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Research Article

Enduring Cognitive and Linguistic Deficits in Individuals With a History of Concussion

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Purpose: The purpose of this research is to determine whether individuals with a history of concussion retain enduring differences in narrative writing tasks, which necessitate rapid and complex integration of both cognitive and linguistic faculties.
Method: Participants aged 12–40 years old, who did or did not have a remote history of concussion, were recruited to take an online survey that included writing both a familiar and a novel narrative. They also were asked to complete multiple tasks targeting word-level and domain general cognitive skills, so that their performance could be interpreted across these dimensions.
Results: Participants with a concussion history were largely similar to participants with no history of brain injury across tasks that targeted a single skill in isolation. However, participants with prior concussions demonstrated difficulty in providing both key content and details when presented with a novel video and asked to provide a summary of what they had just seen. Number of lifetime concussions predicted the inclusion of key content when summarizing the video. Thus, differences in cognitive and linguistic skills required for written narrative language may continue to be present far after concussion, despite average normative levels of performance on tasks targeting these skills in isolation.
Conclusions: These findings suggest that individuals with a concussion history, particularly a history of multiple concussions, may continue to experience difficulties for a long period after injury and are likely to benefit from more complex and ecologically valid assessment prior to discharge. Individuals with a concussion history who return to full participation in work, school, and recreational activities may continue to benefit from assistance when asked to rapidly acquire and distill novel information, as is often required in academic and professional environments.

Concussion injury, the mildest and most common form of mild traumatic brain injury (mTBI; National Center for Injury Prevention and Control, 2003),[1] frequently results in patients who describe difficulties in daily situations and conversations and overall "fogginess" (Crewe-Brown, Stipinovich, & Zsilavecz, 2011; Kontos et al., 2012), but said deficits are not captured consistently on traditional assessments of language. Language is one domain in which a deficit can have particularly far-reaching ramifications, including difficulties in school and work and in maintaining relationships (Catale, Marique, Closset, & Meulemans, 2009; Ewing-Cobbs et al., 1997; Fay et al., 2010). Despite the importance of written communication—especially in the age of social media—the majority of what is known about language following mTBI is based on oral language (Salvatore & Fjordbak, 2011).

Language deficits have been observed immediately following mTBI. Most commonly, these have included lexical deficits in naming (Barnes, Dennis, & Wilkinson, 1999; Ewing-Cobbs & Barnes, 2002; K. A. King, Hough, Walker, Rastatter, & Holbert, 2006; Shaffer, Bijur, Chadwick, & Rutter, 1980; Stockbridge, Doran, King, & Newman, 2018; Wrightson, McGinn, & Gronwall, 1995) and verbal fluency for both semantic categories (Ewing-Cobbs, Levin, Eisenberg, & Fletcher, 1987; McCauley et al., 2014) and phonemes (Stockbridge & Newman, 2018). Deficits also have been observed in repeating sentences aloud, writing sentences in response to dictation (Ewing-Cobbs & Barnes, 2002; Ewing-Cobbs et al., 1987), providing transitions between topics, using clear referents (Biddle, McCabe, & Bliss, 1996; Chapman et al., 1992; Ewing-Cobbs, Brookshire, Scott, &

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[1]While some disciplines consider the terms *concussion* and *mild TBI* to be synonymous, our work follows the approach that the two terms refer to different injury constructs (McCrory et al., 2013), as this traditional distinction seemed most likely to map onto the usage by individuals asked to self-report their injury history.

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Fletcher, 1998), story grammar (i.e., the pattern of introduction, rising and falling action or conflict, and resolution, present in typical descriptions of events), and cohesion (Galetto, Andreetta, Zettin, & Marini, 2013; Marini et al., 2011; Stockbridge & Newman, 2018; Tucker & Hanlon, 1998). Recent and emerging evidence from concussion alone (as compared to mTBI more broadly) has, understandably, provided a more nuanced and inconsistent account of these effects, particularly with regard to deficits in more complex linguistic performance (e.g., Harvey, 2016; Kovach, 2015). Auditory processing of language, including both speech perception in quiet and in noise, recently has garnered interest as an underlying deficit impacting language skills following injury (Hoover, Souza, & Gallun, 2017; Thompson et al., 2018; Turgeon, Champoux, Lepore, Leclerc, & Ellemberg, 2011; Vander Werff & Rieger, 2017). However, the varied deficits observed following concussion generally are thought to improve with time and are often presumed to dissipate entirely after sufficient healing has occurred (McCrea et al., 2003; McCrory et al., 2013).

Deficits that appear to be domain specific to language may reflect an interaction with depressed cognitive abilities, such as deficits in delayed recall, working memory, attention, and executive function (Bialunska & Salvatore, 2017; Blanchet, Paradis-Giroux, Pépin, & Mckerral, 2009; Borgaro, Prigatano, Kwasnica, & Rexer, 2003; Ewing-Cobbs et al., 1998; Green, Keightley, Lobaugh, Dawson, & Mihailidis, 2018; McInnes, Friesen, MacKenzie, Westwood, & Boe, 2017; Petley et al., 2018; Rabinowitz & Levin, 2014), even when these broader cognitive differences remain within the normal range (Wäljas et al., 2014). Deficits in attention, information processing, fluency, and memory acquisition and recall are observed more frequently as task demands increase (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005; Belanger & Vanderploeg, 2005; Bohnen, Jolles, & Twijnstra, 1992; Gentilini et al., 1985; Leininger, Gramling, Farrell, Kreutzer, & Peck, 1990; MacFlynn, Montgomery, Fenton, & Rutherford, 1984), suggesting the possibility that a reduction in overall cognitive resources or efficiency in processing (productivity over time with minimum wasted effort) may explain concussion effects. Adding to this overall profile, slowed information processing is a classic observation following mTBI (Babikian & Asarnow, 2009; Tromp & Mulder, 1991) that has garnered increased attention in recent years (Fueger, 2017; Gagnon, Swaine, Friedman, & Forget, 2004) due to observable effects long after the mildest injuries. Mild deficits in problem solving, executive function, and delayed recall have been observed in adults with mTBI as long as 2 years after injury (Galetto et al., 2013). More sensitive measures related to how an individual processes information, rather than task accuracy, may capture a richer array of cognitive changes from mTBIs. Poor cognitive efficiency would lead to greater difficulty as task demands increase and would impact multifaceted tasks more significantly than simple ones (Norman, 2017; Whiteside et al., 2016). That is, the individual may have no apparent difficulty with simpler tasks (e.g., word reading in isolation), but significant difficulty in more complex contexts (e.g., word reading in a paragraph). We do not know the extent to which such nonlinear effects are present in concussion, rather than mTBI more broadly.

Neuropsychological tools for assessing concussion typically combine an array of simple, focused tasks (e.g., the ImPACT). When individuals achieve their pre-injury baseline performance (or an average normative performance), in the absence of a prohibitive increase in somatic symptoms when returning to full participation in daily activities, they frequently are discharged from concussion management (e.g., Doolan, Day, Maerlender, Goforth, & Brolinson, 2012; Lovell, Collins, & Bradley, 2004). Generally, this threshold is met within a few months, though 3 months frequently is cited as the threshold before a diagnosis of *postconcussion syndrome,* the label given to somatic symptoms persisting beyond the typical window of recovery in a small proportion of individuals who experience a concussion (Bernard, Ponsford, McKinlay, McKenzie, & Krieser, 2017; McInnes et al., 2017).

