Visual and linguistic narrative comprehension in autism spectrum disorders: Neural evidence for modality-independent impairments

Emily L. Coderre[a,b,*], Neil Cohn[c], Sally K. Slipher[b,d], Mariya Chernenok[b,e], Kerry Ledoux[b], Barry Gordon[b,f]

[a] Department of Communication Sciences and Disorders, University of Vermont, Burlington, VT, United States
[b] Cognitive Neurology/Neuropsychology, Department of Neurology, The Johns Hopkins University School of Medicine, Baltimore, MD, United States
[c] Tilburg Center for Cognition and Communication (TiCC), Tilburg University, Tilburg, The Netherlands
[d] Department of Health Professions, Montana State University, Bozeman, MT, United States
[e] Department of Human Ecology, University of California at Davis, Davis, CA, United States
[f] Department of Cognitive Science, The Johns Hopkins University, Baltimore, MD, United States

ARTICLE INFO

ABSTRACT

Individuals with autism spectrum disorders (ASD) have notable language difficulties, including with understanding narratives. However, most narrative comprehension studies have used written or spoken narratives, making it unclear whether narrative difficulties stem from language impairments or more global impairments in the kinds of general cognitive processes (such as understanding meaning and structural sequencing) that are involved in narrative comprehension. Using event-related potentials (ERPs), we directly compared semantic comprehension of linguistic narratives (short sentences) and visual narratives (comic panels) in adults with ASD and typically-developing (TD) adults. Compared to the TD group, the ASD group showed reduced N400 effects for both linguistic and visual narratives, suggesting comprehension impairments for both types of narratives and thereby implicating a more domain-general impairment. Based on these results, we propose that individuals with ASD use a more bottom-up style of processing during narrative comprehension.

1. Introduction

The ability to understand sequential events is thought to be unique, even fundamental, to the human condition. The comprehension of narrative sequences is central to school, work, and everyday life, but poses significant challenges for individuals with communication and neurodevelopmental disorders like autism. This study explores whether such comprehension deficits in individuals with autism are language-specific or represent global difficulties with understanding narrative sequences.

Narrative theory has a long history in philosophy, literature, and psychology, with many different specific definitions of what constitutes a narrative (e.g. Bruner, 1991, 1997; Richardson, 2000; Walsh, 2007). For the purposes of the current study, we conceptualize "narrative" or a "story" according to several characteristics included in many of these definitions: a narrative consists of an actor or actors with goals and motivations (Bruner, 1997) and a temporal sequence of events (Bruner, 1991; Richardson, 2000) with causal connections between those events (Richardson, 2000).

Although narrative *production* and narrative *comprehension* are interrelated, the two should be considered separately, as these two functions can comprise different processes. Narrative production may include narrative comprehension at its heart, as a story must first be understood to be told/retold. But narrative production also requires other skills, such as framing the story in a coherent manner that is understandable to the listener and using appropriate morphological and syntactic structures, which distinguish it as a separate process from comprehension. Narrative production studies have occasionally tested spontaneous narrative production in which participants tell a story such as a personal experience (e.g. Losh & Capps, 2003), which involves describing experienced events within a self-generated narrative structure. Spontaneous narrative is also often elicited by asking participants to recount the plot of a wordless picture book (AbdulSabur et al., 2014; Diehl, Bennetto, & Young, 2006; Losh & Capps, 2003; Tager-Flusberg, 1995; see reviews in Berman, 2009; Liles, 1993). Still other studies have examined retell, in which participants recount the plot of a spoken narrative (Diehl et al., 2006). Note that in retell, and also in spontaneous production of wordless picture books, the original narratives

* Corresponding author at: Department of Communication Sciences and Disorders, University of Vermont, 489 Main St., Burlington, VT 05405, United States.
  E-mail address: emily.coderre@med.uvm.edu (E.L. Coderre).

(whether orally or visually presented) have a narrative structure that is then internalized and re-produced, whereas in truly spontaneous production (e.g. describing a personal experience) this narrative structure is created on-line by the storyteller. In both types of production studies, narratives are commonly analyzed in terms of the presence of linguistic features such as the use of references, temporality, and syntactic connectivity; these production abilities are used to examine cognitive, social, and linguistic development (Berman, 2009; Liles, 1993).

In contrast, "narrative comprehension" refers to the access of semantic information – how various themes, characters, and plotlines fit together – mediated by narrative structures (Cohn, 2013a, 2013b). Narrative comprehension has been assessed by, for example, asking participants to answer comprehension questions following presentation of a written or spoken narrative (Horowitz-Kraus, Buck, & Dorrmann, 2016; Nuske & Bavin, 2011; Schmithorst, Holland, & Plante, 2006; Yarkoni, Speer, & Zacks, 2008); to judge the coherence or comprehensibility of a written story (Ferstl & von Cramon, 2001; Martín-Loeches, Casado, Hernández-Tamames, & Álvarez-Linera, 2008); to verbally recall or retell a story (Martín-Loeches et al., 2008); or to arrange sentences to create a coherent story (Jolliffe & Baron-Cohen, 2000; see Mar, 2004, for a review).

1.1. Narrative production and comprehension in individuals with autism

Autism spectrum disorder (ASD) is a developmental disorder defined by deficits in social communication and interaction as well as restricted and repetitive behaviors or interests (APA, 2013). In practice, ASD often presents with a wide constellation of deficits in motor, sensory, cognitive, and social domains. Deficits in language processing, although no longer a diagnostic criterion (APA, 2013), often co-occur in ASD, and can have great functional consequences for many individuals. Language deficits are particularly prominent in higher-level processes such as semantics, syntax, and narrative production and comprehension (Groen, Zwiers, van der Gaag, & Buitelaar, 2008; Tager-Flusberg, Paul, & Lord, 2005).

Narrative production abilities in individuals with ASD have received considerable attention; many studies report deficits in personal and/or fictional storytelling in children and adults with ASD (Diehl et al., 2006; Losh & Capps, 2003; Tager-Flusberg & Sullivan, 1995). As a recent meta-analysis summarizes, children with ASD show poorer performance on variables related to both microstructure and macrostructure of narrative production, as well as lower use of internal state language, compared to TD peers (Baixauli, Colomer, Roselló, & Miranda, 2016).

Studies of narrative comprehension in individuals with ASD, although less numerous than production studies, have also suggested deficits in children and adults with ASD, including: difficulty arranging written sentences into coherent narratives (Jolliffe & Baron-Cohen, 2000); impairments in making inferences about stories (Jolliffe & Baron-Cohen, 2000; Kaland, Smith, & Mortensen, 2007; Nuske & Bavin, 2011); and atypical brain activation and connectivity when reading passages requiring inferences (Mason, Williams, Kana, Minshew, & Just, 2008). These difficulties with making inferences during comprehension, extracting the main theme of a narrative, and connecting meaningful elements of the discourse have been attributed to an inability to connect pieces of information to thematically link together linguistic elements (Jolliffe & Baron-Cohen, 2000; Vermeulen, 2015).

Since successful narrative comprehension underlies successful narrative production, impairments in narrative production in individuals with ASD could arise, in part, from impaired comprehension. However, in comparison to the number of narrative production studies, investigations of narrative comprehension abilities in individuals with ASD are relatively sparse. Our understanding of the narrative comprehension abilities of individuals with ASD is incomplete, making it difficult to fully interpret production abilities. In the current study, we seek to address this relative paucity in the literature and gain a more comprehensive picture of narrative abilities in individuals with ASD.

1.2. Neural correlates of narrative production and comprehension

Previous neuroimaging studies in typically developing (TD) individuals have demonstrated that narrative production and comprehension recruit largely overlapping brain regions, including parts of the language network (e.g. left inferior frontal gyrus and temporal lobe); areas involved in the construction and maintenance of a mental representation of the story (e.g. dorsomedial prefrontal cortex, precuneus, inferior parietal lobes); and areas involved in theory of mind (ToM; the ability to understand the mental states of others; e.g. medial prefrontal cortex, temporo-parietal junction) (AbdulSabur et al., 2014; Ferstl, Neumann, Bogler, & Von Cramon, 2008; Mar, 2004). However, production and comprehension also elicit dissociable patterns of brain activation, such as a greater reliance on motor regions in narrative production (AbdulSabur et al., 2014) and a more bilateral involvement of perisylvian language areas in narrative comprehension (AbdulSabur et al., 2014; Mar, 2004). Other studies have also proposed a more bilateral or right-hemisphere dominant pattern of activity for narrative comprehension (e.g., Karunanayaka et al., 2007; Schmithorst et al., 2006), although this conjecture has not always been empirically supported (e.g., Ferstl & von Cramon, 2001; Yarkoni et al., 2008).

Several of the neural regions underlying narrative comprehension are abnormally activated or connected in ASD during language processing, which may contribute to some of the observed differences in narrative comprehension in this population. For example, consistent with evidence of impaired ToM in autism, Mason et al. (2008) observed atypical activation of the ToM network during narrative comprehension in individuals with ASD. Individuals with ASD also showed reduced connectivity between the ToM network and left-hemisphere language areas during narrative comprehension (Mason et al., 2008). This research therefore suggests a neural basis for the observed narrative comprehension impairments in individuals with ASD.

Of particular relevance to the current study, electrophysiological studies have also documented impairments in several aspects of language comprehension in individuals with ASD (Braeutigam, Swithenby, & Bailey, 2008; Dunn & Bates, 2005; Dunn, Gaughan Jr., Kreuzer, & Kurtzberg, 1999; McCleery et al., 2010; Pijnacker, Geurts, van Lambalgen, Buitelaar, & Hagoort, 2010; Strandburg et al., 1993). The *N400* event-related potential (ERP) component, a negative-going deflection peaking approximately 400 ms (ms) after stimulus presentation, has been established as an index of semantic processing (Kutas & Federmeier, 2011). In TD individuals, N400 amplitude is reduced for semantically congruent stimuli (e.g., contextually congruent sentence-final words) relative to semantically incongruent stimuli (e.g., contextually incongruent sentence-final words; Kutas & Federmeier, 2011; Kutas & Hillyard, 1980; Lau, Phillips, & Poeppel, 2008). The amplitude difference between congruent and incongruent conditions is referred to here as the *N400 effect*. (For current purposes, the N400 is taken to reflect semantic processing and integration [Kutas & Hillyard, 1980; Lau et al., 2008] although other functional interpretations exist [e.g., Brouwer, Fitz, & Hoeks, 2012; see Kutas & Federmeier, 2011 for a broader discussion.]) The N400 has been localized to areas of the frontal and temporal cortices (Kutas & Federmeier, 2011), which aligns with neuroimaging studies of narrative comprehension. Following the N400, a later positive component (*LPC*, alternatively called the *P600*) is also sometimes observed (Pijnacker et al., 2010; Sassenhagen, Schlesewsky, & Bornkessel-Schlesewsky, 2014; van de Meerendonk, Kolk, Vissers, & Chwilla, 2010). This component is characterized by a more positive-going waveform for incongruent conditions compared to congruent conditions and generally occurs between approximately 500 and 900 ms. The LPC has been linked to later linguistic reanalysis (Sassenhagen et al., 2014; van de Meerendonk et al., 2010).

Individuals with ASD often show reduced or absent N400 effects for language compared to TD individuals (Braeutigam et al., 2008; Dunn & Bates, 2005; Dunn et al., 1999; McCleery et al., 2010; Pijnacker et al., 2010; Strandburg et al., 1993), suggesting difficulty with integrating

lexical meaning with semantic context to arrive at a holistic understanding. For instance, Pijnacker et al. (2010) found that incongruent sentence-final words (e.g. "Finally, the climbers reached the top of the *tulip*") elicited smaller N400 effects compared to congruent sentence-final words (e.g. "Finally, the climbers reached the top of the *mountain*") for individuals with ASD compared to TD individuals. In contrast, the ASD group showed a larger LPC than the TD individuals, which the authors interpreted as reflecting a later re-evaluation process triggered by less-automatic initial semantic integration. Such difficulties with semantic integration may underlie many observable language deficits in this population, including those in narrative comprehension (Jolliffe & Baron-Cohen, 2000; Kaland et al., 2007; Mason et al., 2008; Nuske & Bavin, 2011).

1.3. Lexico-semantic vs. visuo-semantic processing in individuals with ASD

Notably, language has been central to previous studies of narrative comprehension in individuals with ASD, which have predominantly used written or spoken narratives. However, because individuals with ASD often experience language deficits, using verbal materials to assess comprehension may misrepresent their abilities and could drive narrative impairments. Many studies account for this possibility by matching participant groups on language measures (Jolliffe & Baron-Cohen, 2000; Nuske & Bavin, 2011) or including language ability as a covariate in statistical analyses (Kaland et al., 2007). The current work takes a different approach by exploring whether deficits in narrative comprehension are observed in a non-linguistic modality. (Here and throughout, we use the term "linguistic" to mean "involving or related to written or spoken language.") Given their non-linguistic nature, picture sequences (i.e., visual narratives, as in comics) could bypass verbal bottlenecks, which may make them preferable for individuals with language difficulties. Indeed, the assumption that visual narratives such as wordless picture books are transparent to such populations underlies their use in narrative elicitation tasks (Diehl et al., 2006; Losh & Capps, 2003; Tager-Flusberg, 1995).

