtain total composite scores. Only scores fully corrected against a national normative sample were used in the present study to ensure generalizability. Higher scores indicate better performance.

Sentence comprehension task

The Sentence Comprehension task, adapted from the Philadelphia Comprehension Battery for Aphasia (50), characterized sentence comprehension and was selected because it contains the same sentence types as the *Whatdunit*. Higher scores indicate poor comprehension.

Setting, participant eligibility, and procedure

The University of Texas Health San Antonio (UTHSA) Institutional Review Board approved all procedures. Participants were screened by telephone between February 2018 and February 2020. Those who met eligibility criteria were scheduled for UTHSA sessions within 1 month. Eligible participants reported (1) being between the age 18–55 (2), English as their primary language, and (3) having self-reported history of mTBI (concussion) confirmed via following definition: 'A blunt injury to the head or to the body with impulsive force transmitted to the head that resulted in any of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, drowsiness, blurred vision, memory difficulty, or difficulty concentrating (51). ' To include individuals in the present study with mTBI history who did not seek clinical care post-mTBI, no medical records or equivalents were used to confirm TBI history and mild severity. Including individuals who have not received clinical care post-mTBI is critical because they account for half (n = 924) of a previous study sample (n = 1835) that investigated concussion evaluation patterns in the U.S. (52). Participants with (1) history of pre-injury medical or neurological disease affecting the brain (other than mTBI) (2) or language disability or (3) a health-care surrogate were excluded. Four individuals were excluded due to injury history not consistent with mTBI, hearing screening failure, non-native English speaker status and a technical error resulting in unsaved unspeeded data.

After obtaining written consent, participants completed a single, 2-h study session in a quiet, distraction-free room and compensated $25 per hour for completion. To improve internal validity, participants were not aware of study objectives until completion. Experimenter bias was minimized by following a strict protocol. Upon arrival, a pure-tone hearing screen, Maico MA 25 Audiometer, at 500, 1000, and 2000 hz was conducted by a licensed clinician or trained graduate assistant. Individuals were excluded if they did not meet the hearing threshold (30 dB or better in one ear, averaged across 500, 1000, and 2000 hz). Next, the case history form and three questionnaires were administered: NSI, PSQI, and LCQ-30-S. The remaining measures were randomly administered: NIH Toolbox, WAIS-IV, sentence comprehension, TBI Bank (50), Barrow Category Naming (53), and *Whatdunit* (33) tasks. TBI Bank and Barrow Category Naming results are outside the scope of this study, see (40) for details. All data was managed using REDCap hosted at UTHSA (54,55).

Statistical approach

SPSS Version 29 was used for analyses. A power analysis was not performed for this exploratory pilot study. T-tests were used to determine differences between interpretation and baseline motor RTs, accuracy, errors, NIH, PSQI, WAIS, sentence comprehension, and LCQ-30-S total scores and descriptive variables. Two-way repeated measures of ANOVAs were conducted with NBS group (low/high) as the between-subjects factor, speed (speeded/unspeeded) as the within-subjects factor, and accuracy and RT as dependent variables. Correlations, independent of group, were used to examine the relationship between experimental and WAIS, PSQI, and NIH Cognitive Total variables. For unexpected differences between groups, post-hoc correlations were used. Correlations with least fair relationships ($r > 0.35$) were used to predict performance.

Results

Participant and descriptive variables

Demographic results are shown in Table 1. No difference on any demographic variable was observed, except for years of education $t\,(29) = 2.291$, $p = 0.029$. The high NBS group reported fewer years of education than the low NBS group. Table 2 shows mTBI injury characteristics. No significant differences were observed.

Relationship between language comprehension task performance and processing speed in adults with high and Low NBS

Table 3 shows the *Whatdunit* experimental task results. ANOVA results (Figure 1) indicated a main effect of speed (F (1,29) = 16.952, $p < 0.001$, $\eta^2 = 0.369$) and interaction between speed and symptom groups (F (1,29) = 4.808, p = 0.037, η^2 = 0.142). No group-by-speed interaction on accuracy was noted.

Participants with high NBS had greater unspeeded sentence interpretation RT $t\,(16.937) = -1.98$, $p = 0.032$, and baseline mean motor RT, $t\,(29) = -2.934$, $p = 0.006$, compared to those with low NBS. Groups did not differ in speeded sentence interpretation speed, accuracy, or errors.