Yet, in clinical experience and in the literature, it is clear that many individuals report that, despite having putatively returned to baseline performance, they still perceive themselves as having greater difficulty in cognitive and linguistic tasks than they did prior to their concussion injury (Sandel, Lovell, Kegel, Collins, & Kontos, 2013). This is particularly true among individuals who have experienced multiple concussions over their lifetime (National Research Council, Institute of Medicine, Board on Children, Youth, and Families, Committee on Sports-Related Concussions in Youth, 2014). Repeated injuries frequently are experienced in the context of sports and recreation participation (Giza et al., 2013), and the younger a child is when he or she experiences the first concussion, the more concussions that individual is likely to experience in his or her lifetime (Schmidt et al., 2018). Sustaining more than one concussion, even when events occur many years apart, has been shown to result in increased impairment in cognition (Karr, Areshenkoff, & Garcia-Barrera, 2014) and spatial learning (Dashnaw, Petraglia, & Bailes, 2012) compared to a single injury. Multiple-impact exposure is a risk factor for neurodegenerative diseases, such as dementia and parkinsonism (Martland, 1928; McMillan et al., 2017; Rabadi & Jordan, 2001; D. H. Smith, Johnson, & Stewart, 2013), which carry complementary risk factors in mental health (Chrisman & Richardson, 2014; Cole & Bailie, 2016; Cummings & Masterman, 1999; Didehbani, Munro Cullum, Mansinghani, Conover, & Hart, 2013; Guskiewicz et al., 2007; Menza, Robertson-Hoffman, & Bonapace, 1993; Nuti et al., 2004; Seignourel, Kunik, Snow, Wilson, & Stanley, 2008). As individuals are exposed to concussions and subconcussive impacts for longer periods, spoken linguistic complexity decreases (Berisha, Wang, LaCross, Liss, & Garcia-Filion, 2017), whether or not a given impact meets a somewhat arbitrary threshold for definition as a concussion (Moore, Lepine, & Ellemberg, 2017).

The current study examines whether narrative performance differs in those who have experienced one or more concussions in their remote past. While individuals with a history of concussion typically can match their pre-injury performance at the time of discharge when completing simple cognitive or linguistic tasks targeting a single skill, do they demonstrate observable persisting differences in complex written narrative language tasks that require the integration of multiple skills? We hypothesize that individuals with a concussion history will show poor cognitive efficiency, leading to greater difficulties as task demands increase. In the domain of language, this leads to the prediction that larger units of language, such as narrative or expository language samples, should be more difficult for individuals with persisting deficits. This increased difficulty is perhaps further compounded by the interconnected nature of language as it increases in scale. Narratives demand local and distal relationships both among sentence forms and across content (Glosser & Deser, 1992; Hudson & Shapiro, 1991), placing a greater demand on resources. Narrative samples are unique in anticipating a specific structure ("story grammar"). A narrative, based on a sentence prompt or a wordless book or video, provides an opportunity for assessing spontaneous language production while still controlling the individual's produced language with specific expected content. If deficits are observed when these more complex tasks are attempted, this would provide validation for individuals' enduring complaints of difficulty in complex real-world activities beyond discharge from concussion management. Such knowledge could be applied to ongoing research and individualized medical, professional, and educational management of these individuals.

Method

Participants

All data were collected remotely through online surveys managed via the Qualtrics experience management software tools. Individuals aged 12–40 years with a history of concussion (but without recent concussion), as well as those with no concussion history, were recruited via social media, clinician referral, use of the on-campus database of University of Maryland Psychology undergraduate students (Sona Systems), public advertisements, and notices. This range of ages was selected to include adolescence, the period in which the highest incidence of concussion occurs (Thurman, Branche, & Sniezek, 1998), and to extend into adulthood to account for the possibility of months or years between concussion events and testing. Although this window was established for recruitment, the age ranges in the two groups differed slightly, with individuals who had a concussion history trending older (see Table 1). While prior studies operationalized concussion recency at various points (e.g., under 10, 14, and 30 days; McCrory et al., 2013; Meier et al., 2015; Putukian, Aubry, & McCrory, 2009), a more protracted window of 50 days was selected in light of increasing evidence of continued cognitive deficits beyond these time frames (Howell, Osternig, & Chou, 2018; McInnes et al., 2017). Thus, individuals with a history of concussion had their most recent injury at minimum nearly 2 months prior to testing.

Based on reported medical histories, individuals with pervasive developmental disorders, developmental cognitive processing disorders (i.e., disorders of attention, memory, or executive function), developmental language disorders, language delay, fluency disorders, speech and articulation disorders, auditory processing disorders, and diagnosed deficits in literacy were excluded from both groups. The exception was that participants were retained if their sole diagnosis was a history of attention-deficit disorder (ADD)/attention-deficit/hyperactivity disorder (ADHD) because of concerns that this disorder is likely to have been overly diagnosed at the time when many of the participants were children and adolescents (Angold, Erkanli, Egger, & Costello, 2000; International Narcotics Control Board, 1998); as such, excluding those with an ADD/ADHD diagnosis might have resulted in an overly restrictive (and nonrepresentative) subject population. Participants were also excluded if they had a history of neurological disorders (past severe brain injury, neurosurgery, or radiation therapy), if they did not report normal or corrected-to-normal hearing and vision, or if English was not their reported primary language (minimum of 80% exposure to English reported in the home).

Between 2017 and spring of 2018, 137 individuals responded to the study by visiting the website and completing at least one experimental task. Of these, seven were excluded due to being outside the recruitment age range (12–40 years); 29 were excluded due to reported English exposure lower than 80% or prior diagnoses of learning, speech, language, reading, or fluency disorders; and nine individuals were excluded from analysis due to a reported neurological history significant for events more severe than concussion (e.g., tumors, cancer, severe brain injury). Following the application of the exclusion criteria, 92 participants remained: 11 individuals with recent concussion (addressed in Stockbridge, 2018), 23 individuals with no history of head injury, and 58 individuals with a history of at least one concussion or mild head injury but no injury within the last 50 days. Among those with a history of concussion, participants reported an average of just under three concussions in their lifetime (M = 2.76, SD = 3.11, range: 1–20 concussions), with the most recent nearly 5 years previous. Participants were not asked to estimate dates of historical concussions beyond the most recent concussion due to concerns that these estimates would be unreliable (Gabbe, Finch, Bennell, & Wajswelner, 2003). Thus, it is not possible within this data set to determine the extent to which concussions reported by individuals of any age occurred in their childhood versus their adulthood. Group characteristics are summarized in Table 1. Detailed comparisons of the two groups can be found in the results.

Procedure

Data were collected via online survey in order to minimize barriers to participation for individuals experiencing

Table 1. Group characteristics.