Basic, low-level visual processing abilities like discrimination appear to be relatively intact in individuals with ASD; for example, a recent meta-analysis of low-level visual processing abilities in individuals with ASD found that for many tasks (including visual search, block design, and embedded figures tasks), individuals with ASD do not differ in performance from their TD peers (Van der Hallen, Evers, Brewaeys, Noortgate, & Wagemans, 2015). Several studies have also suggested that semantic processing of non-linguistic stimuli is intact in individuals with ASD (Coderre, Chernenok, Gordon, & Ledoux, 2017; Kamio & Toichi, 2000; McCleery et al., 2010; Sahyoun, Soulières, Belliveau, Mottron, & Mody, 2009). For example, children with ASD performed better on a picture-word priming task than on a word-word priming task, suggesting an advantage for visuo-semantic processing (Kamio & Toichi, 2000). McCleery et al. (2010) reported an N400 effect for linguistic stimuli (pairs of pictures and spoken words) in TD children but not in children with ASD, reflecting difficulties with lexico-semantic processing. However, for non-linguistic stimuli (pairs of pictures and environmental sounds), N400 effects were similar for children with ASD and TD children, suggesting intact semantic processing of non-linguistic stimuli. This work suggests a language-specific deficit in semantic processing, which could explain the observed narrative comprehension difficulties (which have previously relied solely on linguistic stimuli). Given that basic visual discrimination and visuo-semantic processing appear intact in individuals with ASD, would higher-level comprehension remain intact for narratives presented visually?

1.4. Visual narratives

In the context of narrative theory, it has long been recognized that narratives are not restricted to the linguistic modality but can also be portrayed non-linguistically or non-verbally (Bruner, 1991; Richardson,

2000; Walsh, 2007). Discourse and narrative research has demonstrated that similar cognitive processes are at work in comprehending narratives across different modalities, particularly written, drawn, and filmed (Cohn & Kutas, 2015; Cohn & Wittenberg, 2016; Cohn, Paczynski, Jackendoff, Holcomb, & Kuperberg, 2012; Gernsbacher, Varner, & Faust, 1990; Magliano, Kopp, McNerney, Radvansky, & Zacks, 2012; Magliano, Larson, Higgs, & Loschky, 2016; Magliano, Loschky, Clinton, & Larson, 2013; Radvansky & Zacks, 2014). Like language, sequential image comprehension is characterized by two processing streams. First, readers must integrate semantic information across images and update a mental model of the unfolding scene (Magliano & Zacks, 2011; Zwaan & Radvansky, 1998). Second, a "narrative grammar" organizes and constrains this semantic information with categorical roles embedded in hierarchic constituent structures, similar to the syntactic structure of sentences (Cohn et al., 2012; Cohn, 2013b). While these categories are similar to traditional notions of narrative (e.g., set up, rising action, climax, resolution), such roles are not descriptors of meaning itself but are determined through interactions between the bottom-up semantic content in images and the top-down sequential context (Cohn, 2013b, 2014). Just as meaningful information in a sentence can be independent of its syntax, meaningful information in a story is independent from the narrative structure ordering that meaning (e.g., Brewer, 1985; Cohn, 2013b). Thus, this narrative grammar is separate from semantics, just as syntactic structure is separate from – yet interfaced with – meaning in sentences (Cohn et al., 2012).

Although relatively little research examines the neurobiological basis of picture arrangement and visual narrative comprehension, some studies have indicated the importance of frontal and temporal areas (Cohn & Maher, 2015; McFie & Thompson, 1972; Nagai, Endo, & Kumada, 2007; Osaka, Yaoi, Minamoto, & Osaka, 2014): similar areas that are recruited by linguistic narratives. Lesion studies have also highlighted the role of the right hemisphere (Boone et al., 1999; Huber & Gleber, 1982; McFie & Thompson, 1972).

Further support for the similarity between visual and linguistic narratives comes from studies examining ERPs to sequential images using manipulations like those in sentence processing studies. Just as incongruent sentence-final words elicit an enhanced N400 relative to congruent words (Kutas & Hillyard, 1980), an enhanced N400 is evoked when the final panel of a visual narrative is incongruent with its preceding context (West & Holcomb, 2002). Coherent visual narratives also typically yield attenuated N400 amplitudes across ordinal positions of the sequence (Cohn et al., 2012), similar to that observed across ordinal words in sentences (van Petten & Kutas, 1991). This attenuation is not observed for scrambled or grammar-only sentences/sequences (Cohn et al., 2012; van Petten & Kutas, 1991), suggesting a "build up" of meaning. Thus, much like linguistic narratives, semantic processing in visual narratives integrates meaning across disparate information units. This growing literature suggests that visual narrative comprehension balances a narrative structure and the semantic content of individual images, largely paralleling linguistic narrative comprehension.

Visual narratives thus provide a means of assessing narrative comprehension abilities in individuals with ASD in the absence of language, one that may allow an alternative assessment of meaning-making while bypassing documented language deficits. Studies using visual narratives and sequential image comprehension in individuals with ASD (Baron-Cohen, Leslie, & Frith, 1986; Davis, Dautenhahn, Nehaniv, & Powell, 2007; Zalla, Labruyère, Clément, & Georgieff, 2010) have suggested deficits in sequential image comprehension, in line with studies of narrative comprehension in the linguistic domain. For instance, children with ASD have shown impairments compared to TD children in picture arrangement for stories requiring ToM (Baron-Cohen et al., 1986), inferring missing panels from visual event sequences (Davis et al., 2007), and predicting the final image of event sequences (Zalla et al., 2010).

Altogether, these studies hint that similar deficits may appear in

visual and linguistic narrative comprehension in individuals with ASD. However, these methods also have limitations. For instance, performance on picture arrangement tasks is modulated by age and experience reading comics (Nakazawa, 2016), and reconstructions often marked as "errors" to a presumed "correct" sequence may still be narratively well-formed (Cohn, 2014). Furthermore, these prior studies of visual narrative comprehension of individuals with ASD have all been performed behaviorally, whereas the addition of neuroimaging methods may be better suited to illuminating subtle differences in cognitive processing between groups (especially those that might be masked by relatively intact behavioral performance; see for example, Braeutigam, Swithenby, & Bailey, 2008; Dunn & Bates, 2005; Dunn et al., 1999; Strandburg et al., 1993, for reports of atypical N400 effects in individuals with ASD in the absence of group differences in behavioral performance). In the current study, we employ ERPs to investigate narrative comprehension abilities in individuals with ASD.

1.5. The current study

We examined the comprehension of linguistic narratives (written sentences) and visual narratives (comic strips) in adults with ASD and TD adults to explore whether narrative comprehension deficits in ASD also occur in non-linguistic modalities. Our stimuli were adapted from previous studies using *Peanuts* comic strips for visual narratives (Cohn & Paczynski, 2013; Cohn et al., 2012; Cohn, Jackendoff, Holcomb, & Kuperberg, 2014); linguistic narratives were short sentences translated from these comic strips. Narratives ended with either a semantically congruent or incongruent word, for written narratives; or a semantically congruent or incongruent comic panel, for visual narratives (Fig. 1). Narrative comprehension was assessed using the N400 ERP component. (Participants performed a behavioral task on a subset of trials to maintain attention. However, our main outcome measure was the N400 component.)

For linguistic narratives, we expected to replicate previous findings on N400 effects to linguistic stimuli in individuals with ASD, predicting a reduced or absent N400 effect in the ASD group compared to the TD group. As interpreted by prior studies, this result would suggest impaired semantic processing for linguistic narratives and a difficulty with semantic integration in the global context of the narrative. For visual narratives, we predicted an N400 effect for the TD group (replicating the findings of West and Holcomb, 2002). However, for visual narratives in the ASD group, we proposed two alternative outcomes.

First, if individuals with ASD have intact visuo-semantic processing,

as several studies have suggested, visual narrative comprehension may be unimpaired. This may suggest that narrative comprehension remains generally intact in ASD, but difficulties with linguistic narratives may be driven by language processing deficits. For instance, visual narratives may recruit a slightly different brain network for comprehension – one that is perhaps less affected by underconnectivity in the long-range networks required for language processing. A language-specific deficit in narrative comprehension would predict an asymmetrical pattern of results in the current study: similar N400 effects in the visual narratives between groups and a reduced or absent N400 effect for the ASD group compared to the TD group in linguistic narratives only.

Alternatively, visual narratives require integrating information across the sequential narrative context to identify semantic incongruity and appear to use similar cognitive and neural mechanisms as linguistic processing. If individuals with ASD have trouble with integrating contextual information, this may lead to similar impairments in narrative comprehension regardless of modality of presentation. This may suggest that visual and linguistic narrative comprehension rely on largely shared neural substrates, and impaired narrative comprehension in individuals with ASD stems from modality-independent difficulties with integrating information into a broader context. Consequently, this would predict a symmetrical pattern of results: reduced or absent N400 effect for both the linguistic and visual narratives in the ASD group compared to the TD group.

2. Methods

2.1. Participants

One group consisted of 20 adults with ASD, ages 18–68 ($M = 33$, $SD = 15$); 16 males, 4 females; 19 Caucasian, 1 mixed race. The clinical diagnosis of autism or ASD (according to DSM-IV or DSM-5 classification, depending on the most recent diagnosis/evaluation) was established through record review and confirmed through administration of the Autism Diagnostic Observation Schedule (First or Second Edition, depending on the current version at the time of initial testing; Lord et al., 2000, 2012).

A second group consisted of 20 TD participants ages 19–68 ($M = 34$, $SD = 16$); 16 males, 4 females; 17 Caucasian, 1 Asian, 2 African American. Groups were matched on a participant-by-participant basis on age and gender (Table 1). TD participants had no histories of neurological disorder or learning disability.

Participants were recruited through newspaper advertisements,

a)

Preceding narrative context:
Charlie Brown and Snoopy were playing fetch.
Charlie Brown accidentally hit Snoopy with the ball.

Final target sentence:
Congruent sentence: Snoopy got mad and refused to return the *ball.*
Incongruent sentence: Snoopy got mad and refused to return the *foodbowl.*
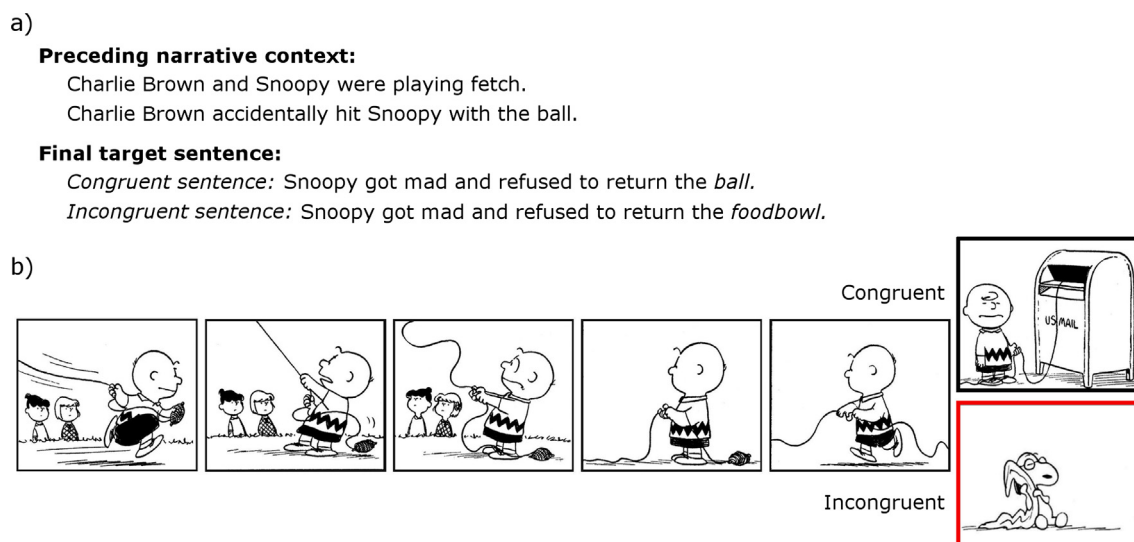
b)

Fig. 1. Examples of (a) linguistic stimuli in which the last word of the final sentence was congruent or incongruent with the preceding narrative context; and (b) visual stimuli in which the last panel was congruent or incongruent with the preceding context.