Relationship between self-perceived and standardized variables and language comprehension in adults with high and low NBS

Table 3 shows results for self-perceived neurobehavioral symptoms (NSI), sleep quality (PQSI), and communication

Table 1. Participant demographic characteristics.

Characteristic	Low NBS ($n = 18$)	High NBS ($n = 13$)
Age, years, *M (SD)*	27.50 (5.21)	28.69 (10.77)
Age range	18–44	19–53
Gender, *n* (%)		
Female	10 (55.6)	11 (84.62)
Male	8 (44.4)	2 (14.3)
Race, *n* (%)		
Caucasian	15 (83.3)	8 (61.54)
African American	1 (5.6)	1 (7.69)
Other race	2 (11.2)	4 (30.77)
Ethnicity		
Hispanic or Latino	7 (38.89)	3 (23.08)
Non-Hispanic or Latino	11(61.11)	10 (76.92)
Highest level of education		
Education, years, *M (SD)*	16.61 (2.09)*	14.85 (2.07)
High school/GED	3 (16.7)	5 (38.46)
Some college/associate/tech degree	9 (50.0)	7 (53.85)
Bachelor's degree	6 (33.3)	1 (7.69)
Employment status		
Unemployed	8 (44.4)	3 (23.07)
Part-time employment	3 (16.7)	6 (46.15)
Full-time employment	7 (38.9)	4 (30.77)
Student status		
Yes	7 (38.9)	9 (69.23)
No	11 (61.1)	4 (30.76)

Note. NBS = neurobehavioral symptoms. *Significant at the $p < 0.05$, two-tailed test.

Table 2. Participant descriptive and injury characteristics.

Characteristics	Low NBS ($n = 18$)	High NBS ($n = 13$)
Handedness[+], *n (%)*		
Right	16 (89.9)	8 (64.3)
Left	2 (11.1)	4 (28.6)
Time postinjury, days, *M (SD)*	1378.26 (1180.433)	1305.38 (1146.211)
Total Number of TBIs, *M (SD)*	2.5 (1.79)	2.08 (1.754)
Mechanism of injury, *n (%)*		
Moving vehicle accident	2 (11.1)	4 (37.77)
Fall	10 (55.6)	5 (38.46)
Hit	4 (22.2)	1 (7.69)
Fight/Assault	2 (11.1)	3 (23.08)
Loss of consciousness, *n (%)*		
Yes	14 (77.8)	7 (53.85)
No	4 (22.2)	6 (46.15)

Note. NBS = neurobehavioral symptoms; SD = standard deviation; *M* = mean; TBIs = traumatic brain injuries. [+] Missing handedness data for one participant in the High NBS group.

abilities (LCQ-30-S). The high NBS group reported more communication problems (LCQ-30-S), $t\ (29) = -3.236$, $p = 0.003$ (two-tailed), poorer sleep quality $t\ (29) = -2.642$, $p = 0.007$, and more frequent and severe NBS $t\ (17) = -7.595$, $p < 0.001$ (equal variance not assumed), compared to the low NBS.

Table 4 shows results for potential standardized variables (processing speed, WAIS-IV; cognition, NIH Toolbox; sentence comprehension). Working memory $t\ (27) = 2.115$, $p = 0.044$, and fluid cognition scores $t\ (27) = 2.248$, p=0.033 differed between groups. The high NBS group showed lower (poorer) working memory and fluid cognition scores compared to the low NBS group. The low NBS group also had faster processing speed (higher scores) on the WAIS-IV $t\ (28) = 3.713$, $p < 0.001$. No standardized sentence comprehension difference was observed.

Relationship between standardized cognition and processing speed scores, sleep quality and Whatdunit language comprehension task measures

Table 5 shows results of correlations used to determine if cognitive skills (cognition – NIH Toolbox Cognitive Total or processing speed WAIS-IV scores) or sleep quality were associated with and predicted language comprehension performance, as measured by response times, accuracy, and errors.