Variable	Concussion	No concussion	Test statistics
n	58	23	
Age, *M* (*SD*)	29.89 (7.36)	23.75 (7.21)	$t(79) = 3.024$, $p = .003$*
Range	17.43–40.32	12.27–38.12	
Proportion of males	0.17	0.22	$p = .752$
Most recent concussion	4.80 (6.54) years		
Total concussions	2.76 (3.11)		
Self-report ratings			
Symptom score	25.86 (20.95)	10.52 (12.40)	$U = 311.50$, $z = –3.73$, $p < .001$*, $r = –.41$
Cognitive change	2.83 (0.76)		
Sleep behavior			
Sleepiness Scale	14.58 (3.64)	14.50 (6.39)	$U = 212.50$, $z = –0.86$, $p = .397$
Sleep/Wake Problems Behavior Scale	20.19 (6.70)	19.57 (6.07)	$U = 240.50$, $z = –0.25$, $p = .810$

Note. Statistics are reported as mean (standard deviation) where applicable. Test statistics refer to independent-samples *t* tests in all cases of continuous data, Mann–Whitney *U* tests when data were ordinal, and Fisher's exact test between gender proportions. Symptom score (adapted minimally from the Rivermead Post Concussion Symptoms Questionnaire by HeadFirst Concussion Care Centers; N. S. King et al., 1995): Participants rated the severity of 18 somatic symptoms within the 24 hr prior to testing on a scale of 0–6, with 6 being the *most severe* (maximum score of 108). Cognitive change: Participants rated three questions commonly used in concussion care on a scale developed for this study: (a) Has your ability to focus changed since the injury? (b) Has your mood changed since the injury? (c) Has your ability to complete tasks (e.g., make a sandwich, get ready to go out, finish homework) changed? Each of these questions was rated on a 4-point scale of *improved, stayed the same, gotten worse,* and *gotten much worse*. Ratings were averaged to quantify overall perceived change. Sleepiness Scale (Wolfson & Carskadon, 1998): Scale developed to target daytime sleepiness, commonly reported in concussion. Participants rate the presence and frequency of sleepiness during 10 daytime activities on a 4-point scale of *none* to *both struggled to stay awake and fallen asleep* (maximum score of 40). Sleep/Wake Problems Behavior Scale (Wolfson & Carskadon, 1998): Scale developed to target sleep disturbance. Participants rate the presence and frequency of 15 common disrupted sleep experiences on a 5-point scale of *never* to *every day/night* (maximum score of 75).

*$p < .05$.

symptoms that would preclude travel and to attracta more diverse sampling of the population than those typically inclined to travel to participate in unpaid behavioral research. While methods of remote behavioral data collection are still relatively new, they are becoming increasingly common (Barak & English, 2002; Buchanan, Johnson, & Goldberg, 2005; Chuah, Drasgow, & Roberts, 2006; Illingworth, Morelli, Scott, & Boyd, 2015; Templer & Lange, 2008) and have even included the use of self-reported linguistic behaviors (James, Brumfitt, & Cowell, 2009) in adults and teens with concussion (Lewandowski, Rieger, Smyth, Perry, & Gathje, 2009). While remote data collection improves the capacity for representative sampling, it is associated with increased variability in participation across tasks, as individuals participating remotely more frequently skip tasks or prematurely discontinue participation in comparison to individuals who are physically present in the laboratory. Despite this, crowdsourced remote online data collection platforms, such as Amazon's Mechanical Turk, have been thoroughly investigated for validity of use in behavioral sciences, and prior studies have found that differences in attention and distraction have little effect on data quality (Chandler, Mueller, & Paolacci, 2014; Chandler & Shapiro, 2016; Paolacci, Chandler, & Ipeirotis, 2010). More directly of concern in this study, samples from these platforms are consistently found to have similar or improved scale reliability, as well as concurrent and convergent validity over other samples, including in-person samples (Behrend, Sharek, Meade, & Wiebe, 2011), leading to these data collection methods becoming increasingly recognized as valuable tools for clinical research (Chandler & Shapiro, 2016). Participants were only excluded if they provided too little information for their data to be analyzed; partially completed entries were retained so long as they appeared to be attempted in good faith (i.e., responses relevant to the questions being asked). As a result, participant counts (*n*) are included in the statistical reporting for all tasks that were not completed by all participants.

Participants completed a combination of traditional standardized assessments of language and cognition (see Table 2). Self-reported health history included head injury history, orthopedic injury history, history of developmental cognitive or linguistic diagnoses, and self-reported ratings of both somatic symptoms (adapted minimally from the Rivermead Post Concussion Symptoms Questionnaire by HeadFirst Concussion Care Centers; N. S. King, Crawford, Wenden, Moss, & Wade, 1995) and cognitive changes. Participants rated the severity of 18 somatic symptoms within the 24 hr prior to testing on a scale of 0–6, with 6 being the *most severe* (maximum score of 108). Perceived changes to cognition were rated across three questions commonly used in concussion care: (a) Has your ability to focus changed since the injury? (b) Has your mood changed since the injury? (c) Has your ability to complete tasks (e.g., make a sandwich, get ready to go out, finish homework) changed? Each of these questions was rated on a 4-point scale of *improved, stayed the same, gotten worse*, and *gotten much worse*. The health history questionnaire also provided multiple opportunities for participants to report relevant cognitive or linguistic diagnoses not specified.

Table 2. Experimental, health-related, and cognitive–linguistic tasks completed by the participants.

Task	Description
Experimental tasks	
Structured narrative task based on familiar images	Participants viewed illustrations of Disney's *Cinderella* embedded in Qualtrics and told the story of the images while being able to view them by typing in a recorded textbox (5 min maximum)
Structured narrative task based on provided video	Participants watched *Pigeon: Impossible* embedded in Qualtrics and subsequently told the story of the video they just watched using a recorded textbox (5 min maximum)
Letter fluency (FAS) task (Slomine et al., 2002)	Examines verbal fluency and divergent/nonlinear cognitive–linguistic reasoning
Naming task	Examines confrontation naming based on written descriptions
Health information	
Brief health questionnaire	Basic health history and concussion history information
Sleepiness Scale (Wolfson & Carskadon, 1998)	Examines daytime sleepiness, commonly reported in concussion
Sleep/Wake Problems Behavior Scale (Wolfson & Carskadon, 1998)	Examines sleep disturbance
Big Five Inventory–Second Edition Neuroticism/Negative emotionality (Soto & John, 2017)	Measures of personality dimensions
State–Trait Anxiety Inventory (Spielberger et al., 1983)	Measures of self-reported state and trait anxiety
Multidimensional Scale of Perceived Social Support (Bruwer et al., 2008; Zimet et al., 1990)	Measures of perceived support
Brief Adolescent Life Event Scale (Shahar et al., 2003)	Determines presence of stressful events in recent past
Cognitive–linguistic data	
Digit span task (Backward only; McCrea, 2001)	Tests immediate and working memory
Flanker task (Levin et al., 2004; Mayr et al., 2003) via PsyToolkit (Stoet, 2016)	Tests response inhibition associated with executive control
Spot the difference task (Nishiguchi et al., 2015)	Tests visual processing

Participants were further asked to complete a number of questionnaires and assessment tools targeting personality, temperament, and social support, in consideration of the broader mental health implications of repeated impacts and persisting complaints following injury. These included the Big Five Inventory–Second Edition (BFI-2; Negative Emotionality items only; Soto & John, 2017), State–Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), Brief Adolescent Life Events Scale (only the Negative Events Index was used; Shahar, Henrich, Reiner, & Little, 2003), and Multidimensional Scale of Perceived Social Support (Bruwer, Emsley, Kidd, Lochner, & Seedat, 2008; Zimet, Powell, Farley, Werkman, & Berkoff, 1990).

Finally, they were asked to produce two written narrative language samples: a retelling of the classic story of *Cinderella* (accompanied by pictures of key events) and a retelling of a short video (*Pigeon: Impossible*) immediately after watching it. In the *Cinderella* task, participants reviewed 19 pictures from the familiar story of *Cinderella* individually and wrote the story while able to view the images. In the *Pigeon: Impossible* task, participants viewed a short, animated, wordless video and then wrote a summary. Participants had 5 min to complete each narrative task.