Table 1

Participant characteristics for the TD and ASD groups. Means and ranges are reported for each measure. The 'group difference' column shows the results of independent-samples t-tests on each measure. Asterisks indicate statistically significant results (* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$).

		TD group (n = 20)	ASD group (n = 20)	Group difference
Age		34 (19–68)	33 (18–68)	$t(37.9) = 0.21$, $p = 0.83$
PPVT		120 (104–136)	104 (71–137)	$t(26.2) = 3.11$, $p < 0.01$**
K-BIT	Verbal	114 (92–130)	101 (71–154)	$t(27.6) = 2.27$, $p < 0.05$*
	Non-verbal	111 (92–132)	101 (44–132)	$t(31.0) = 1.80$, $p = 0.08$
Autism quotient		15 (7–28)	28 (16–36)[a]	$t(35.7) = 6.24$, $p < 0.0001$***
ADOS	Original algorithm social + communication total	NA	11 (6–21)	NA
	Revised algorithm SA + RBB total[b]		13 (8–25)	
	Calibrated severity score (CSS)[c]		7 (4–10)	
Visual language fluency index	Overall score	10 (3–25)	13 (3–33)	$t(29.1) = 1.29$, $p = 0.21$
	Peanuts familiarity as a child	3.15 (1–5)	2.45 (1–4)	$t(37.0) = 2.02$, $p = 0.05$
	Peanuts familiarity currently	2.4 (1–4)	2.65 (1–5)	$t(36.5) = 0.64$, $p = 0.52$

[a] AQ scores were not available for two participants in the ASD group.

[b] This revised algorithm is specific to the ADOS-2 (Hus & Lord, 2014). There were three participants in our sample who were originally tested when the ADOS-1 was the most up-to-date version, and for whom we were not able to complete updated retesting with the ADOS-2. For all other participants, we were able to redo testing with the ADOS-2. Therefore this demographic only includes scores from 17 participants. SA = Social Affect; RBB = Restricted and Repetitive Behaviors.

[c] Calibrated severity scores (CSS) have only been derived for the revised algorithms in the ADOS-2. There were three participants in our sample who were tested with the ADOS-1, and for whom CSS are therefore unavailable. In addition, the CSS for Module 4 were calibrated only for participants ages 9–39 (Hus & Lord, 2014). No calibrated scores were provided for participants older than 40, which means that technically we cannot calculate CSS for our older participants. In our sample, five participants were over 40 (two of whom were already excluded from CSS because of performing ADOS-1). When considering all participants under

public announcements, and fliers at The Johns Hopkins University and Hospital. ASD participants were recruited with the assistance of the Interactive Autism Network (IAN) Research Database at the Kennedy Krieger Institute, Baltimore. All procedures were approved by the Johns Hopkins University Institutional Review Board. Written informed consent was obtained before experimental testing. Participants were monetarily compensated for their participation.

All participants had self-reported normal or corrected-to-normal vision. Both groups completed the Peabody Picture Vocabulary Test (PPVT-4; Dunn & Dunn, 2007) to assess receptive vocabulary; the Kaufman Brief Intelligence Test (K-BIT-2; Kaufman & Kaufman, 2004) to assess verbal and non-verbal intelligence; the Autism Quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) to assess autistic traits; and a history questionnaire to rule out any neurological deficits. Participants also completed the Visual Language Fluency Index (VLFI) to assess expertise at comprehending comics and visual narratives. The metric generated by this questionnaire correlates with behavioral and neurological aspects of visual narrative comprehension (Cohn & Maher, 2015; Cohn et al., 2012). This questionnaire also included a yes/no question about whether participants were familiar with the *Peanuts* comics and asked them to rate their familiarity currently and as children on a scale from 1 (below average) to 5 (above average).

Groups did not differ on age or VLFI scores (all p's > 0.21; Table 1). On the VLFI, 17 ASD participants and all 20 TD participants reported familiarity with the *Peanuts* comics. This raises the potential that prior knowledge may aid in interpretation of the narratives. However, "familiarity" is a vague term, especially as the *Peanuts* franchise extends to many different media (e.g., participants may have watched the movies but never read the comic strips). Even if participants were highly familiar with the hundreds of *Peanuts* comic strips used to create these novel stimuli (see Section 2.2), the use of prior interpretation to predict upcoming events would be limited. There were no significant group differences on current familiarity with the *Peanuts* comics ($p = 0.52$), although there was a statistical trend toward the TD group reporting higher familiarity as children compared to the ASD group ($p = 0.05$).

As expected, the ASD group had higher AQ scores than the TD group ($p < 0.0001$). The ASD group also had lower receptive vocabulary knowledge ($p < 0.01$), lower verbal IQ ($p < 0.05$), and a trend toward lower non-verbal IQ ($p = 0.08$) compared to the TD group.

2.2. Stimuli

Stimuli were selected from an extensive corpus of more than 500 visual narrative sequences designed by recombining panels from volumes of *The Complete Peanuts* by Charles Schulz (Fantagraphic Books, 2004–2006) to create novel sequences for experimental purposes. The narrative qualities of these stimuli have been confirmed theoretically and empirically (e.g., Cohn & Bender, 2017; Cohn et al., 2012). They contain critical semantic components of narratives such as goal-directed actions (e.g., Snoopy kicks birds off his doghouse because they are noisy) and emotions (e.g., Charlie Brown is mad when Lucy throws a snowball at him). Because these stimuli contain multiple sentences or panels, which must be individually understood and integrated with each other, they are complex (at least above the sentence level) and coherent. Furthermore, unlike many other studies, these stimuli were designed in reference to a specific narrative theory – the narrative grammar outlined by Cohn (2013b) – and experiments have validated this structure (Cohn, 2014; Cohn et al., 2014, 2012). These sequences have also been used in several ERP studies, which have confirmed their semantic and narrative structures (e.g., Cohn & Maher, 2015; Cohn et al., 2012).

From this corpus, 100 6-panel comic strips were selected for the visual narratives (50 congruent, 50 incongruent). For incongruent visual narratives, the final panel was switched with that of another strip, ensuring no semantic overlap between the two strips. Following

previous studies with these stimuli (Cohn et al., 2012), 20 filler trials (10 congruent, 10 incongruent) consisting of strips of 7–12 panels were also created to dissuade participants from expecting incongruent panels to appear in the sixth position, which could have affected N400 results (Kutas & Federmeier, 2011).

An additional 100 6-panel comic strips were selected for the linguistic narratives (50 congruent, 50 incongruent). For these stimuli, the original comic strips were translated into three short sentences. Incongruent stimuli were created by switching the final word in the sentence with that of another sentence, avoiding semantic overlap between the two sentences or narratives. Semantic violations were designed to be incongruent only with the narrative context: The final sentence alone would not be anomalous, but when read in the preceding narrative context, the final word would be incongruent (see Fig. 1). To dissuade a strategy of expecting the third sentence to be the target sentence, 20 filler trials (10 congruent, 10 incongruent) were created for the linguistic condition from the longer comic strips, similar to the filler trials for visual narratives. These were translated into narratives of 4–7 sentences in length.

Two additional comic strips and corresponding linguistic narratives, not included in the experimental stimuli, were used as practice stimuli in each modality.

Twenty percent of trials (10 in each experimental condition, 2 in each filler condition) were followed by a comprehension question to maintain attention to the stimuli and confirm that participants were semantically processing the narratives. For visual narratives, a different comic panel (not used in any other stimuli) was presented, and participants were asked to determine whether the "theme" of that panel matched the preceding narrative. For example, if the preceding narrative showed Charlie Brown building a snowman, the comprehension probe could be a panel showing snow falling (correct answer 'yes'), or Snoopy at the beach (correct answer 'no'). For linguistic narratives, participants determined whether a single word matched the semantic theme of the preceding narrative. For example, if the narrative described Charlie Brown and his friends playing baseball, the comprehension probe could be the word "SPORT" (correct answer 'yes'), or "WEATHER" (correct answer 'no'). The comprehension probe word did not appear in the preceding narrative, prompting semantic processing and avoiding participants answering comprehension questions based on surface-level information like visual matching. Half of the comprehension questions had a correct answer of 'yes' and half 'no.'

Although we attempted to equate linguistic and visual narratives, the modalities were not formally matched on certain variables. For instance, visual narratives featured more characters depicted in the panels (mean 2.74 per narrative) than were mentioned by name in linguistic narratives (mean 1.9 per narrative; $p < 0.0001$). Some comic panels featured "inactive" characters – figures in the background that did not take part in sequential actions (Cohn, 2013a) – which increased the average number of physically depicted characters. When translating the comic stimuli into sentences for linguistic narratives, some of this extra "background" information was necessarily lost. Because we were not able to match stimuli across modalities on variables such as stimulus complexity or emotional content, we first considered each modality separately in our analyses before directly comparing visual and linguistic narratives.

2.3. Procedure

Participants attended one session of approximately two hours, including consenting and completing paperwork, behavioral tests, EEG net application, and experimental testing.

Stimuli were presented using E-Prime version 2.0.8.74. Modality was counterbalanced between participants. Each modality consisted of five blocks, with 24 stimuli per block. The number of congruent and incongruent stimuli, filler trials, and comprehension questions were

equal across blocks. The order of stimulus presentation within each block was pseudorandomized.

Each trial began with a "Ready?" screen, which remained until participants pressed a button, followed by a fixation cross presented for 500 ms. For linguistic narratives, on each trial the non-target sentences (i.e., first two sentences in 3-sentence trials; first three sentences in 4-sentence trials; etc.) were presented in a self-paced reading style. Each sentence remained on screen in its entirety until the participant pressed a button to view the next sentence. These initial sentences served to set up the narrative context (Fig. 1). The groups did not differ on the time taken to read these self-paced sentences ($p = 0.22$). The final target sentence was presented word-by-word in rapid serial visual presentation (RSVP). Each word was presented for 300 ms (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Pijnacker et al., 2010), with a 200 ms inter-stimulus interval (ISI). For visual narratives, each panel was presented for 1350 ms, with an ISI of 350 ms (Cohn & Maher, 2015).

On trials with comprehension questions, following presentation of the entire narrative the comprehension probe was presented in the center of the screen under a red question mark with a red border around the slide. Participants were asked to indicate whether the comprehension word/panel matched the narrative they had just read or viewed. Accuracy, rather than speed, was emphasized for comprehension questions. The comprehension probe remained on screen until participants responded with a button press.

Stimuli were presented on a Dell 17″ LCD monitor with 1280 × 1024 resolution. Participants sat approximately 24″ away from the screen. Each comic panel was 5.5″ wide and 4.5″ high, yielding a visual angle of 13.1° horizontally and 10.7° vertically. Linguistic stimuli were presented in 18-point Times New Roman font. Words were 1/8″ high, yielding a visual angle of 0.3° vertically, and ranged from 1/8″ to 3/4″ in width, yielding a visual angle between 0.3 and 1.8° horizontally.

EEG data were continually recorded at 250 Hz using EGI's Geodesic EEG System (GES) 300, a 256-channel EGI Geodesics Sensor net, and NetStation version 4.3. Data were acquired with a 4 kHz antialiasing lowpass filter and were referenced to the Cz electrode. Impedances were kept under 50 kΩ wherever possible.

2.4. Data preprocessing

Preprocessing of EEG data was performed with EEGlab version 13.3.2 (Delorme & Makeig, 2004) and Matlab 2014a. The continuous data were filtered using a 0.1–50 Hz bandpass filter and then segmented into epochs time-locked to the onset of the final word or panel. Segments extended from 100 ms before to 1500 ms after the target. Artifact correction was performed using independent component analysis (ICA; Delorme, Sejnowski, & Makeig, 2007; Jung et al., 2000). Prior to ICA decomposition, the mean of each trial was removed (Groppe, Makeig, & Kutas, 2009), and data were reduced to 32 dimensions. ICA was run for each participant separately. Following ICA decomposition, the topographic plots and ERP waveforms of each component were displayed and reviewed. Components clearly contributing to movement, eye blinks or saccades, or other sources of noise were then marked for removal by a trained examiner (EC). Following ICA decomposition, segments were baseline corrected using data from the first 100 ms of the segment and re-referenced to the average of the left and right mastoids. Bad epochs were identified and rejected using a joint probability computation (Delorme et al., 2007) with a threshold of 3 standard deviations. Following this step, each individual trial was visually reviewed and a trained experimenter (EC) marked any further bad trials for removal (e.g. those containing additional eye movements, blinks, muscle artifacts, and other noise components that might not have been caught by the joint probability algorithm). On average, 82% of trials (41 per trial type) were included in statistical analyses. Similar numbers of trials were included in each condition between modalities and

groups. (Visual narratives, TD group: congruent = average 42/50 trials retained, incongruent = 40/50 trials. Visual narratives, ASD group: congruent = 39/50 trials, incongruent = 39/50 trials. Linguistic narratives, TD group: congruent = 42/50 trials, incongruent = 40/50 trials. Linguistic narratives, ASD group: congruent = 41/50 trials, incongruent = 41/50 trials.)