Whatdunit language comprehension task reaction time predictors

Negative correlations were observed between speeded sentence interpretation RT (language comprehension) and two variables: processing speed (WAIS PSI) and cognitive scores (NIH Cognition Total Score). Unspeeded sentence interpretation RT also negatively correlated with WAIS PSI and NIH Cognition

Table 3. Independent sample T-Tests results for experimental task and subjective measures.

	p	Low NBS (n = 18) M (SD)	High NBS (n = 13) M (SD)
Experimental Tasks			
Interpretation RT+ speeded	0.113	321.12 (281.21)	490.05 (476.87)
Interpretation RT+ unspeeded	0.032*	532.72 (576.11)	1183.79 (1079.69)
Accuracy, speeded	0.088	90.66% (12.23%)	82.40% (18.42%)
Accuracy, unspeeded	0.192	89.90% (13.73%)	85.08% (16.54%)
Baseline Motor RT, Mean	0.006*+	735.66 (115.18)	898.87 (194.08)
Speeded condition			
SVO errors	0.066	0.28 (0.46)	1.08 (1.75)
PAS errors	0.141	2.06 (3.69)	3.77 (5.02)
SR errors	0.116	0.72 (0.90)	1.23 (1.42)
OR errors	0.105	3.11 (4.03)	5.54 (5.83)
Unspeeded condition			
SVO errors	0.186	0.39 (0.61)	0.77 (1.64)
PAS errors	0.256	2.67 (4.69)	3.85 (5.11)
SR errors	0.060	0.61 (0.98)	1.23 (1.67)
OR errors	0.284	3.00 (4.24)	4.00 (5.39)
Subjective Measures			
LCQ-30-S Total Score	0.001*+	56.50 (7.91)	67.70 (9.61)
NSI Total Score	<.001**	9.61 (5.19)	31.23 (9.27)
NSI Cognitive	<.001**	2.00 (1.82)	6.92 (3.48)
NSI Affective	<.001**	3.94 (2.80)	12.46 (3.57)
NSI Somatosensory	<.001**	3.67 (2.77)	11.85 (5.08)
PSQI Total Score	0.007*	6.11 (2.89)	9.31 (3.87)

Note. NBS = neurobehavioral symptoms; RT = reaction time; SD = standard deviation; NSI = Neurobehavioral Symptom Inventory; PSQI = Pittsburgh Sleep Quality Index. Sentence error types: SVO = subject-verb-object; PAS = passive; SR = subject relative; OR = object relative. +Interpretation RT is derived from RT on the *Whatdunit Sentence Task* subtracted by RT on the *Baseline Motor Task*.
*Significant at the $p < 0.05$, single-tailed test **Significant at the $p < 0.01$, single-tailed test *+two-tailed test.

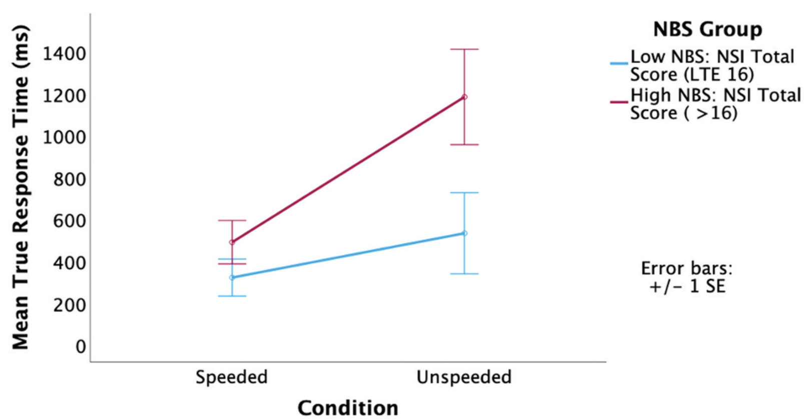

Figure 1. High and low symptom group sentence interpretation reaction time by condition. Mean true response time (sentence interpretation reaction time) is plotted on the y axis in milliseconds and the speeded and unspeeded conditions are plotted on the x axis with the red line representing high NBS and blue line representing low NBS. Across groups, sentence interpretation RTs are comparable in the speeded condition. In the unspeeded condition, those with high NBS show significantly slower sentence interpretation RTs. Note. NBS = neurobehavioral symptoms; SE = standard error; LTE = less than or equal to.

Total Score. Additionally, a negative correlation with NIH Fluid Cognition Total scores was observed. NBS (NSI scores) and unspeeded RTs were positively correlated. Baseline motor RTs are negatively correlated with sleep quality, processing speed, NIH Fluid Cognition Total scores and years of education.