Developing a Scoring Rubric for the Narratives

The story grammar of each of the two structured narratives was analyzed. Story grammar refers to the features that all stories include, which build the course of events in time in a described context (Roth & Spekman, 1986). Thus, in order to evaluate participants' story grammar, we first needed to identify what were the important events (or propositions) that took place. The story grammar for *Cinderella*[2] included 41 previously established propositions from Stark (2010), based on the schematic structure put forth by Labov and Waletzky (2003). Of these 41 propositions, 23 previously were identified as the "constituent events," those considered to be crucial for the (re)telling of this fairy tale (Stark, 2010). A standard story grammar for the video *Pigeon: Impossible* was constructed in parallel to the process Stark (2010) reported using to generate the existing *Cinderella* story grammar. Stark stated that independent participants were asked to "analyze the list of propositions and to determine which propositions were necessary for a summary narration of the fairy tale Cinderella. On a second pass, the participants were asked to slim down their initial selection to the most essential, indispensable propositions. Those propositions agreed upon by (almost) all evaluators in this second-pass analysis are considered to be the constituent events." Using the same approach, 12 native English, healthy

[2]Although retelling *Cinderella* is very common in language research, studies vary in the visual stimuli utilized to assist participants in telling the story. The two most common stimulus sets are the Disney imagery available through the AphasiaBank protocol (https://aphasia.talkbank.org/protocol/pictures/Cinderella-book.pdf) and those used in the original Grimm story. While the two versions of the story and their images vary slightly, the key features of the narrative are consistent. Here, the Disney images available from the AphasiaBank protocol were used, as these were the ones most familiar to participants and the ones consistent with the previously published story grammar employed here (Stark, 2010).

university students (not participants in the study) were asked to analyze the video and identify a minimal list of events necessary to a summary of the video from the propositions. They identified a total of 42 propositions. These 12 individuals were then brought back several weeks later and asked to evaluate the combined list of propositions and identify those that were most essential to the story. A total of 20 minimally necessary "constituent events" were identified by the raters based on consensus. As in Stark (2010), there were a few cases within the setting/orientation and coda conditions (how the story was introduced and concluded) when the raters disagreed in terms of which propositions were most critical; we then considered these sets as acceptable alternatives (i.e., we would expect all participants to give at least one of these alternative propositions, but not necessarily the same one). The two scoring rubrics are available from the corresponding author.

Narrative Ratings and Analysis

For both *Cinderella* and *Pigeon: Impossible,* study participants' narratives were de-identified (thus, scorers were blind to group status, age, gender, etc.) and examined for inclusion of story grammar propositions. Only factually correct propositions were scored; incorrect statements (e.g., "The pigeon launched a missile to Russia.") were ignored. Propositional content could occur in any order, as long as the logical order of events remained intact. Two individual scorers (the first author and another researcher) each evaluated all of the narratives independently. Interrater agreement was quite high: 91.8% for *Cinderella* and 92.3% for *Pigeon: Impossible.*

Story grammars generally include seven components or episodes that are presented in a canonical order: the setting, initiating events, response, plan, attempt, direct consequence, and reaction. While this study did not include any planned comparisons specifically addressing episodic structure, exploratory analyses of this dimension of performance were conducted. Episodic contents for each narrative are described in greater detail in the context of group performance reported in the results.

Analysis of structural length and complexity of the language samples was carried out using tools developed by the CHILDES project (MacWhinney, 2000). Analyses included measures of total utterances, mean length of utterance in morphemes, vocabulary diversity, and clausal density (estimated by verbs per sentence). Another potential indicator of underlying deficits emerging under increasing demands would be the use of more general or empty words (e.g., general all-purpose [GAP] verbs) in written text. Frequent use of GAP verbs is often seen in individuals suspected of language deficits (Thordardottir, Ellis, & Weismer, 2001). Overreliance on high-frequency, underspecified nouns and verbs in language can be another signal that an individual is experiencing word-finding difficulties, even when verbal fluency targeted task performance is typical. Other words are underspecified in a given context. For example, in *Pigeon: Impossible,* the story is clearly set in Washington, DC, and the missile is heading toward Moscow, Russia. So, if an individual described the story as taking place in a city, that would be omitting or underspecifying the setting based on the information given. Ten words were identified for each of the three types of underspecified words listed in Table 3. GAP words were identified from the study of Thordardottir, Ellis, and Weismer (2001) and narrowed down through examination of the GAP words found across participants in the sample.

The written samples were minimally edited for orthography-specific error types prior to calculating language measures in order to facilitate analysis with tools intended for spoken language (samples in original and edited form are available from the corresponding author). Clear typographical spelling (e.g., *slepe for "sleep") and orthographically identified usage errors (e.g., "they're" for "there") were corrected. Incomplete sentences at the end of the sample, suggesting the time had run out midsentence, were edited in order to preserve the greatest amount of correctly formed independent clauses (e.g., "In her haste, the girl loses a slipper that the princes servants show around and" would be edited to "In her haste, the girl loses a slipper that the princes servants show around"). To our surprise, a number of the participants wrote out comments to the experimenter despite the indirect and remote nature of the data collection (e.g., "I know this is Cinderella."; "I really have nothing else to say but I still have 45 seconds left. I'm just letting time run out now."; "Can I just call her Cinderella?"). These were left in for the purposes of this analysis in order to retain the largest sample of language possible, as is common clinical practice in spoken language sampling.

Statistical Analyses

Given the large number of independent and dependent variables being collected in this study, it is important to note that steps were taken to address multiple comparisons and resultant increases in Type I and Type II error. Care was taken to limit exploration of less robust signals in the present investigation in the absence of significant findings in omnibus analyses of variance tests. Following this process, a sequentially rejective multiple test procedure

Table 3. Underspecified or overly general words.

Universally general	GAP verbs	Contextually underspecified
thing	go	person
things	have	place
stuff	get	lady
some	know	ride
something	say	shoe
somehow	put	guy
someone	come	bird
whenever	take	breakfast
whatever	try	weapon
whoever	make	city

Note. GAP = general all-purpose.

was used (Bretz, Maurer, Brannath, & Posch, 2009). Moreover, all significance testing was calculated two-tailed, essentially halving the alpha directly associated with testing the hypotheses of interest across all analyses (i.e., there was no reason to expect individuals with a recent concussion or concussion history would perform better than individuals with no history of concussion on any task or measure associated with this study, yet only $\alpha = .025$ was applied to this direction).

Our hypothesis was that adolescents and young adults with a history of concussion would show deficits on complex writing. This was operationalized as differences in proposition score. First, we planned a simple group comparison (independent-samples *t* tests were used to determine group differences unless otherwise specified) between averaged proposition scores across both narratives, considered at $\alpha = .05$. If this demonstrated a significant difference, we would look to see if the difference was present in only the constituent events, a subset of these propositions (again considered at $\alpha = .05$). Should our findings lead us to reject the null hypothesis, suggesting a deficit in complex writing was present, we planned to consider the two narratives separately in order to examine whether the novelty and complexity associated with the *Pigeon: Impossible* video (and the delay between seeing and reporting in this case) resulted in a different pattern of narrative performance than the *Cinderella* images. Each story would then be considered simultaneously at $\alpha = .025$, first for propositions and, then constituent events.

Beyond this explicit hypothesis testing, exploratory analyses were anticipated, including examining the effect of number of concussions on performance and deeper descriptions of each group's narrative performance, including examining differences in the pattern of performance across episodes within the narrative story grammar and describing lexical and structural features commonly utilized when analyzing language samples. For the purposes of interpretation and discussion, levels of marginal significance are reported and interpreted as though considered at $\alpha = .05$; however, these comparisons are not directly relevant to the calculation of a study-wide likelihood that the true population parameter for propositions lies outside the confidence interval. The reported measures of complex language are summarized in Table 4.