2.5. Statistical analyses

Statistical analyses were performed using R version 3.2.2 (R Core Team, 2015). ERP amplitude was evaluated at nine clusters across the scalp centered around F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4. Because this is the first study to use EEG to investigate narrative comprehension in individuals with ASD, it is possible that this group may show atypical scalp distributions of the N400. Therefore, these sites were chosen to provide a broad scalp representation and avoid missing any potential effects outside of a predefined region of analysis. Time windows for analyses were chosen based on visual inspection. Because the stimuli varied across modalities on several variables (see Section 2.2), and because we expected different N400 topographies for each modality (a frontal N400 response to visual narratives compared to a parietal effect for linguistic narratives; Cohn et al., 2012; Kutas & Federmeier, 2011; West & Holcomb, 2002), analyses were first performed for visual and linguistic narratives separately. To evaluate group differences in ERP amplitude, repeated-measure ANOVAs were run for each modality with within-subject factors of *congruency* (congruent/incongruent), *site* (frontal/central/parietal), and *laterality* (left/midline/right), and a between-subjects factor of *group* (TD/ASD). To directly compare whether the groups differed in their responses to linguistic vs. visual narratives, we also ran a 2 (group) × 2 (modality) × 3 (site) × 3 (laterality) repeated-measures ANOVA on the average difference wave amplitude (incongruent minus congruent). While direct comparison of the raw ERPs would be confounded by physical differences between visual and linguistic stimuli, by calculating difference waves these domain-specific effects are subtracted out, allowing us to examine the effects of our contextual manipulation. To account for group differences in language abilities, PPVT score was included as a covariate in all analyses.[1]

3. Results

3.1. Behavioral data

Although behavioral performance was not our main outcome measure, we analyzed accuracy rates[2] to the comprehension questions presented on 20% of trials to ensure that participants were successfully attending to the stimuli. There was no threshold for exclusion based on comprehension accuracy. Among the TD group, the mean accuracy on the comprehension questions was 90% (over all modalities and congruencies; range 70–100%), whereas among the ASD group the mean accuracy was 83% (range 50–100%). A series of one-sample *t*-tests also

---

[1] We also ran all analyses with verbal K-BIT and non-verbal K-BIT as covariates instead of PPVT and the results were highly similar. Because the group difference in PPVT scores showed the largest effect, we choose to report the results using this variable as a covariate.

[2] Because accuracy, rather than response speed, was emphasized for the comprehension questions, the reaction times (RTs) for these questions may not be as reliable a measure of performance as accuracy. Nevertheless, we also compared RTs between groups and modalities. The results showed a main effect of modality ($F(1, 38) = 15.81$, $p < 0.001$) such that over both groups, RTs were slower for visual narratives (mean RT = 2317 ms) than for linguistic narratives (mean RT = 1829 ms). This result mirrors the finding of higher error rates in the visual narratives for both groups and suggests that comprehension of visual narratives was more challenging than comprehension of linguistic narratives. There were no main effects or interactions with group in the RT analysis (all *p*'s > 0.29), indicating no group differences in RTs.

showed that both groups were significantly above 50% chance for all modalities and congruencies (all *p*'s < 0.0001).

A two-way (modality: visual/linguistic) repeated-measures ANOVA, with group as a between-subjects factor and PPVT as a covariate, showed a main effect of modality ($F(1, 38) = 8.89$, $p < 0.01$) such that responses to visual narratives were less accurate (84%) than those to linguistic narratives (89%). This suggests that both groups found comprehension of the visual narratives more challenging. There was no main effect of or interaction with group (all *p*'s > 0.21), suggesting that participants did not differ in their attention to the stimuli.

3.2. ERP data

3.2.1. Linguistic narratives

Visual inspection of linguistic narrative waveforms for the TD group (Fig. 2) indicated a central N400 effect from approximately 300–500 ms. There was also a late positive component (LPC), in which the incongruent condition was more positive than the congruent condition, from approximately 500–900 ms over centro-parietal scalp. Visual inspection of waveforms for the ASD group (Fig. 3) indicated a small N400 effect over midline parietal scalp from approximately 200–500 ms and an LPC effect over fronto-central scalp from approximately 500–1200 ms. Overall, initial visual inspection revealed an N400 effect from approximately 300–500 ms and an LPC effect from approximately 500–900 ms in both groups. The ASD group also had a more sustained LPC effect extending to approximately 1200 ms.

Comparison of incongruent-congruent difference waves in each group (Fig. 4) suggested potential group differences in N400 and LPC effect magnitudes. To statistically investigate these group differences, we ran ANOVAs in three time windows: 300–500 ms, 500–800 ms, and 800–1200 ms. Below we report only main effects of or interactions with group (see Table 2 for full results).

From 300 to 500 ms (N400 window), an interaction of group, congruency, and site ($F(2, 76) = 4.32$, $p < 0.05$) arose from a group * congruency interaction at frontal sites ($F(1, 38) = 5.12$, $p < 0.01$) and a trend toward an interaction at central sites ($F(1, 38) = 3.13$, $p = 0.08$). At frontal and central sites, TD participants showed main effects of congruency (all *p*'s < 0.01), with incongruent conditions more negative than congruent conditions (i.e., an N400 effect). ASD participants did not show any congruency effects (all *p*'s > 0.35). In sum, TD participants showed stronger N400 effects to linguistic narratives than ASD participants at frontal and central sites from 300 to 500 ms.

From 500 to 800 ms (early LPC window) there was an interaction of group, congruency, and site ($F(2, 76) = 4.97$, $p < 0.01$). The TD group showed a congruency * site interaction ($F(2, 38) = 4.85$, $p < 0.05$), but there were no significant congruency effects at any site (all *p*'s > 0.19). The ASD group did not show a congruency * site interaction ($p = 0.32$). In sum, although there was a trend of an LPC effect in the TD group from 500 to 800 ms, this was not statistically significant in either group.

From 800 to 1200 ms (late LPC window) there were no significant effects of or interactions with group.

3.2.2. Visual narratives

Visual inspection of visual narrative waveforms for the TD group (Fig. 5) indicated a sustained fronto-central N400 effect from approximately 300–1300 ms. Visual inspection of waveforms for the ASD group (Fig. 6) indicated an N400 effect from approximately 300–800 ms over frontal sites. Overall, initial visual inspection revealed fronto-central N400 effects in both groups.

Comparison of difference waves (Fig. 7), suggested the N400 effect began at approximately 300 ms in both groups but was more sustained in TD participants. To statistically investigate group differences in the earlier and later portions of this effect, we ran ANOVAs from 300 to 500 ms, 500–800 ms, and 800–1200 ms. Below we report only main effects of or interactions with group (see full results in Table 2).
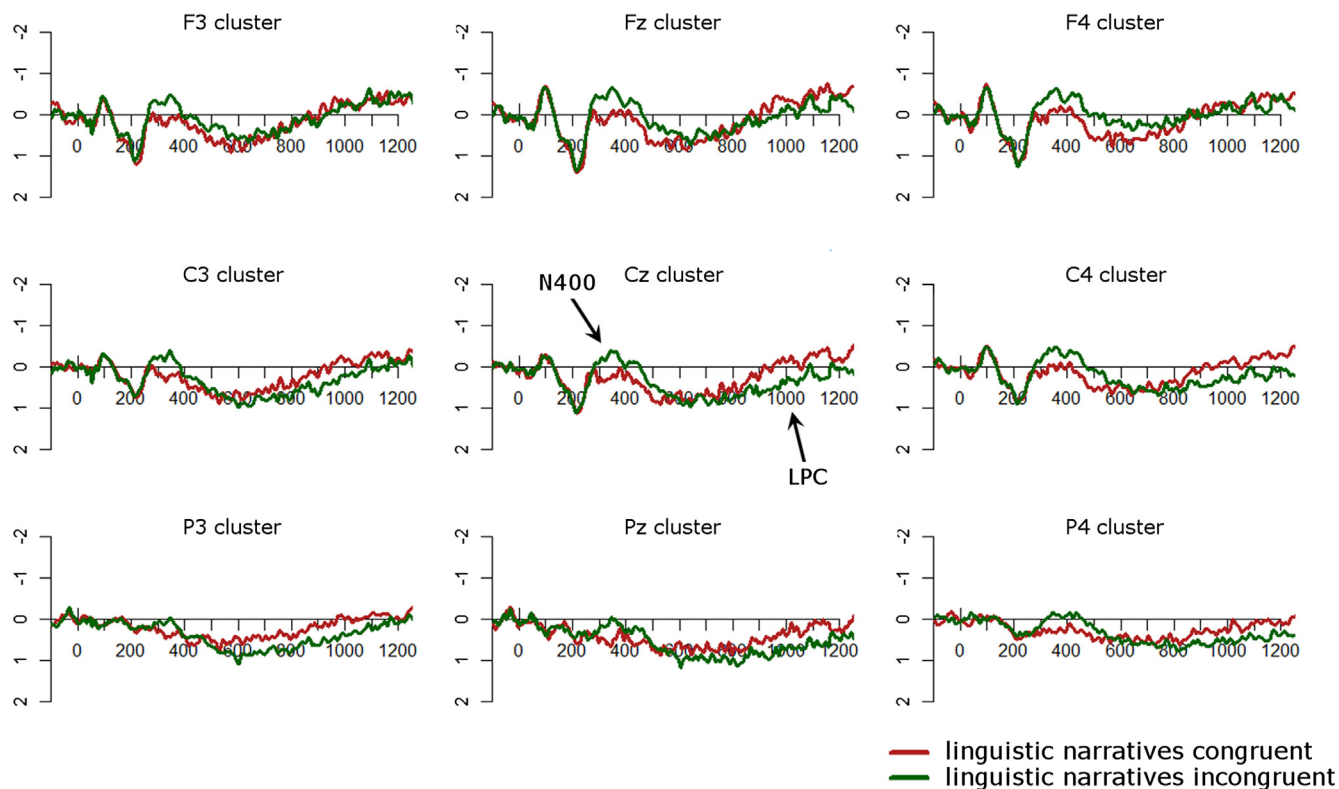
Fig. 2. ERPs for linguistic narratives in the TD group.
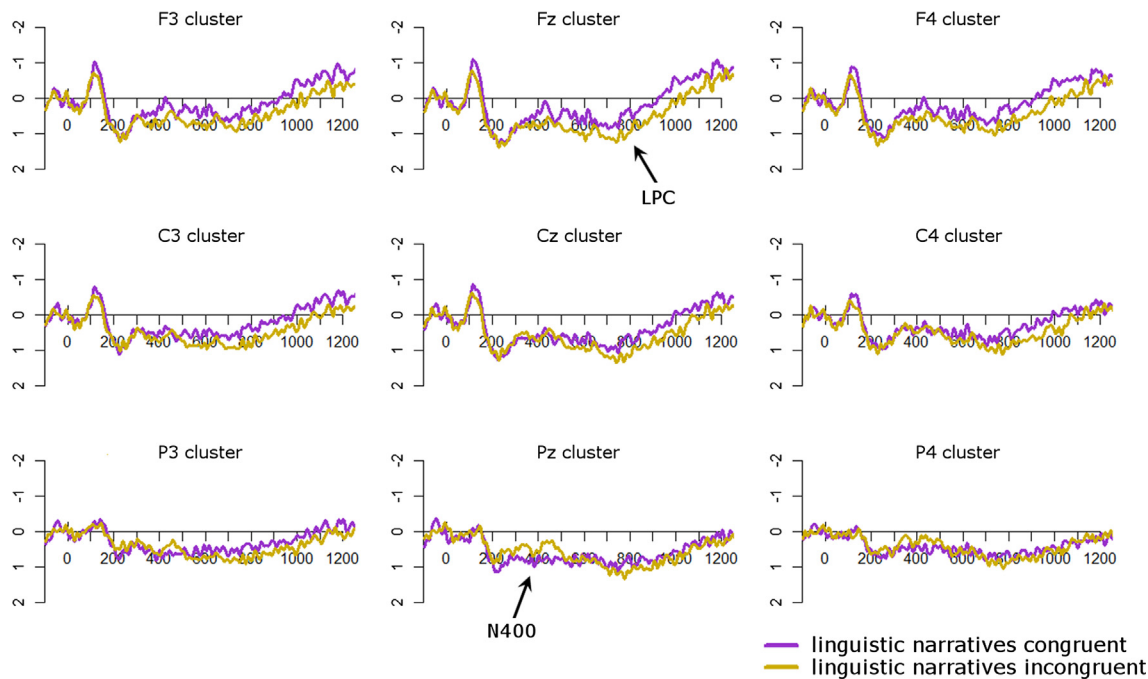

Fig. 3. ERPs for linguistic narratives in the ASD group.