Regressions were conducted to predict speeded/unspeeded sentence interpretation and baseline RTs. See appendix (**A3**) for visualizations. Two variables (WAIS PSI and NIH Cognition Total Score) were used to predict speeded sentence interpretation RT. The overall regression was significant (R^2 = 0.463, F (2,25) = 9.661, p = < .001). Two variables predicted speeded sentence interpretation RT, with WAIS PSI contributing most powerfully to the model (β = −0.415, p = 0.016), followed by NIH Cognition total score (β = −0.389, p = 0.022).

Four variables (WAIS PSI, NIH Cognition Total Score, and NSI scores) were used to predict unspeeded sentence interpretation RT. The overall regression was significant R^2 = 0.520, F (2,24) = 8.681, p = < .001. Again, WAIS PSI contributed most powerfully to the model (β = −0.398, p = 0.030), followed by NIH Cognition total score (β = −0.392, p = 0.020). NSI Total score did not significantly contribute (β = 0.112, p = 0.541).

Four variables (PSQI, WAIS PSI, and NIH Fluid Cognition Total scores and years of education) were used to predict baseline mean motor RT. The overall regression was significant (R^2 = 0.527, F (4,23) = 6.403, p = < .001). Only PQSI predicted (β = 0.567, p = 0.001) baseline mean motor RT (WAIS-β = −1.379, p = 0.451, Years of Education - β = 1.981, p = 0.872, NIH Fluid Cognition Total - β = −3.031, p = 0.241).

Table 4. Independent sample T-Tests results for cognitive measures.

Measure	p	Low NBS (M, SD)	High NBS (M, SD)
WAIS PSI⁺	<0.01**	114.11(15.04)	95.25 (11.10)
NIH⁺⁺ Oral Reading Recognition	0.721	58.11 (10.26)	56.73 (9.62)
NIH⁺⁺ Picture Vocabulary	0.324	53.72 (11.24)	57.82 (9.57)
NIH⁺⁺ Working Memory	0.044*	50.61 (9.04)	44.18 (5.60)
NIH⁺⁺ Processing Speed	0.261	54.00 (7.61)	48.27 (15.05)
NIH⁺⁺ Picture Sequence Memory	0.213	55.72 (14.66)	49.27 (10.29)
NIH⁺⁺ Flanker Inhibitory Control and Attention	0.325	43.67 (11.68)	39.36 (10.41)
NIH⁺⁺ Dimensional Change Card Sort	0.218	52.50 (12.95)	46.55 (11.22)
NIH⁺⁺ Cognition Fluid Total	0.033*	51.72 (10.30)	43.09 (9.57)
NIH⁺⁺ Cognition Crystallized Total	0.694	56.33 (11.51)	58.00 (9.30)
NIH⁺⁺ Cognition Early Childhood Total	0.118	51.94 (10.84)	47.27 (8.59)
NIH⁺⁺ Cognition Total	0.236	54.89 (8.09)	50.73 (9.56)
Sentence Comprehension⁺⁺⁺	0.067	19.25 (0.77)	18.63 (1.29)

Note. ⁺Missing WAIS PSI scores for one participant in the High NBS group; ⁺⁺missing NIH scores for two participants in the high NBS group ($n = 11$); ⁺⁺⁺ missing Sentence Comprehension scores for four participants (Low NBS $n = 16$, High NBS $n = 11$); NBS = neurobehavioral symptoms; M = mean; SD = standard deviation. Two-tailed tests were used for NIH and sentence comprehension analyses. Single tailed test was used for the WAIS. *Significant at the $p < 0.05$ **Significant at the $p < 0.01$.*

Table 5. Overall correlations between *Whatdunit* experimental task variables, NIH toolbox, WAIS, NSI, PSQI, and LCQ-30-S scores.