Results

Group Description

Demographics

We first compared our two groups of participants to ensure they were comparable in a variety of factors that might impact narrative or cognitive performance. Overall, the two groups were well matched across a rich array of variables. Although education was not widely reported by participants, among those who responded ($n = 24$), education in both groups ranged between high school graduates and individuals who had attained professional degrees. Participants responded categorically, not numerically, to this question. When years of education were estimated based on these responses, difference between groups was not significant (concussion: $M = 15.6$, $SD = 4.9$; no concussion: $M = 15.9$, $SD = 2.7$), $t(22) = 0.18$, $p = .86$, *ns.*

Of note, individuals with a history of concussion were significantly older ($M = 29.20$ years, $SD = 7.36$ years) than the no concussion group ($M = 23.75$ years, $SD = 7.21$ years) based on an independent-samples *t* test, $t(79) = 3.024$, $p = .003$. However, age was not a significant factor influencing average story grammar performance in propositions based on a simple linear regression analysis, $F(1, 52) = 0.044$, $p = .835$, $R^2 = .001$. Additional simple linear regressions demonstrated that age did not significantly predict flanker effect, $F(1, 49) = 1.864$, $p = .178$, $R^2 = .037$; total letter fluency, $F(1, 61) = 1.303$, $p = .258$, $R^2 = .021$; or naming reaction time, $F(1, 31) = 0.735$, $p = .398$, $R^2 = .023$. Age did not significantly correlate with the total number of concussions ($r = .002$, $p = .988$), symptom score ($r = .204$, $p = .068$), or cognitive change ($r = .155$, $p = .237$). Age did not significantly correlate with story grammar performance as measured in propositions or constituent events in either the retelling of *Cinderella* (propositions: $p = .472$; constituent events: $p = .244$) or *Pigeon: Impossible* (propositions: $p = .821$; constituent events: $p = .279$) or words per minute typed across tasks ($p = .593$). These findings suggest that age, by itself, was not driving the relationship among the variables.

Personality, Temperament, and Mental Health

Given the mental health and psychosocial implications of patient complaints of persisting somatic or cognitive symptoms, a variety of psychological tools were completed by all participants following the experimental tasks (see Table 5). The BFI ratings are used to calculate gendered *T* scores for Negative Emotionality dimension score based on a norming sample of 313 men and 146 women (Soto & John, 2017). As expected, STAI State and Trait scores demonstrated significant correlations with BFI Negative Emotionality *T* score (State: $r = .571$, $p < .001$; Trait: $r = .773$, $p < .001$), Brief Adolescent Life Events Scale (State: $r = .545$, $p < .001$; Trait: $r = .504$, $p < .001$), and each other ($r = .804$, $p < .001$). As none of these degrees of correlation was above a desired moderate level except state and trait anxiety captured within the same measure (STAI), trait anxiety was removed and state anxiety was retained. In a multivariate analysis of variance including the remaining measures of affect and personality, groups did not differ on these indices: Box's $M = 8.975$, $F(10, 576.990) = 0.781$, $p = .611$; Pillai's trace = 0.125, $F(4, 22) = 0.787$, $p = .546$ (two-tailed). These findings suggest that it is unlikely that personality, temperament, or mental health risk factors were, in themselves, driving any differences seen in these individuals with a concussion history, as is sometimes implied when symptoms are reported well beyond the typical window of recovery.

In order to account for the possibility that the inclusion of individuals with ADHD/ADD diagnoses was skewing results, hypothesis-testing analyses were recalculated, eliminating those participants with a self-reported diagnosis of

Table 4. Statistics calculated from language samples.

Measure	Description
Hypothesis testing	
Proposition score	Proportion of correct statements of events from the narrative to total number of events identified
Constituent events score	A subset of proposition score; proportion of correct statements crucial to the retelling of the narrative to the total number of crucial events
Description	
Episodic story grammar	Indicator of suprastructural organization of content (Coelho, 2002)
Total time of the sample	Used for determining rate
Total number of sentences and propositions	Measure of overall productivity of participant
Average length of the sentence in words and meaning units (MLU)	Measure of sentence complexity
Type–token ratio (TTR)	Norm-referenced measure of lexical diversity (Miller & Leadholm, 1992)
Vocabulary diversity score	Alternative measure of lexical diversity to TTR that is less influenced by sample size
Average number of clauses per sentence	Measure of clausal density or grammatical complexity
Underspecified word choice (e.g., "thing" instead of "toaster")	Indicator of word-finding difficulties

Note. MLU = mean length of utterance.

attention deficits in their clinical history—this represented three of 23 (13%) of participants without concussions and eight of 58 (14%) of those with a concussion history. The results of this re-examination of a subset of our sample are reported below.

Sleep Behavior

Due to the importance of sleep behavior and sleep disturbance to cognitive performance, multiple measures of sleep behavior were collected. Based on a multivariate analysis of variance, groups did not differ in sleep behavior measured in four complementary, moderately correlated (mean correlation coefficient = .27) ways: how many hours participants slept each night on average, how long after going to bed participants usually fell asleep, Sleepiness Scale (Wolfson & Carskadon, 1998), and Sleep/Wake Problems Behavior Scale (Wolfson & Carskadon, 1998; Pillai's trace = 0.086), $F(4, 45) = 1.058$, $p = .388$ (two-tailed).[3] This suggests that sleep behavior was not meaningfully contributing to differences between groups on cognitive and linguistic tasks. On average, participants reported falling asleep between 15 and 30 min after going to bed and slept between 7 and 8 hr a night.

Table 5. Means and standard deviations for measures of affect and personality.

BFI-2 NE *T* score	47.39 (10.0)	51.78 (12.17)	$U = 147.50$ $z = -1.39$ $p = .169$
MSPSS	5.15 (1.26)	5.59 (1.32)	$U = 50.50$ $z = -1.47$ $p = .147$
BALES-NEG	10.55 (6.75)	11.57 (4.79)	$U = 65.00$ $z = -0.61$ $p = .566$
STAI-S	42.61 (13.28)	40.79 (10.59)	$U = 231.50$ $z = -0.44$ $p = .665$
STAI-T	44.36 (10.78)	48.14 (9.11)	$U = 197.00$ $z = -1.19$ $p = .240$

Note. Values in the table are presented as mean (standard deviation). Test statistics refer to independent-samples *t* tests in all cases of continuous data and Mann–Whitney *U* tests when data were ordinal. BFI-2 NE = Big Five Inventory–Second Edition Neuroticism subscore; MSPSS = Multidimensional Scale of Perceived Social Support; BALES-NEG = Brief Adolescent Life Event Scale Negative Events Index (interpersonal and achievement-related negative events); STAI-S = State–Trait Anxiety Inventory State subscore; STAI-T = State–Trait Anxiety Inventory Trait subscore.

Somatic Symptoms and Perceived Change

All participants were asked to rate the severity of somatic symptoms. Those with a history of concussion reported significantly greater somatic symptom severity ($Mdn = 19$) than those with no such history ($Mdn = 5$) based on the nonparametric Mann–Whitney *U* test, selected due to the ordinal nature of this measure ($U = 311.50$, $z = -3.73$, $p < .001$, $r = -.41$). It is unclear whether those with a history of concussion were still experiencing (or reporting) symptoms from their earlier concussion or are more sensitive to typical levels of these symptoms (e.g., headache, fatigue) since their injury. When individuals with a concussion history were asked to rate their perceived changes to cognition, self-reported symptom scores positively correlated with self-reported cognitive change rating ($r_s = .709$, $p < .001$). Both self-reported symptom score ($r_s = .516$, $p < .001$) and cognitive change ($r_s = .578$, $p < .001$) were positively correlated with the cumulative number of concussions.