From 300 to 500 ms there were no main effects of or interactions with group.

From 500 to 800 ms there was an interaction of group, congruency, and site ($F(2, 76) = 4.53$, $p < 0.05$) arising from a group * congruency interaction at frontal sites ($F(1, 38) = 4.90$, $p < 0.05$): The TD group showed a significant congruency effect ($F(1, 19) = 23.42$, $p < 0.001$), with incongruent conditions more negative than congruent conditions (i.e., an N400 effect), whereas the ASD group showed no congruency

effect ($p = 0.22$). In sum, TD participants showed a larger N400 effect than ASD participants over frontal sites from 500 to 800 ms.

From 800 to 1200 ms there was an interaction of group, congruency, and site ($F(2, 76) = 5.23$, $p < 0.01$) arising from a trend toward a significant group * congruency interaction at frontal sites ($F(1, 38) = 3.46$, $p = 0.07$): The TD group showed a significant congruency effect ($F(1, 19) = 16.22$, $p < 0.001$), with incongruent conditions more negative than congruent conditions (i.e., an N400 effect), whereas
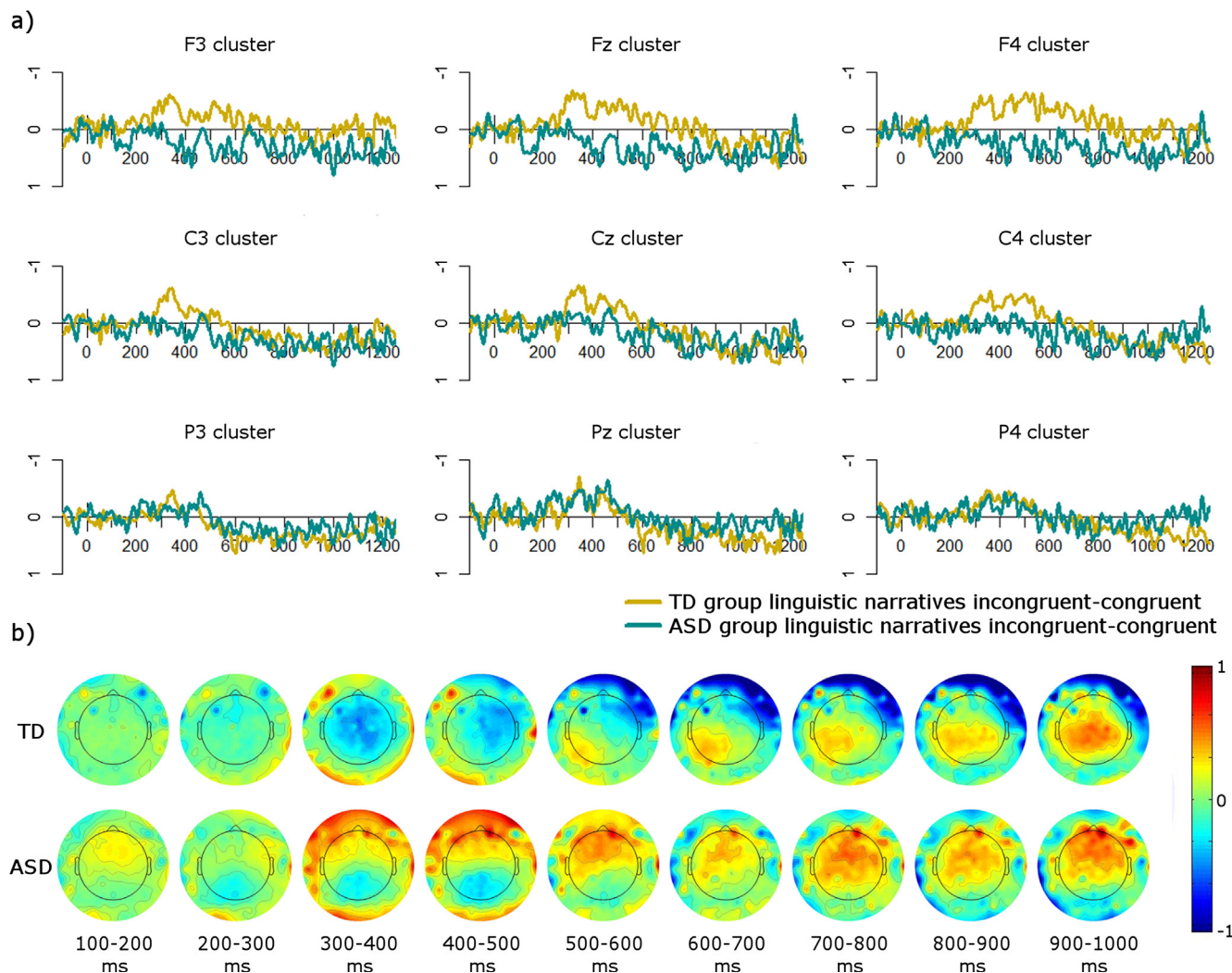
Fig. 4. Group comparisons for linguistic narratives. (a) ERP difference waves (incongruent – congruent) for each group. (b) Topographic plots (incongruent – congruent) in 100 ms windows from 100 to 1000 ms for each group.

Table 2

F-values for the repeated-measures ANOVAs, with a between-subjects factor of *group* (TD, ASD), within-subjects factors of *congruency* (congruent, incongruent), *site* (frontal, central, parietal), and *laterality* (left, midline, right), and PPVT as a covariate, in each narrative type and analysis window. Asterisks indicate statistically significant results (* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$). Main effects of group and interactions with group are highlighted in bold.

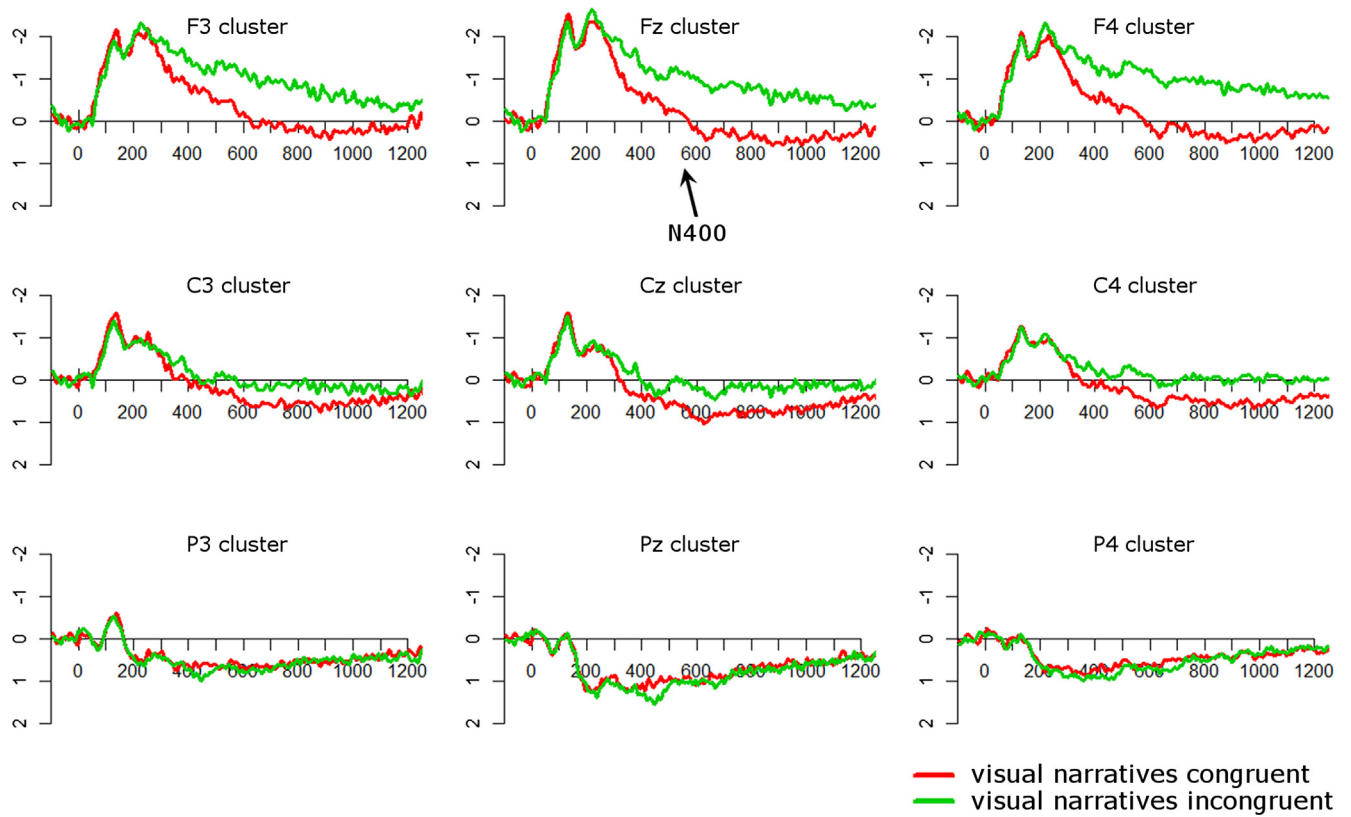| Main effect or interaction	Linguistic narratives			Visual narratives		
	300–500 ms	500–800 ms	800–1200 ms	300–500 ms	500–800 ms	800–1200 ms
PPVT	0.003	0.20	0.06	3.00	4.05	3.25
Congruency	3.29	1.40	4.46*	8.98**	8.38**	5.41*
Site	1.72	1.78	15.67***	35.02***	22.52***	8.87***
Laterality	7.20***	8.18***	2.20	2.37	3.39*	2.83
Group	3.33	0.53	0.01	0.49	0.94	1.81
Group × congruency	3.34	1.32	0.02	0.02	2.56	1.05
Group × site	2.44	0.33	0.01	0.42	0.51	0.28
Group × laterality	1.60	1.54	0.05	0.44	0.14	0.04
Congruency × site	1.25	0.53	0.55	19.18***	21.08***	9.60***
Congruency × laterality	1.87	2.16	0.42	0.18	0.53	1.79
Site × laterality	1.29	1.30	7.41***	5.25***	1.99	1.08
Congruency × site × laterality	0.67	1.41	0.57	0.87	0.57	0.63
Group × congruency × laterality	0.25	0.50	0.27	0.17	0.11	0.37
Group × congruency × site	**4.32***	**4.97****	2.00	1.47	**4.53***	**5.23****
Group × site × laterality	0.74	0.34	0.31	0.88	0.73	0.26
Group × congruency × site × laterality	0.47	0.22	0.22	0.66	0.55	0.63

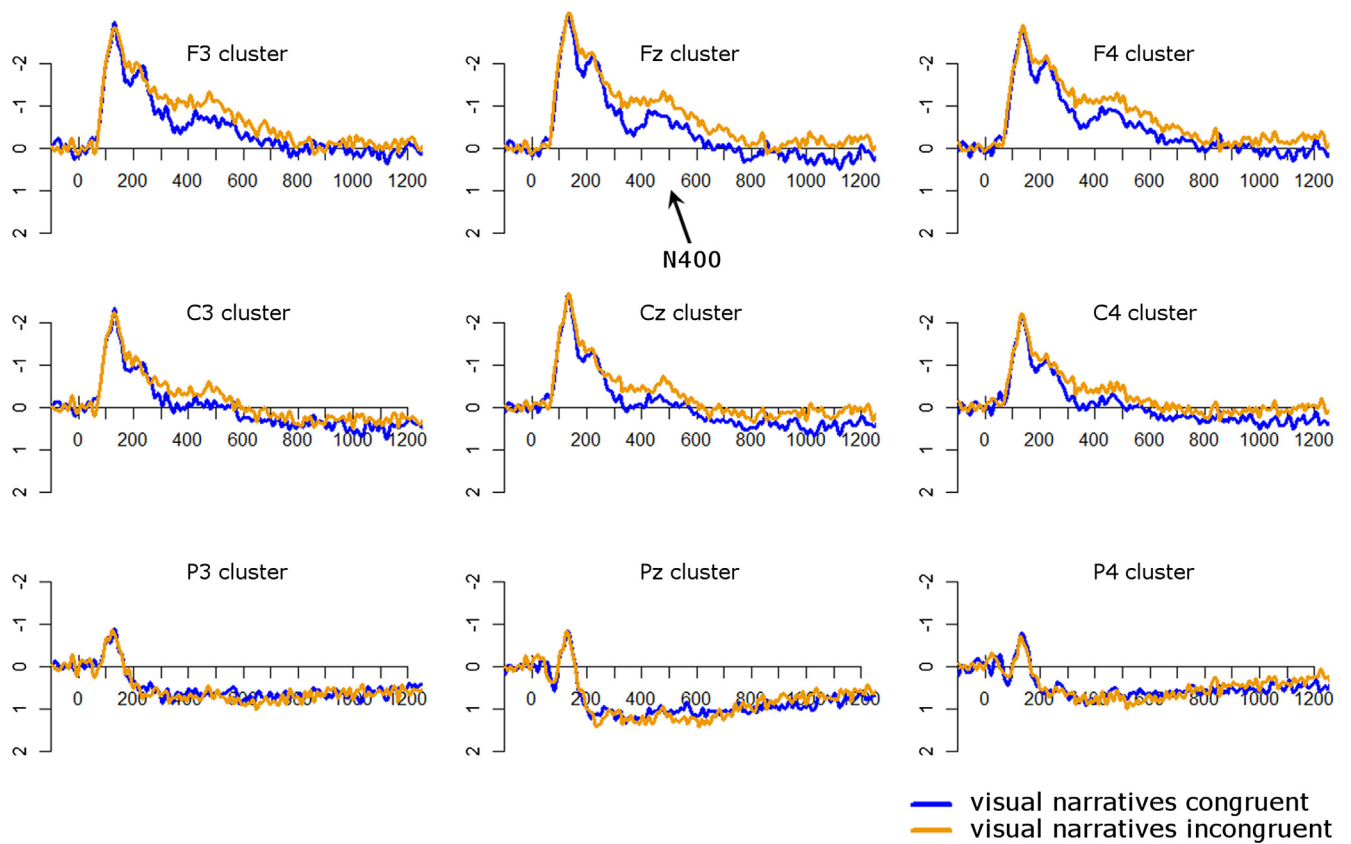**Fig. 5.** ERPs for visual narratives in the TD group.