		1	2	3	4	5
1. Speeded Mean Interpretation RT	r	–				
	N	31				
2. Unspeeded Mean Interpretation RT	r	**.747****	–			
	p	0.000				
	N	31	31			
3. Speeded Accuracy	r	−0.279	**−.414***	–		
	p	0.129	0.020			
	N	31	31	31		
4. Unspeeded Accuracy	r	**−.387***	**−.509****	**.819****	–	
	p	0.031	0.003	0.000		
	N	31	31	31	31	
5. Baseline Mean Motor RT	r	0.131	0.262	−0.116	−0.200	–
	p	0.483	0.155	0.536	0.281	
	N	31	31	31	31	31
6. WAIS PSI	r	**−.518****	**−.581****	0.306	0.285	**−.435***
	p	0.003	0.001	0.100	0.127	0.016
	N	30	30	30	30	30
7. NIH Cognition Total Score	r	**−.531****	**−.584****	0.189	0.229	−0.360
	p	0.003	0.001	0.327	0.231	0.055
	N	29	29	29	29	29
8. NIH Working Memory	r	−0.325	−0.315	0.040	0.086	−0.126
	p	0.086	0.096	0.837	0.657	0.514
	N	29	29	29	29	29
9. NIH Fluid Cognition	r	−0.362	**−.490****	0.121	0.198	**−.414***
	p	0.054	0.007	0.530	0.304	0.026
	N	29	29	29	29	29
10.PSQI Total Score	r	0.121	0.098	−0.004	0.019	.597**
	p	0.518	0.598	0.982	0.921	0.000
	N	31	31	31	31	31
11. LCQ-30-S Total Score	r	0.058	0.215	0.040	−0.154	0.275
	p	0.757	0.247	0.830	0.408	0.135
	N	31	31	31	31	31
12. NSI Total Score	r	0.136	**.380***	−0.299	−0.265	**.495****
	p	0.464	0.035	0.102	0.150	0.005
	N	31	31	31	31	31
13. Years of Education	r	−0.314	−0.292	0.312	0.328	**−.358***
	p	0.086	0.110	0.088	0.072	0.048
	N	31	31	31	31	31

Note. ** Significant at the 0.01 level; * Significant at the 0.05 level.

Whatdunit language comprehension task accuracy and errors predictors

No relationship was observed between speeded or unspeeded accuracy and processing speed, NIH, communication ability, NBS scores or years of education. Since no differences between groups were observed, correlations for errors were not performed.

Discussion

The present study examined whether NBS levels influence language comprehension after mTBI, if cognitive skill and processing speed scores predict language comprehension response times and accuracy, and if variables like sleep quality and processing speed correlate with language comprehension. Outcomes are described below.

Descriptive measures

While no group differences were expected on the descriptive measures, the groups unexpectedly differed in the years of education completed. The low NBS group had more years of education compared to the high NBS group. A negative correlation between years of education and NSI Total score, but no other experimental variables of interest was observed. These results suggest that those with fewer years of education perceive more symptoms, which is consistent with studies showing lower education is associated with more symptoms (56). Future investigations may be warranted to determine the significance of this relationship.

Relationship between language comprehension task performance and processing speed in adults with high and low NBS

To determine the relationship between language comprehension, processing speed, and NBS, the *Whatdunit* was administered to measure baseline motor planning and execution and sentence interpretation RTs, accuracy for sentences from individuals with self-reported mTBI history and either high or low NBS. These hypotheses were partially supported, as described below.

Response times

Unexpectedly, motor planning and execution speed differed by group. The high NBS group had slower RTs, suggesting that motor planning and execution speed and NBS are associated. However, there is no causal relationship, and further research is needed to determine whether NBS directly influences baseline processing differences. Nevertheless, differences in the motor planning and execution speed highlight the importance of baseline adjustment when comparing sentence interpretation times across groups.

After baseline adjustment, group differences were observed in the unspeeded condition, with the high NBS group showing slower sentence interpretation of RTs than the low NBS group. Below are several explanations for the results.

One explanation is that the *Whatdunit* is more sensitive to certain cognitive processes under unspeeded conditions. Speeding up prioritizes quick and automatic responses and may mask subtle cognitive processing differences. However, it would be expected that those with mTBI would engage in a common cognitive strategy of trading accuracy for speed (57,58) due to their presumably limited cognitive capacity. Our lack of accuracy differences in the speeded condition does not support this explanation.

The most plausible explanation is that the high NBS group was more affected by the lack of a definite response window and clear expectations for performance, while the same participants in the speeded condition were not affected by this phenomenon because expectations were clearer. In the unspeeded condition, there was more flexibility, perhaps these participants are more vulnerable to the effects of their neurobehavioral symptoms (e.g., sleep and communication problems). Indeed, these same participants with high NBS reported significantly reduced sleep quality and communication (LCQ-30-S) abilities. It seems plausible that executive functioning or the set of higher-level cognitive processes that are needed to plan thoughts and actions were impacted by the unspeeded condition because altered executive function can follow mTBI (16,59,60). Additionally, it may be that self-perception alone influenced performance, where those who perceived themselves as having slow processing speed, went slower in the unspeeded condition. Importantly, the lack of NBS, as a significant predictor of unspeeded sentence interpretation RT weakens this argument because slow processing speed is included as NBS item in the NSI. However, the lack of significance may be partially attributed to a lack of power and high NBS variability in the NSI. Future targeted recruitment could address this issue.