[3]Box's test of equality of covariance matrices was significant (Box's $M = 24.383$), $F(10, 2875.549) = 2.134$, $p = .019$; however, this statistic is reasonably robust to violations of this assumption in samples of this size. Thus, violations, though noted, were ignored for the purposes of analysis.

Cognitive and Linguistic Skill Performance in Isolation (Discrete Skills)

As anticipated, individuals with a history of concussion did not perform more poorly than individuals with no concussion history on either cognitive or linguistic task that targeted a single or discrete skill, suggesting that the typical performance associated with discharge was maintained for the majority of individuals with a history of one or more concussions. A summary of the three cognitive tasks administered to all participants is presented in Table 6. A multivariate analysis of variance was not significant based on these tasks considered together: Box's M = 33.193, F(6, 165.944) = 3.268, p = .005; Hotelling's T = 0.036, F(3, 16) = 0.190, p = .902 (two-tailed). Potential true differences in performance on the flanker task may have been obscured by substantial variance in this effect across individuals, which could be due to an increased prioritization of accuracy over rapid automatized responses (accuracy on the flanker task was unexpectedly high, not falling below 90% for any group). The observed variability did not appear to be the result of outlier participants (removal of a single outlier has no impact on the results) nor of outlier trials (response times were trimmed to within 2 *SD*s above and below each participant's mean, and this likewise had no effect). Rather, it appears that individuals with a concussion history show a high degree of variability in response times, and this prevents any clear interpretation of their flanker task performance. Performance on the spot-the-difference task was unexpectedly poor for both those with a history of concussion and those without. The pattern of findings was unchanged by the inclusion or exclusion of individuals who self-reported ADHD/ADD. A multivariate analysis of variance was not significant based on the single-skill cognitive tasks considered together: Box's M = 13.17, F(6, 175.50) = 1.29, p = .265; Hotelling's T = 0.01, F(3, 13) = 0.042, p = .988 (two-tailed).

As anticipated, similar null findings were observed in the two discrete linguistic tasks, considered together in a multivariate analysis of variance, Box's M = 1.56, F(3, 1143.22) = 0.439, p = .725; Hotelling's T = 0.08, F(2, 25) = 1.0, p = .074 (two-tailed), or separately based on independent-samples t tests. In letter fluency, participants had 1 min each to name as many words as they could that began with the letters F, A, and S (concussion: n = 38, M = 13.78, SD = 4.23; no concussion: n = 15, M = 14.58, SD = 4.37), t(51) = 0.612, p = .543. In confrontation naming speed, participants read a series of 20 definitions and were asked to provide the word best fitting the definition as quickly as possible (concussion: n = 23, M = 10.11 s, SD = 3.64; no concussion: n = 7, M = 8.99 s, SD = 2.44), t(28) = 0.76, p = .45. In both cases, however, those with a history of concussions showed worse average scores in keeping with the possibility of existing impairments that simply do not appear significant when assessed with simple tasks. Finally, across written tasks, individuals with a history of concussion did not differ in typed words per minute (M = 48.54, SD = 24.64) compared to those with no such history (M = 53.64, SD = 20.22) based on an independent-samples t test, t(72) = 0.855, p = .36 (two-tailed), suggesting their comparable capacity to answer questions in writing within time constraints.

Planned Analyses of Narrative Samples

The most important question we sought to answer was whether persisting differences would be observed when an individual is taxed by a set of linguistic demands approximating those in the real world, as in the written retelling of a narrative. We used two structured narrative tasks to address this: *Cinderella* and *Pigeon: Impossible.* When propositions were averaged across the two narrative samples, the individuals with a history of concussion (n = 36, M = 13.32, SD = 5.36) provided significantly fewer propositions than individuals with no concussion history based on an independent-samples t test (n = 18, M = 16.97, SD = 5.69), t(52) = 2.31, p = .03 (two-tailed). In addition, individuals with a history of concussion tended to include fewer constituent events or the events most important to the story (concussion: M = 8.03, SD = 3.48; no concussion: M = 10, SD = 3.33), t(52) = 1.99, p = .05.

Differences in performance of propositions and constituent events were not consistent across the two narratives when considered separately. When retelling the somewhat familiar story of *Cinderella,* with the pictures present as scaffolding, differences between groups were not significant on either propositions (concussion: M = 13.30, SD = 6.16; no concussion: M = 15.20, SD = 6.135), t(68) = 1.167, p = .247, or constituent events (concussion: M = 8.58, SD = 3.92; no concussion: M = 9.35, SD = 3.68), t(68) = 0.756, p = .452. However, differences were prominent when individuals with a concussion history were asked to view and summarize novel content without scaffolding in *Pigeon: Impossible*. Those with a concussion history provided fewer

Table 6. Summary of measures of cognition.

	Flanker		Backward digit span		Spot the difference	
	n	*M* (*SD*)	*n*	*M* (*SD*)	*n*	*M* (*SD*)
Concussion	27	137.64 (176.78)	27	5.33 (0.83)	26	0.24 (0.16)
No concussion	18	67.01 (71.61)	11	5.27 (0.91)	7	0.29 (0.13)
Test statistics	t(43) = 1.60, p = .116		t(36) = 0.20, p = .844		t(31) = 0.65, p = .518	

Note. Values in the table are presented as mean (standard deviation).

details as reflected in overall propositions (concussion: M = 12.76, SD = 6.12; no concussion: M = 17.63, SD = 7.31), $t(55) = 2.65$, $p = .01$, and fewer pieces of plot-central constituent information (concussion: n = 38, M = 7.24, SD = 3.97; no concussion: n = 19, M = 9.95, SD = 4.35), $t(55) = 2.35$, $p = .02$.

Narrative performance differences across groups were unchanged by the exclusion of individuals with ADHD/ADD. Individuals with a history of concussion produced significantly fewer propositions than individuals with no concussion history on the *Pigeon: Impossible* task based on an independent-samples t test, $t(50) = 2.602$, $p = .012$ (two-tailed), but not the *Cinderella* task, $t(60) = 1.251$, $p = .216$ (two-tailed). Constituent events followed the same pattern; differences were significant when considering *Pigeon: Impossible,* $t(50) = 2.348$, $p = .023$, but not *Cinderella,* $t(60) = 0.809$, $p = .422$.

Additional Analyses of Narrative Language Samples

Analyses were done to further understand the findings from the planned comparisons. A Poisson regression was performed in order to predict the number of constituent events included in the *Pigeon: Impossible* retelling from the total number of concussions when controlling for age. The model was significant ($\chi^2 = 8.362$, $p = .015$), and the total number of concussions ($B = 0.057$, $p = .015$) was a significant predictor of performance while age ($B = -0.014$, $p = .115$) was not.

Performance of Narratives by Episode

In addition to considering the inclusion of propositions across the entirety of each narrative, proposition completeness was considered within each of the episodes. This was done to determine whether the pattern of storytelling adopted by the two groups differed. In *Cinderella,* the identified sections were (a) the Setting or Orientation, (b) Episode 1: preparing for the ball, (c) Episode 2a: attacked by the evil stepsisters, (d) Episode 2b: assisted by the fairy godmother, (e) Episode 3: attending the ball, (f) Episode 4/Complication: losing the slipper, (g) Episode 5/Solution: found by the prince, and (h) Coda. In no episode considered independently was performance by individuals with a history of concussion significantly different from individuals with no concussion history (see Figure 1).