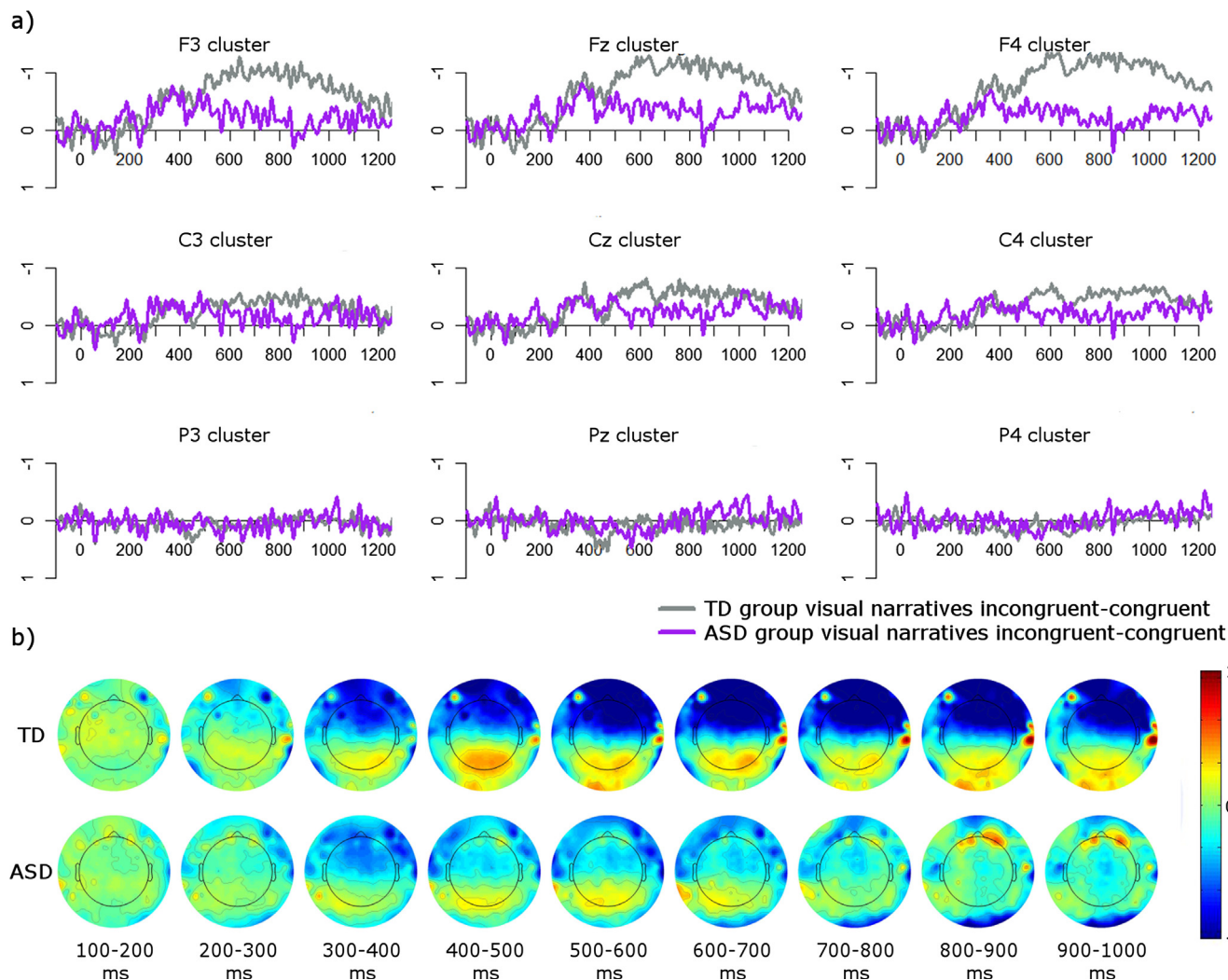**Fig. 6.** ERPs for visual narratives in the ASD group.

a)

b)

Fig. 7. Group comparisons for visual narratives. (a) ERP difference waves (incongruent – congruent) for each group. (b) Topographic plots (incongruent – congruent) in 100 ms windows from 100 to 1000 ms for each group.
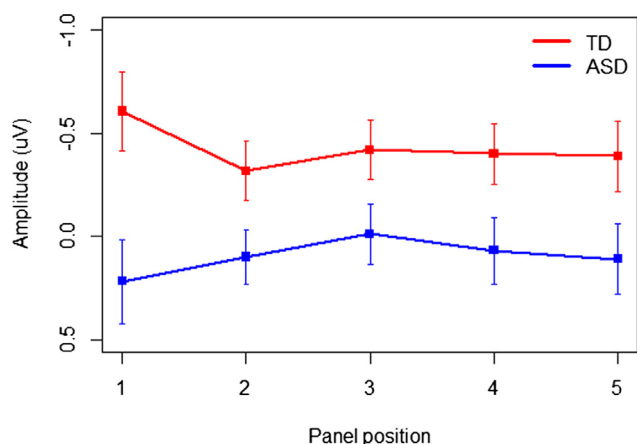

Fig. 8. Average ERP amplitude in the left hemisphere (averaged over site) from 200 to 400 ms for each visual narrative panel. Error bars show the standard error of the mean. Negativity is plotted upwards.

the ASD group showed no congruency effect ($p = 0.46$). In sum, TD participants also showed a larger sustained negativity than ASD participants over frontal sites from 800 to 1200 ms.

3.2.2.1. Ordinal sequence position analyses. We also evaluated whether the position of each panel in the ordinal sequence of visual narratives affected N400 amplitudes. Previous studies have used such an analysis to investigate the build-up of meaning across a narrative sequence (Cohn & Paczynski, 2013; Cohn & Wittenberg, 2016; Cohn et al., 2012). (Note that an analogous ordinal sequence position analysis could not be done for linguistic narratives: Because each word in the target sentence was presented for only 300 ms, ERP segments would overlap.)

ERP responses to panels 1–5 were collapsed over congruent and incongruent conditions. (Panel 6, the congruent or incongruent panel, was not evaluated.) Initial visual inspection of ERP waveforms for each group and panel position suggested potential group differences at all panel positions in an early N400 window from approximately 200–400 ms. A 2 (group) × 5 (panel position) × 3 (site) × 3 (laterality) repeated-measures ANOVA, with PPVT as a covariate, on the average amplitude from 200 to 400 ms showed an interaction of group, panel position, and laterality ($F(8, 304) = 3.05$, $p < 0.01$). This arose from group * laterality interactions at panel 1 ($F(2, 76) = 5.84$, $p < 0.01$) and panel 5 ($F(2, 76) = 4.04$, $p < 0.05$) such that, for both positions, ERP amplitudes over left hemisphere sites were more negative for TD participants than for ASD participants (Fig. 8).

3.2.3. Direct comparison of linguistic and visual modalities

To directly compare whether the groups differed in their responses

Table 3

F-values for the repeated-measures ANOVAs directly comparing modalities using incongruent-congruent difference waves, with a between-subjects factor of *group* (TD, ASD), within-subjects factors of *modality* (linguistic, visual), *site* (frontal, central, parietal), and *laterality* (left, midline, right), and PPVT as a covariate, in each analysis window. Asterisks indicate statistically significant results (* = *p* < 0.05; ** = *p* < 0.01; *** = *p* < 0.001). Main effects of group and interactions with group are highlighted in bold.

Main effect or interaction	300–500 ms	500–800 ms	800–1200 ms
PPVT	0.36	0.61	0.01
Modality	0.57	7.95**	7.91**
Site	6.03**	15.47***	4.84*
Laterality	1.48	1.64	1.09
Group	1.71	3.33	1.25
Group × modality	1.39	0.11	0.33
Group × site	5.37**	9.34***	7.05**
Group × laterality	0.37	0.44	0.38
Modality × site	14.68***	10.22***	5.58**
Modality × laterality	0.56	0.94	1.06
Site × laterality	0.15	0.29	0.06
Modality × site × laterality	1.91	1.92	1.30
Group × modality × laterality	0.02	0.12	0.26
Group × modality × site	0.51	0.08	0.43
Group × site × laterality	0.50	0.33	0.62
Group × modality × site × laterality	0.74	0.50	0.21

to linguistic vs. visual narratives, we ran a 2 (group) × 2 (modality) × 3 (site) × 3 (laterality) repeated-measures ANOVA on the average difference wave amplitude (incongruent minus congruent) for each time window of interest (300–500 ms, 500–800 ms, and 800–1200 ms). The full results can be found in Table 3.

In all three time windows, there were significant interactions of group and site (all *p*'s < 0.01), which arose from significant effects of group at frontal sites (all *p*'s < 0.01). At frontal sites, the mean difference wave amplitude was more negative for the TD group than for the ASD group. This effect can also be seen in Figs. 4 and 7.

Also notable is that in the 500–800 ms and 800–1200 ms windows, there was a significant interaction of modality and site (all *p*'s < 0.01), which arose from a main effect of site for visual narratives (*p* < 0.01) but not linguistic narratives (all *p*'s > 0.59). In visual narratives, the mean difference wave amplitude was most negative over frontal sites, followed by central and parietal sites, with significant differences between all as determined by paired-sample *t*-tests (all *p*'s < 0.01). This effect can also be seen in Fig. 7.

4. Discussion

Previous studies have suggested that individuals with ASD have difficulties comprehending narratives in the linguistic modality (Jolliffe & Baron-Cohen, 2000; Kaland et al., 2007; Nuske & Bavin, 2011). Meanwhile, visuo-semantic processing in individuals with ASD may be intact for individual images (Kamio & Toichi, 2000; Sahyoun et al., 2009), but impaired for sequential images (Davis et al., 2007; Johnels, Hagberg, Gillberg, & Miniscalco, 2013; Zalla et al., 2010). We evaluated narrative comprehension in linguistic vs. visual modalities, via the N400 component, to explore whether narrative comprehension difficulties in individuals with ASD are language-specific or reflect more general deficits.

4.1. Linguistic narratives

In linguistic narratives, ASD participants showed smaller N400 effects than TD participants at fronto-central sites from 300 to 500 ms. When comparing congruency effects within each group individually, the ASD group did not show a statistically significant N400 effect, whereas the TD group did. This lack of an N400 effect in the ASD group

aligns with previous studies showing absent N400 effects in individuals with ASD in response to linguistic stimuli (Dunn et al., 1999; McCleery et al., 2010; Pijnacker et al., 2010). We interpret our data in a similar way as those previous studies and conclude that, as predicted, the ASD group had impaired semantic processing of linguistic narratives. (We note, though, that there are many possible factors that could be driving these null effects, an important area for future research.)

It is also notable that although both groups showed an LPC effect on visual inspection of the data, this effect was not statistically significant for either group. (The TD group showed a trend toward a significant congruency * site interaction in the 500–800 ms time window, but on follow-up analyses there were no significant congruency effects.) The lack of an LPC effect in our ASD group contradicts a previous study reporting enhanced LPC effects in individuals with ASD (Pijnacker et al., 2010), which was interpreted as a later re-evaluation process triggered by less-automatic initial semantic integration. In the current study, the fact that linguistic narratives consisted of multiple sentences may have compounded semantic integration difficulties in ASD participants, such that later re-evaluation processes were less effective or were not initiated at all.