Additionally, the results are consistent with the literature on speeded demands on human performance. Speeded tasks tend to increase cognitive load because the individual must engage in effective resource allocation, defined as ‘a person’s ability to divide mental resources between concurrent mental activities’ (61). In speeded tasks, the individual must complete the given task and moderate speed. As a result, weaker cognitive skills may not be engaged. Time is not constrained in unspeeded tasks, so even weaker cognitive resources can be engaged. As a result, the likelihood of a specific cognitive process of interest to be engaged and measured increases in the unspeeded task. Evidence showing that those with mTBI have reduced resource allocation abilities (24,62) supports this view. However, the lack of speeded condition group differences undermines this argument, as resource allocation challenges should have emerged under this condition. Perhaps, cohort differences or differences due to some but not all the NBS endorsed by the cohorts underly this inconsistency.

In summary, several explanations have been proposed for sentence interpretation RT group differences in unspeeded condition. Further research is needed to elucidate the underlying causes and mechanisms.

Accuracy and errors

No between-group difference in accuracy or number of speeded/unspeeded errors produced across the various sentence types was observed. Comparable accuracy suggests a ceiling effect, similar to that observed in an unimpaired sample of adults on the *Whatdunit* (34), and a more challenging task is needed to measure accuracy differences, which is supported by a similar study showing no group (mTBI/OI) difference in speeded/unspeeded accuracy using the *Whatdunit* (32).

Relationship between self-perceived and standardized variables and language comprehension in adults with high and low NBS

Relationship between language comprehension, sleep quality and general processing speed (WAIS PSI) and cognitive skills (NIH cognition total)

Our hypothesis that only sleep quality (PSQI) and general processing speed (WAIS PSI) and cognitive skills (NIH Cognition Total), variables would be related to language comprehension was partially supported. As expected, the high NBS group perceived poorer sleep quality compared to the low NBS group. However, PSQI scores were not associated with slower *Whatdunit* RTs or accuracy. PSQI scores positively correlated with and predicted baseline motor RTs only. The results indicate that poor sleep quality may affect non-linguistic processing speed during motor planning and execution but not higher-order cognitive processing during sentence interpretation.

Additionally, as expected, the high NBS group was slower compared to the low NBS group, as measured by the WAIS PSI. Our hypothesis that processing speed (WAIS PSI) would correlate with RTs, accuracy, and errors was partially supported. A negative relationship was found between speeded/unspeeded RT scores but not accuracy or error scores. This is somewhat consistent with previous research showing that *Whatdunit* RTs were strongly correlated with the WAIS PSI, suggesting that the two measures were concurrently valid (32).

Like the processing speed, cognitive skills speeded and unspeeded sentence interpretation times negatively correlated with cognitive scores (NIH Cognition Total Score), meaning those with slower or increased response times had lower overall cognitive scores. However, cognitive skills did not relate to accuracy or errors on the *Whatdunit*. Since *Whatdunit* is a relatively simple task, the lack of an association between processing speed and cognitive skills and accuracy and errors on the task could be due to adults performing at or near ceiling in the present study.

Unexpected group differences on other measures: working memory, fluid cognition, and perceived communication abilities

Contrary to expectations, the groups differed on three additional measures of working memory, fluid cognition, and perceived communication abilities. Interpretations of the exploratory analyses listed below should be considered with caution. Future studies may be warranted to confirm and explore the underlying mechanisms of these differences.

Working memory (WM). Working memory (WM) is a cognitive system used to hold and manipulate information needed in various tasks (63). We observed that the high symptom group had lower WM scores, indicative of reduced WM, than the low symptom group. Hence, NBS could be associated with poor working memory deficits. Although WM deficits might be related to NBS, the effect on sentence interpretation speed or non-verbal processing speed is likely indirect, as WM scores did not correlate with RTs, accuracy, or errors. Results may also suggest that targeted WM interventions could help those with a high NBS, but WM improvements may not necessarily improve language comprehension. Several factors may have contributed to the lack of association, such as the small sample size or participants using compensatory strategies, like context cues or prior knowledge to comprehend or engage cognitive processes that minimize the influence of WM.