In *Pigeon: Impossible,* the identified sections were (a) the Setting or Orientation, (b) Episode 1: Walter encounters the pigeon, (c) Episode 2a: the pigeon attacks Walter, (d) Episode 2b: the pigeon wreaks havoc with the briefcase, (e) Episode 3: Walter lures the pigeon from the briefcase, (f) Episode 4/Complication: the bagel launches a nuclear missile toward Moscow, (g) Episode 5/Solution: Walter rushes to stop the missile, and (h) Coda. Participants with a history of injury differed from those with no history of injury across all three of the final components of the story, the Complication, Solution, and Coda (see Figure 2), suggesting that they were omitting more information as the story progressed. This may have been due to difficulty storing additional details in the working memory or due to implementing a poor strategy for responding to the question within the allotted time, resulting in running out of time before providing details of the end of the story.

Structural Features and Complexity of Written Language

A second exploratory analysis compared measures of structural language complexity found in *Pigeon: Impossible*. A spectrum of statistics was calculated automatically using tools from the CHILDES project: total utterances, mean length of utterance in morphemes, vocabulary diversity, and clausal density (estimated by verbs per sentence). A multivariate analysis of variance was not significant (Pillai's trace = 0.194), $F(5, 45) = 2.17$, $p = .08$, $\eta_p^2 = .194$ (see Table 7). These findings suggested that, even though individuals with a concussion history included less key content in their retellings, other aspects of their language complexity were largely similar to that of individuals without concussions.

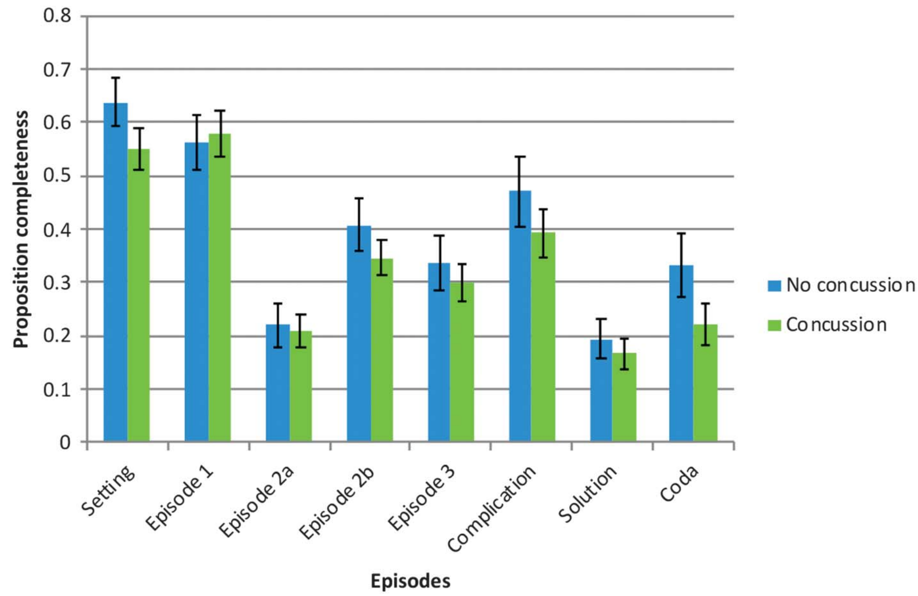
Another potential indicator of underlying deficits emerging under increasing demands would be the use of more general GAP verbs. In an exploratory analysis, individuals with a history of concussion used a greater proportion of GAP verbs (39.26 per 1,000 verbs) than individuals with no such history (32.22 per 1,000 verbs), which approached significance based on an independent-samples t test, $t(77) = 1.85$, $p = .07$ (two-tailed). The two groups did not differ in use of universally general and contextually underspecified words.

Discussion

The purpose of this research was to examine whether individuals with a remote concussion history would experience differences on a complex cognitive–linguistic writing task. Indeed, differences in story grammar were observed in those with a history of at least one concussion in an average of nearly 5 years prior to this evaluation. The primary evidence of these differences was observed in the performance of the injured group in the retelling of *Pigeon: Impossible,* a brief but highly eventful and dynamic animated video utilized for the first time in this study.

Individuals with a concussion history more frequently omitted both key story components and details of *Pigeon: Impossible* as the story progressed. One contributor to this pattern appeared to be that individuals with an injury history ran out of time and were unable to complete their narratives within the allotted 5-min window, as evidenced by multiple instances in which samples ended midclause or midword. Individuals without a history of concussion seemed to experience this far less frequently as a group. One possibility is, although individuals with a concussion history were able to recount details of the story no differently from individuals with no concussion and were able to type at a speed no different from uninjured individuals, they took longer to recall and include those details in their written narrative. This could be examined in future work that more closely examined the demands on working memory experienced by individuals in this population when asked

Figure 1. Performance on *Cinderella* sections by group.



to recount events from a video, as in *Pigeon: Impossible,* in comparison to the more traditionally used *Cinderella* task, in which the pictures (which remained present) served as a memory cue. This type of scaffolding may be less important for individuals without a history of concussion. However, differences in working memory were not, in fact, noted when this skill was examined in isolation on the backward digit span task. Aside from the apparent difficulty with omission of key components and details over time, the narratives appeared largely typical, mirroring the findings on skill-specific targeted tasks, such as letter fluency, naming, and cognitive tasks, such as the flanker and backward digit span.

Based on the present findings, it is perhaps reasonable to consider that individuals with a concussion history can fail to raise "red flags" for clinicians while still experiencing increased difficulty in complex communication. These individuals may benefit from more integrated multidisciplinary management (i.e., neuropsychology, psychology, speech-language pathology, and physical therapy coordinating therapy together, as is increasingly common in specialized

Figure 2. Performance on *Pigeon: Impossible* sections by group.

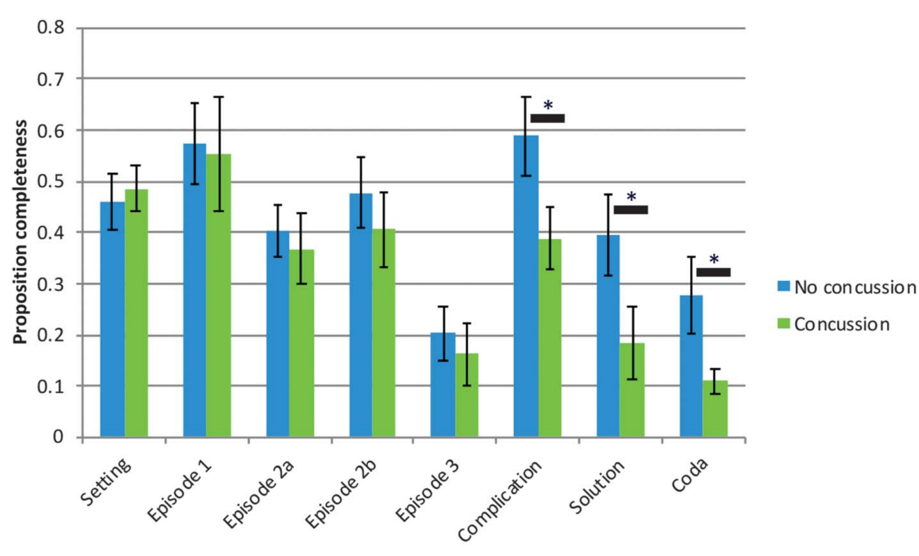


Table 7. Structural statistics from narrative tasks.