4.2. Visual narratives

In visual narratives, TD participants showed a sustained frontal N400 effect, beginning around 300 ms and extending past 1000 ms. The topography of this effect replicates previous observations that the N400 response to visual stimuli is typically more frontal than to linguistic stimuli (Cohn et al., 2012; West & Holcomb, 2002). The time window of this effect is also consistent with previous reports showing sustained frontal N400 effects beginning at approximately 300 ms and peaking at approximately 500 ms (Cohn et al., 2012; West & Holcomb, 2002). Importantly, the N400 effect for visual narratives in TD participants was significantly larger than in ASD participants over frontal sites from 500 to 800 ms. Given the slightly later N400 effect observed for visual narratives (Cohn et al., 2012; West & Holcomb, 2002), group differences in this later window rather than the earlier 300–500 ms window were not surprising. The reduced N400 effect for ASD participants may suggest difficulty with semantic comprehension of narratives when presented visually, which supports previous behavioral findings of deficits in sequential image comprehension in individuals with ASD (Davis et al., 2007; Johnels et al., 2013; Zalla et al., 2010).

4.3. Narrative comprehension in ASD

Overall, these results showed a reduced N400 amplitude for both visual and linguistic narratives in individuals with ASD compared to TD individuals, suggesting that narrative comprehension abilities may be more generally impaired in ASD. This interpretation is further supported by our direct comparison of the difference waves between linguistic and visual modalities, which showed no interactions of group and modality, suggesting equivalent deficits in both types of narratives. Although the groups were not matched on language ability (ASD participants had lower PPVT and verbal K-BIT scores than TD participants), we accounted for this difference statistically by including PPVT as a covariate in all analyses. Even when controlling for group differences in language abilities,[3] the data suggested that individuals with ASD showed impaired comprehension of both visual and linguistic narratives. (Similar results held when including verbal K-BIT or non-verbal K-BIT as covariates; see Footnote [1].) These results suggest that comprehension difficulties among individuals with ASD may not solely be

---

[3] Note, however, that we assessed receptive vocabulary abilities and verbal intelligence as measures of language abilities, whereas other higher-level linguistic functions may have influenced the data in ways our experimental design could not assess.

related to language ability, but rather may represent more global impairments in understanding narrative sequences. We conclude, albeit speculatively, that prior evidence of an advantage of visuo-semantic over lexico-semantic processing in individuals with ASD (Coderre et al., 2017; Kamio & Toichi, 2000; Sahyoun et al., 2009) may not necessarily completely overcome more general difficulties with narrative comprehension in these individuals.

Our ordinal sequence position analyses may provide some additional insight into the nature of narrative comprehension deficits in individuals with ASD. Narrative comprehension begins with a process of establishing a narrative context, or "laying a foundation" of information for a subsequent sequence (Cohn & Paczynski, 2013; Gernsbacher, 1990). In visual narratives, this process is reflected as longer viewing times and greater N400 amplitudes to the initial panel in a visual narrative (Cohn & Paczynski, 2013; Cohn & Wittenberg, 2016; Cohn et al., 2012; Cohn, 2014). Viewing times and N400 amplitudes typically decrease progressively across a sequence as incoming semantic information is more easily integrated with a building context.

In our ordinal sequence position analyses, the TD group showed enhanced N400 amplitudes to the first visual narrative panel compared to subsequent panels (Fig. 8), consistent with previous research, but the ASD group showed no such attenuation. The ASD group also showed smaller N400 amplitudes than the TD group from 200 to 400 ms at the first panel, which may suggest deficits in laying a foundation of semantic information for use across the subsequent narrative. In other words, this group may not process the start of the narrative with the intent to be understood "for a sequence," or draw on earlier information to form an ongoing coherent narrative.

Difficulty laying a foundation at the first panel may reflect a broader impairment in narrative comprehension in our ASD population, who may process narratives in a more bottom-up manner instead of benefitting from top-down knowledge of a sequence (e.g., facilitation from context). Such a processing tendency may begin with the first panel, with no initiation of additional processing necessary to understand the images as a sequence, and may also extend to subsequent panels as suggested by the reduced N400 amplitudes across all panels in Fig. 8. Such bottom-up processing could also explain the reduced N400 effects at the anomalous final panels, in which semantic processing of anomalous stimuli may rely on the same bottom-up strategies as other units in the sequence. This would also complement our recent findings of a more bottom-up, post-lexical integration strategy of semantic processing in ASD compared to a more top-down, prediction-based strategy in TD individuals (Coderre et al., 2017).

In sum, we propose that a bottom-up processing style that does not integrate across units may explain the observed deficits in visual narrative comprehension in individuals with ASD. Although we could not evaluate ordinal sequence position effects in the linguistic narratives (due to the short presentation interval of the words), this processing style may also explain the observed deficits in linguistic narrative comprehension observed here and elsewhere (Jolliffe & Baron-Cohen, 2000; Kaland et al., 2007; Mason et al., 2008; Nuske & Bavin, 2011). Such a process would extend beyond modality-specific constraints.

From a neurobiological point of view, our observation of impaired comprehension for both linguistic and visual narratives in the ASD group suggests that impaired narrative comprehension may result from atypical activation or connectivity of domain-general brain areas involved in narrative comprehension, as opposed to, for example, a specific abnormality in language regions. The coarse spatial resolution of EEG limits our ability to draw any concrete conclusions regarding the precise brain areas involved in impaired narrative comprehension in ASD. However, as the N400 has been localized to areas of the frontal and temporal lobes, the reduced N400 effect observed in the ASD group suggests that these regions may be implicated in impaired narrative comprehension. Future neuroimaging work in this area will be an important line of research and could shed light on the nature of comprehension deficits. For example, if narrative comprehension

impairments in ASD primarily stem from ToM deficits, this would predict atypical activation and connectivity of ToM regions during visual narrative comprehension, similar to findings in linguistic narrative comprehension (Mason et al., 2008).

4.4. Limitations and future directions

This study provided an initial exploration of linguistic and visual narrative comprehension in individuals with ASD. However, because it is the first study of its kind, further work should be done to replicate and further explore our findings. For instance, we interpret our EEG results as indicative of different processing styles between individuals with ASD and TD individuals. However, we did not include a validity check to confirm how participants were interpreting the visual and linguistic stimuli that could further support these conclusions. Correlations between the N400/LPC effects and behavioral performance on the comprehension questions also did not yield any significant results. (It is important to note that these comprehension questions were not designed specifically to tap into narrative processing beyond semantic processing. Because the comprehension questions simply asked participants to indicate whether the target semantic theme (e.g. "baseball", "snow") was present in the previous narrative, this task could have been performed using a semantic matching strategy without requiring complete understanding of the narrative.) Because this study was meant as an initial exploration of visual vs. linguistic narrative comprehension in individuals with ASD, our interpretations must remain speculative without follow-up work.

Future work could also manipulate certain variables that we did not assess or control. For example, individual differences in narrative comprehension could be a matter of personal processing style. The Object-Spatial Imagery and Verbal Questionnaire (Blazhenkova & Kozhevnikov, 2009) could be used in future studies to determine whether visual and/or verbal processing styles contribute to comprehension deficits. Individual differences in working memory capacity could also have modulated the presence and magnitude of the N400 effect, since some linguistic narratives contained more words than others. Similar influences could affect visual narrative comprehension, as shared memory systems have been implicated in sequential image understanding (Magliano et al., 2016). We also did not assess reading ability or reading frequency, which in the future would be an important variable to assess and/or control for in both TD and ASD participants. It also remains to be seen whether similar results would be observed if the linguistic narratives were presented as spoken stories rather than written stories; this would be an interesting avenue for future investigation.

Some variables, such as stimulus complexity, number of characters, or emotional content, were not or could not be matched between the visual and linguistic modalities. For example, visual narratives may have conveyed more social information through implicit cues like facial expressions and body language.[4] Future studies should equalize the amount of social information in each modality using quantified and verified metrics, and/or manipulate this variable to determine how it modulates narrative comprehension. In addition, our visual stimuli were not necessarily neutral and may have contained inherent meaning or humor. As noted in Section 2.1, most participants reported being familiar with *Peanuts* comics, which raises the potential that prior knowledge aided in interpretation.

Finally, it should be noted that this study tested adults with ASD,

---

[4] To address this possibility, as a post-hoc analysis we asked 3 TD adults (not involved in the full experiment) to rate how "social" each narrative was (e.g., how many characters were involved, whether they interacted with each other, etc.) from 1 to 9. The average ratings did not differ between visual and linguistic narratives ($p = 0.17$), suggesting that both modalities conveyed roughly equal amounts of social information.

whereas most prior work has tested children. Our findings of impaired narrative comprehension in adults with ASD align with the few prior studies of adults (Jolliffe & Baron-Cohen, 2000; Mason et al., 2008) and with studies of children and adolescents (Baron-Cohen et al., 1986; Johnels et al., 2013; Kaland et al., 2007; Nuske & Bavin, 2011). Although we cannot generalize our results to children with ASD, the consistency between the current results and the prior literature suggest that comprehension deficits persist into adulthood. Future studies may also investigate whether narrative comprehension abilities in ASD change with advancing age, since the N400 is known to decrease with age (e.g. Federmeier & Kutas, 2005) and narrative comprehension strategies are shown to differ with age in TD individuals (e.g. Magliano et al., 2012). The age range for our participants was quite broad (18–68); although post-hoc analyses did not suggest any significant correlations with or effects of age on the data, our study did not include enough older participants to address this question in a systematic fashion.

This study is the first to compare visual vs. linguistic narrative comprehension in individuals with ASD; as such, more research needs to be done to replicate these results and confirm our interpretations. There may, for example, be alternative interpretations of these data that we are unable to account for in the current study. For instance, impaired narrative comprehension may not be specific to the ASD condition but may be the result of more domain-general cognitive impairments. Impairments in visual narrative comprehension are also observed in other clinical populations (see Coderre, in preparation, for a review) such as individuals with specific language impairment SLI (Allen, Lincoln, & Kaufman, 1991; Nenadović, Stokić, Vuković, Đoković, & Subotić, 2014), right-hemisphere brain damage (Huber & Gleber, 1982), and schizophrenia (Beatty, Jocic, & Monson, 1993). We explored whether autism symptomology correlated with the ERP findings by running post-hoc correlations between the social + communication total on the ADOS and the N400/LPC effects (unrelated-related) in the three time windows of interest (300–500 ms, 500–800 ms, 800–1200 ms). No significant correlations occurred for either visual or linguistic narratives (all *p*'s > 0.22, uncorrected). It could be that because the majority of these adults with ASD were not severely affected, there was not enough variability in ADOS scores to identify significant correlations in these data. Alternatively, it could be that impairments in narrative processing are not specific to ASD (and therefore may not be explained by ADOS scores) and may be more related to other aspects of cognitive or narrative processing. Other cognitive functions such as pragmatics, verbal working memory, or sequential processing ability may have influenced comprehension abilities in ways that we could not assess with the current experimental design. Future studies are needed to explore the loci of narrative comprehension impairments in individuals with ASD.

Although a tentative conclusion, if individuals with ASD do experience a domain-general impairment in narrative comprehension, this has implications for reading comprehension intervention strategies, which often advocate visual supports to leverage the visual strengths of these individuals (e.g., Nguyen, Leytham, Schaefer Whitby, & Gelfer, 2015; Styslinger, 2012). While visual supports may be beneficial, our results suggest that solely relying on visual stimuli to convey complex linguistic information may not completely alleviate comprehension difficulties. To be clear, we do *not* disregard the use of visual processing to remediate reading and narrative comprehension in students with ASD. In fact, some authors have speculated on the benefits of comics for these students (Rozema, 2015) and some visual imagery-based reading comprehension interventions (e.g., Bell, 1991) have been successful in this population (Murdaugh, Deshpande, & Kana, 2016; Murdaugh, Maximo, & Kana, 2015). Rather, we wish to highlight that because our data suggested that comprehension deficits may also occur for visually-presented stimuli, researchers and educators should not necessarily assume that the use of visual stimuli will completely alleviate

processing difficulties for individuals with ASD. Instead, more abstract processing challenges may extend beyond differences in modality.

5. Conclusions

In summary, the current research explored whether narrative comprehension deficits in individuals with ASD are language-specific or extend to visual stimuli. Our results suggested comprehension deficits in individuals with ASD for both linguistic and visual stimuli, implying a domain-general impairment. We propose that individuals with ASD may use a more bottom-up processing style at each unit of a narrative sequence. These findings raise important questions for follow-up studies and have implications for interventions and therapies for individuals with ASD.

6. Statement of significance to the neurobiology of language

This work uses electrophysiology to examine the neurobiological mechanisms underlying narrative comprehension. By evaluating visual and linguistic narrative comprehension in individuals with ASD, this study demonstrates that narrative comprehension deficits in this population are not related to the presence of linguistic stimuli, but rather stem from a more general impairment in narrative comprehension.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.bandl.2018.09.001.