NIH fluid cognition total score. It was not anticipated that high NBS groups would have lower NIH Fluid cognition total scores than low NBS groups. Since WM task scores are included in the calculation of this composite score, the difference may reflect the WM difference. A post-hoc correlation analysis showed that NIH Fluid cognition scores negatively correlated with unspeeded RTs but not speeded RTs or accuracy, perhaps to suggest that the unspeeded task engages cognitive skills that are fluid or changing over the lifespan. No further analyses were conducted to investigate this relationship, as it was not expected, and prior hypotheses were not established.

Perceived communication abilities. The high NBS group perceived more communication problems than the low NBS group. These results are consistent with a study that used the LCQ-30-S to investigate language problems and showed those with mTBI history reported more communication problems compared to non-injured control and chronic mixed severity TBI groups (64). A post-hoc correlation analysis, however, showed no significant relationship between *Whatdunit* RTs, accuracy, or errors.

Limitations and future directions

This study has several limitations. First, the sample size was small, which can be attributed to several factors, such as strict inclusion criteria, limited public knowledge about concussions/mTBI, and a short recruitment and enrollment period. Second, causality cannot be established due to the cross-sectional design. Future large-scale prospective studies are needed to build more reliable predictive models. Longitudinal study designs may also be advantageous, as individuals could serve as their own controls to avoid confounds, and the impact of NBS on language performance over time could be explored. Third, the lack of a control group may also be considered a limitation since some studies have shown that reported symptoms do not correlate with neuropsychological performance (65) and may not be specific to mTBI. However, the use of a control group with similar post-concussion symptoms independent of confounding symptoms of depression, sleep quality, and anxiety showed that those with mTBI had reduced cognitive performance, which to some extent was an effect of the brain injury history itself (32). Fourth, this exploratory pilot study assessed many variables. Future studies can be strengthened by assessing key covariates, as identified in the present study. One variable that was not directly assessed in the present study that can influence cognition and language is pain. Future studies should consider exploring the relationship to pain and complex cognitive processes like language comprehension. Fifth, NBS measured using the NSI is subject to individual biases of overreporting or underreporting of symptoms, reliance on retrospective memory, and overestimation of pre- to post-injury function (66,67). Participant selection based on self-perception of TBI history and mild severity without hospital records or equivalent confirmation has similar limitations as the NSI, as reliance on retrospective memory and perceived function prior to and post injury make it difficult to attribute observed differences directly to long-term effects of mTBI. However, this sampling method is valuable. It is estimated that 50.4% of adults with concussion do not report to healthcare providers for medical care (52). Therefore, this approach enabled data collection from individuals who are largely underrepresented in mTBI research community-dwelling adults with mTBI history who did not seek clinical care at the time of injury. Sixth, personal factors (e.g., personality traits and pessimism) were also not considered. However, personal factors alone do not seem to contribute to persistent symptoms (68). The experimental design may also be improved via a modification to the verbal task instructions. Specifically, the unspeeded condition instructions could be improved by instructing participants to 'perform the task at a pace that is comfortable and natural for them.' This adjustment would ensure that time, an important variable of interest, is not de-emphasized and would clarify task expectations. As a further enhancement, sentences could be presented unspeeded at the average comprehension rate for those with mTBI history, then speeded at a faster rate than average. However, many more studies would be required to establish the proper presentation rates. Finally, ecological validity is limited. Future studies should incorporate language tasks more closely resembling naturalistic environments, including conversational tasks to emulate real-world communication demands.

Implications

Communication disorders, like reduced language comprehension skills, are often understudied and under-evaluated in the clinical setting, and place individuals with mTBI at risk for poor social, vocational, and educational outcomes.

Precise measurement of communication skills should be combined with a careful review of symptoms in the follow-up care of adults with mTBI to improve long-term outcomes after injury. This study underscores the importance of monitoring symptomatology and detecting language comprehension impairments even in adults with mTBI. Since the ability to think and communicate effectively often forms the foundation of successful community reentry such as return to work, school, and social activities, optimization of cognitive-linguistic assessment post-mTBI is imperative. The present study results uniquely suggest NBS severity correlates with linguistic impairment. This finding offers the potential to use NBS as an early indicator of language therapy needs and can help shape follow-up care, treatment strategies, and support mechanisms, all of which may lead to faster recovery, social reintegration, and work resumption. However, this relationship must be replicated with larger, more diverse samples, possibly in a longitudinal design.