Statistic	Concussion	No concussion	Test statistics
Cinderella			
No. sentences	10.50 (4.01)	11.45 (4.27)	$t(70) = 0.88, p = .380$
MLU in morphemes	17.08 (4.25)	17.48 (4.33)	$t(70) = 0.35, p = .726$
TTR	0.56 (0.09)	0.54 (0.05)	$t(70) = 0.56, p = .576$
VocD	56.78 (11.35)	57.15 (8.76)	$t(68) = 0.13, p = .895$
Clauses per sentence	2.29 (0.53)	2.38 (0.61)	$t(70) = 0.63, p = .531$
Pigeon: Impossible			
No. sentences	8.92 (3.57)	11.44 (4.50)	$t(52) = 2.25, p = .029^*$
MLU in morphemes	19.35 (4.39)	19.87 (4.94)	$t(52) = 0.39, p = .697$
TTR	0.54 (0.07)	0.47 (0.07)	$t(52) = 2.98, p = .004^*$
VocD	44.22 (10.09)	42.76 (9.17)	$t(49) = 0.50, p = .619$
Clauses per sentence	2.60 (0.60)	2.61 (0.80)	$t(52) = 0.08, p = .941$
Total			
No. sentences	9.81 (3.31)	11.97 (3.95)	$t(50) = 2.07, p = .044^*$
MLU in morphemes	18.29 (3.85)	18.51 (4.10)	$t(50) = 0.19, p = .847$
TTR	0.54 (0.06)	0.51 (0.05)	$t(50) = 2.01, p = .050^*$
VocD	48.89 (8.02)	50.91 (6.36)	$t(46) = 0.88, p = .386$
Clauses per sentence	2.41 (0.47)	2.46 (0.61)	$t(50) = 0.33, p = .740$

Note. Statistics are reported as mean (standard deviation). MLU = mean length of utterance; TTR = type–token ratio; VocD = vocabulary diversity score.

$^*p < .05$.

concussion care centers), particularly if self-reported somatic symptoms are being weighed heavily in the decision to advise individuals of when they may re-integrate into normal levels of participation. An estimated 1.7 million people sustain TBIs each year in the United States alone, with nearly 80% (1.365 million) treated and released from an emergency department (Faul, Xu, Wald, & Coronado, 2010). These statistics highlight the importance of continued effective management for the 80% who are treated and released. It is important that clinicians complete comprehensive evaluations of complex, infrequent, and larger units of language in addition to more common assessments of basic language skills, focusing not just on structural complexity but also on the completeness of the content being conveyed. Some assessments have emerged that target deficits associated with complex, real-world demands (e.g., the Functional Assessment of Verbal Reasoning and Executive Strategies; MacDonald & Johnson, 2005). However, the thorough interpretation of cognitive–linguistic functioning demands the expertise of speech-language pathologists, who are too often not included in concussion management. This recommendation is congruent with the observation that many patients report experiencing ongoing difficulties when engaged in the most demanding social, professional, or academic contexts, despite the fact that clinicians often find little evidence of analogous deficits in controlled evaluation.

Although many of the tasks utilized in this study were previously used in the literature, prior studies of brain injury often included small groups or combined individuals with relatively diverse injury and personal characteristics. Much of what makes the existing literature difficult to interpret is that concussion, the mildest of brain injuries (McCrory et al., 2013), historically was not differentiated from the broader spectrum of what could constitute mild injury. Thus, in these prior studies, it is unclear the extent to which greater injury severities drove group differences, as well as whether studies had sufficient power to reliably find effects. Here, sample size is comparably more substantial. While resulting in a larger sample size and greater quality of descriptive information regarding the two groups, the remote and self-reported nature of this data collection also presents some limitations. For example, participants who did not report a concussion could have, nonetheless, had one at one point. Those who claimed that their health histories did not include developmental language disorders (one of the exclusion criteria utilized in the study) could, indeed, have had such disorders, whether formally diagnosed or not. Dishonesty and earnest inaccuracy in self-reported health information both contribute to poor self-reporting (Bergmann, Byers, Freedman, & Mokdad, 1998; Okura, Urban, Mahoney, Jacobsen, & Rodeheffer, 2004; B. Smith et al., 2008), though overall rates of agreement between self-report and available medical records are generally good. In one study, concordance between self-reported injury and medical records among young adults reached 100%, regardless of self-report data collection method (Rahman et al., 2005). Despite the limitation associated with the lack of secondary verification, self-report remains a valued and informative tool in clinical research, and the authors have relied upon participants' self-reported histories as accurate. In addition to a larger sample size, groups were well matched not just in demographic factors but also in characteristics such as sleep behavior, social support, and stressful life events—dimensions thought to inflate estimates of truly cognitive deficits that trace their etiology to the concussion injury. However, the possibility remains that, in our sample, factors such as undiagnosed developmental language disorders or poor self-report more generally are a more accurate explanation of the differences in performance between groups than the targeted difference in history of concussion. Further work is needed in order to replicate these findings under longitudinal clinical management.

Prior studies have found deficits in the provision of essential story information, use of transitions, and cohesion when reporting on pediatric clinical samples that include both mild and more severe injuries (Biddle et al., 1996; Brookshire, Chapman, Song, & Levin, 2000; Chapman et al., 1992; Ewing-Cobbs et al., 1998) or adults with mild brain injury (Galetto et al., 2013; Marini et al., 2011; Tucker & Hanlon, 1998). Particularly relevant to the present work, Galetto et al. (2013) found increased errors in semantically related remote utterances, including tangential utterances, conceptually incongruent information, repetitions and fillers (global coherence; $\eta_p^2 = .536$), and fewer lexical information units ($\eta_p^2 = .252$) when adult participants within 5 years of an mTBI were asked to generate a series of stories elicited by single pictures. However, until recently, narrative content and organization deficits following concussion exclusively were less explored. Recently, Kovach (2015) and Harvey (2016) found limited evidence of difficulty when college athletes were asked to retell *Cinderella,* describing trends in increased use of disruptions and difficulty maintaining a topic. The present research builds upon these findings by examining individuals with a more remote concussion history, providing complementary evidence of these effects in written language, and extends the discussion of narratives beyond the *Cinderella* retelling to that of a novel, more dynamic wordless cartoon.

A positive observation from this study is the diversity of tasks and dimensions measured on which individuals with a concussion history did not differ from those without one. We did not see differences between individuals with and without a concussion history with regard to their sleep behavior, personality, temperament, or various discrete cognitive–linguistic skills targeted in isolation. Prior literature has reported deficits in working memory on a digit span task, even among those with the mildest concussions (Leininger et al., 1990), leading to the common use of this measure in sideline and neuropsychological evaluation in the period immediately following injury—indeed, the digit span items used in this study were from the Standardized Assessment of Concussion (McCrea et al., 1998). Unfortunately, the use of this task in an online format required changes to be made to the backward digit span protocol, which may have obfuscated group differences, if present. Technical difficulties were reported more on this task than on any other and could not be effectively resolved due to the remote nature of data collection. Future work may help contextualize the findings from our study and better shape our understanding of the nature and duration of these discrete skill deficits and how they relate to more complex skills.

Looking toward the future, this research also demonstrates that the use of video stimuli rather than static pictures can lead to more sensitive measures of performance, particularly when examining narrative structure and organization. Videos provide increased complexity and ecological validity that better parallels the contexts of patient complaints. Like real events, videos happen and then are finished, so they are no longer present to provide reminders of the content a viewer has experienced (unlike the *Cinderella* story, in which the pictures remain). Moreover, videos are highly engaging for a wide variety of ages and complement the broader online data collection model, which removes barriers to obtaining a more representative population sampling than those common in behavioral science.

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