In the interim, perhaps clinical resources should be allocated to managing symptoms and identifying patients at high risk for prolonged symptomatology. Since the present study suggests individuals that perceive themselves as having high NBS and slow processing speed may also experience reduced language comprehension skills post-injury, individuals with mTBI history may initiate this interim identification process, and empathetic medical and therapeutic providers may validate it. In sum, these results highlight the importance of empowering individuals with mTBI history to share their lived experiences with healthcare providers, validating their self-awareness, and underscore the importance of involving individuals with mTBI in assessing and intervening in language comprehension disorders after mTBI. The results also uniquely suggest that future language comprehension research and therapy sessions post-mTBI should consider using more naturalistic response time windows when administering language comprehension tasks to train individuals to comprehend faster. Methodological approaches like conversational analysis, may also be useful as they may reveal subtle differences in language comprehension and aid researchers to better understand how these differences impact communication competence.

Conclusions

The hypothesis that participants in the high NBS group would show decreased language comprehension performance was partially supported. Those with high NBS had slower RTs compared to the low NBS group, in the unspeeded condition only. The results suggest that secondary symptoms influence language comprehension performance in more naturalistic, self-paced conditions versus conditions requiring speeded language comprehension. Overall, the current study fills a critical research gap in understanding how symptoms relate to language comprehension, clinical treatment, and future research. Specifically, the study shows that NBS should be considered alongside any objective measurement of language comprehension post-mTBI and that customized strategies for those with high NBS symptoms and additional research in the area are needed.

Author contributions

Conceptualization, R.S.N.; G.F. and S.C.; methodology, T.G.F, R.S.N., T.R.; formal analysis, T.G.F & R.S.N.; resources, R.S.N.; writing – original draft preparation, T.G.F, R.S.N., G.F. and S.C.; writing – review and editing, T.G.F, R.S.N, T.R.; visualization, T.G.F.; supervision, R.S.N; project administration, R.S.N.; funding acquisition, R.S.N. All authors have read and agreed to the published version of the manuscript.

Data availability statement

Data used in the analysis can be made available through request to the corresponding author.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendices

Appendix A1. Example Whatdunit Task Sentences

Below are example sentences that vary in syntactic complexity from the *Whatdunit* task (Montgomery et al., 2016) reprinted with permission.

Subject–Verb–Object
The hat had hugged the belt behind the very bright new sock.
The ring had moved the square behind the very bright cold bed.
The square had changed the bed under the very new dry key.
The shoe had bumped the fork near the very bright new wheel.
The knife had watched the ball near the very bright hot square.
Subject Relative
The watch that had hugged the truck behind the kite was bright.
The train that had helped the knife under the square was cold.
The boot that had fixed the shoe behind the drum was new.
The cake that had cleaned the bed near the train was bright.
The spoon that had licked the book near the watch was bright.
Passive
The train was watched by the bed behind the very cold cake.
The watch was bumped by the wheel near the very bright clock.
The key was changed by the chair behind the very bright square.
The belt was pulled by the book near the very new bowl.
The clock was rubbed by the shirt behind the very new door.
Object Relative
The box that the kite had splashed behind the shoe was dry.
The truck that the clock had pressed near the door was bright.
The chair that the bread had splashed under the square was new.
The kite that the dress had pressed near the book was hot.
The watch that the sock had wiped near the shirt was dry.

Appendix A2. Independent Sample t-test results for uncorrected Whatdunit RTs

The high NBS group showed slower uncorrected *Whatdunit* RTs in the speeded and unspeeded conditions, compared to the low NBS group.

	p	Low NBS (n = 18) M (SD)	High NBS (n = 13) M (SD)
Experimental Tasks			
Mean Uncorrected RT++ speeded	0.027*	1058.09 (316.76)	1388.93 (511.35)
Mean Uncorrected RT++ unspeeded	0.014*	1268.38 (625.78)	2082.66 (1095.10)

++Uncorrected RT is the raw *Whatdunit Sentence Task* without the Baseline Motor Task subtraction, meaning these RTs contain motor planning, execution, and sentence interpretation speed during sentence comprehension.

Appendix A3. Overall Correlation Plots for Linear Regression Predictive Factors