References

AbdulSabur, N. Y., Xu, Y., Liu, S., Chow, H. M., Baxter, M., Carson, J., & Braun, A. R. (2014). Neural correlates and network connectivity underlying narrative production and comprehension: A combined fMRI and PET study. *Cortex, 57*, 107–127.

Allen, M. H., Lincoln, A. J., & Kaufman, A. S. (1991). Sequential and simultaneous processing abilities of high-functioning autistic and language-impaired children. *Journal of Autism and Developmental Disorders, 21*(4), 483–502.

APA (2013). *Diagnostic and statistical manual of mental disorders: DSM-5.* Washington, DC: American Psychiatric Association.

Baixauli, I., Colomer, C., Roselló, B., & Miranda, A. (2016). Narratives of children with high-functioning autism spectrum disorder: A meta-analysis. *Research in Developmental Disabilities, 59*, 234–254.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1986). Mechanical, behavioural and Intentional understanding of picture stories in autistic children. *British Journal of Developmental Psychology, 4*(2), 113–125.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5–17.

Beatty, W. W., Jocic, Z., & Monson, N. (1993). Picture sequencing by schizophrenic patients. *Bulletin of the Psychonomic Society, 31*(4), 265–267.

Bell, N. (1991). Gestalt imagery: A critical factor in language comprehension. *Annals of Dyslexia, 41*, 246–260.

Berman, R. A. (2009). Language development in narrative contexts. In Cambridge handbook of child language (pp. 356–375).

Blazhenkova, O., & Kozhevnikov, M. (2009). The new object-spatial-verbal cognitive style model: Theory and measurement. *Applied Cognitive Psychology, 23*, 638–663.

Boone, K. B., Miller, B. L., Lee, A., Berman, N., Sherman, D., & Stuss, D. T. (1999). Neuropsychological patterns in right versus left frontotemporal dementia. *Journal of the International Neuropsychological Society, 5*, 616–622.

Braeutigam, S., Swithenby, S. J., & Bailey, A. J. (2008). Contextual integration the unusual way: A magnetoencephalographic study of responses to semantic violation in individuals with autism spectrum disorders. *European Journal of Neuroscience, 27*, 1026–1036.

Brewer, W. F. (1985). The story schema: Universal and culture-specific properties. In D. R. Olson, N. Torrance, & A. Hildyard (Eds.). *Literacy language and learning* (pp. 167–194). Cambridge: Cambridge University Press.

Brouwer, H., Fitz, H., & Hoeks, J. (2012). Getting real about Semantic Illusions: Rethinking the functional role of the P600 in language comprehension. *Brain Research, 1446*, 127–143.

Bruner, J. (1991). The narrative construction of reality. *Critical Inquiry, 18*(1), 1–21.

Bruner, J. (1997). A narrative model of self-construction. *Annals of the New York Academy of Sciences, 818*(1), 145–161.

Coderre, E. L., Chernenok, M., Gordon, B., & Ledoux, K. (2017). Linguistic and non-linguistic semantic processing in individuals with autism spectrum disorders: An ERP study. *Journal of Autism and Developmental Disorders, 47*(3), 795–812.

Coderre, E. L. (in prepartaion). Visual narrative processing in clinical populations.

Cohn, N. (2013a). *The visual language of comics: Introduction to the structure and cognition of sequential images*. London, UK: Bloomsbury.

Cohn, N. (2013b). Visual narrative structure. *Cognitive Science, 37*(3), 413–452.

Cohn, N. (2014). You're a good structure, charlie brown: The distribution of narrative categories in comic strips. *Cognitive Science, 38*(7), 1317–1359.

Cohn, N., & Bender, P. (2017). Drawing the line between constituent structure and coherence relations in visual narratives. *Journal of Experimental Psychology: Learning Memory and Cognition, 43*(2), 289–301.

Cohn, N., Jackendoff, R., Holcomb, P. J., & Kuperberg, G. R. (2014). The grammar of visual narrative: Neural evidence for constituent structure in sequential image comprehension. *Neuropsychologia, 64*, 63–70.

Cohn, N., & Kutas, M. (2015). Getting a cue before getting a clue: Event-related potentials to inference in visual narrative comprehension. *Neuropsychologia, 77*, 267–278.

Cohn, N., & Maher, S. (2015). The notion of the motion: The neurocognition of motion lines in visual narratives. *Brain Research, 1601*, 73–84.

Cohn, N., & Paczynski, M. (2013). Prediction, events, and the advantage of Agents: The processing of semantic roles in visual narrative. *Cognitive Psychology, 67*(3), 73–97.

Cohn, N., Paczynski, M., Jackendoff, R., Holcomb, P. J., & Kuperberg, G. R. (2012). (Pea) nuts and bolts of visual narrative: Structure and meaning in sequential image comprehension. *Cognitive Psychology, 65*, 1–38.

Cohn, N., & Wittenberg, E. (2016). Action starring narratives and events: Structure and inference in visual narrative comprehension. *Journal of Cognitive Psychology, 27*(7), 812–828.

Davis, M., Dautenhahn, K., Nehaniv, C. L., & Powell, S. D. (2007). The narrative construction of our (social) world: Steps towards an interactive learning environment for children with autism. *Universal Access in the Information Society, 6*(2), 145–157.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*, 9–21.

Delorme, A., Sejnowski, T. J., & Makeig, S. (2007). Enhanced detection of artifacts in EEG data using higher-order statistics and independent component analysis. *NeuroImage, 34*(4), 1443–1449.

Diehl, J. J., Bennetto, L., & Young, E. C. (2006). Story recall and narrative coherence of high-functioning children with autism spectrum disorders. *Journal of Abnormal Child Psychology, 34*(1), 87–102.

Dunn, M. A., & Bates, J. C. (2005). Developmental change in neutral processing of words by children with autism. *Journal of Autism and Developmental Disorders, 35*(3), 361–376.

Dunn, L., & Dunn, D. (2007). *Peabody picture vocabulary testsAmerican guidance service* (4th ed.). Circle Pines, MN: American Guidance Service.

Dunn, M. A., Gaughan, H., Jr, Kreuzer, J., & Kurtzberg, D. (1999). Electrophysiologic correlates of semantic classification in autistic and normal children. *Developmental Neuropsychology, 16*(1), 79–99.

Federmeier, K. D., & Kutas, M. (2005). Aging in context: Age-related changes in context use during language comprehension. *Psychophysiology, 42*(2), 133–141.

Ferstl, E. C., Neumann, J., Bogler, C., & Von Cramon, D. Y. (2008). The extended language network: A meta-analysis of neuroimaging studies on text comprehension. *Human Brain Mapping, 29*(5), 581–593.

Ferstl, E. C., & von Cramon, D. Y. (2001). The role of coherence and cohesion in text comprehension: An event-related fMRI study. *Cognitive Brain Research, 11*, 325–340.

Gernsbacher, M. A. (1990). *Language comprehension as structure building*. Hillsdale, NJ: Lawrence Erlbaum.

Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(3), 430–445.

Groen, W. B., Zwiers, M. P., van der Gaag, R.-J., & Buitelaar, J. K. (2008). The phenotype and neural correlates of language in autism: An integrative review. *Neuroscience and Biobehavioral Reviews, 32*, 1416–1425.

Groppe, D. M., Makeig, S., & Kutas, M. (2009). Identifying reliable independent components via split-half comparisons. *NeuroImage, 45*(4), 1199–1211.

Hagoort, P., Hald, L., Bastiaansen, M., & Petersson, K. M. (2004). Integration of word meaning and world knowledge in language. *Science, 304*, 438–442.

Horowitz-Kraus, T., Buck, C., & Dorrmann, D. (2016). Altered neural circuits accompany lower performance during narrative comprehension in children with reading difficulties: An fMRI study. *Annals of Dyslexia, 66*(3), 301–318.

Huber, W., & Gleber, J. (1982). Linguistic and nonlinguistic processing of narratives in aphasia. *Brain and Language, 16*, 1–18.

Hus, V., & Lord, C. (2014). The autism diagnostic observation schedule, module 4: Revised algorithm and standardized severity scores. *Journal of Autism and Developmental Disorders, 44*(8), 1996–2012.

Johnels, J.Å., Hagberg, B., Gillberg, C., & Miniscalco, C. (2013). Narrative retelling in children with neurodevelopmental disorders: Is there a role for nonverbal temporal-sequencing skills? *Scandinavian Journal of Psychology, 54*(5), 376–385.

Jolliffe, T., & Baron-Cohen, S. (2000). Linguistic processing in high-functioning adults with autism or Asperger's syndrome. Is global coherence impaired? *Psychological Medicine, 30*, 1169–1187.

Jung, T. P., Makeig, S., Humphries, C., Lee, T. W., McKeown, M. J., Iragui, V., & Sejnowski, T. J. (2000). Removing electroencephalographic artifacts by blind source separation. *Psychophysiology, 37*(2), 163–178.

Kaland, N., Smith, L., & Mortensen, E. L. (2007). Response times of children and adolescents with Asperger syndrome on an "advanced" test of theory of mind. *Journal of Autism and Developmental Disorders, 37*(2), 197–209.

Kamio, Y., & Toichi, M. (2000). Dual access to semantics in autism: Is pictorial access superior to verbal access? *Journal of Child Psychology and Psychiatry, 41*(7), 859–867.

Karunanayaka, P. R., Holland, S. K., Schmithorst, V. J., Solodkin, A., Chen, E. E., Szaflarski, J. P., & Plante, E. (2007). Age-related connectivity changes in fMRI data from children listening to stories. *NeuroImage, 34*, 349–360.

Kaufman, A., & Kaufman, N. (2004). *Kaufman brief intelligence test* (2nd ed.). Circle Pines, MN: American Guidance Service.

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621–647.

Kutas, M., & Hillyard, S. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203–205.

Lau, E. F., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics: (De) constructing the N400. *Nature Reviews Neuroscience, 9*(12), 920–933.

Liles, B. Z. (1993). Narrative discourse in children with language disorders and children with normal language: A critical review of the literature. *Journal of Speech and Hearing Research, 36*(5), 868–882.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., ... Rutter, M. (2000). The autism diagnostic observation schedule—generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders, 30*(3), 205–223.

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. L. (2012). *Autism diagnostic observation schedule, second edition (ADOS-2) manual (Part 1): Modules 1–4*. Torrance, CA: Western Psychological Services.

Losh, M., & Capps, L. (2003). Narrative ability in high functioning children with autism or asperger's syndrome. *Journal of Autism and Developmental Disorders, 33*(3), 239–251.

Magliano, J. P., Kopp, K., McNerney, M. W., Radvansky, G. A., & Zacks, J. M. (2012). Aging and perceived event structure as a function of modality. *Aging, Neuropsychology, and Cognition, 19*(1–2), 264–282.

Magliano, J. P., Larson, A. M., Higgs, K., & Loschky, L. C. (2016). The relative roles of visuospatial and linguistic working memory systems in generating inferences during visual narrative comprehension. *Memory & Cognition, 44*, 207–219.

Magliano, J. P., Loschky, L. C., Clinton, J. A., & Larson, A. M. (2013). Is reading the same as viewing? An exploration of the similarities and differences between processing text- and visually based narratives. In B. Miller, L. Cutting, & P. McCardle (Eds.). *Unraveling the behavioral, neurobiological and genetic components of reading comprehension* (pp. 78–90). Baltimore, MD: Brookes Publishing Co.

Magliano, J. P., & Zacks, J. M. (2011). The impact of continuity editing in narrative film on event segmentation. *Cognitive Science, 35*(8), 1489–1517.

Mar, R. A. (2004). The neuropsychology of narrative: Story comprehension, story production and their interrelation. *Neuropsychologia, 42*, 1414–1434.

Martín-Loeches, M., Casado, P., Hernández-Tamames, J. A., & Álvarez-Linera, J. (2008). Brain activation in discourse comprehension: A 3t fMRI study. *NeuroImage, 41*(2), 614–622.

Mason, R., Williams, D., Kana, R., Minshew, N. J., & Just, M. A. (2008). Theory of mind disruption and recruitment of the right hemisphere during narrative comprehension in autism. *Neuropsychologia, 46*(1), 269–280.

McCleery, J. P., Ceponiene, R., Burner, K. M., Townsend, J., Kinnear, M., & Schreibman, L. (2010). Neural correlates of verbal and nonverbal semantic integration in children with autism spectrum disorders. *Journal of Child Psychology and Psychiatry, 51*(3), 277–286.

McFie, J., & Thompson, J. A. (1972). Picture arrangement: A measure of frontal lobe function? *British Journal of Psychiatry, 121*, 547–552.

Murdaugh, D. L., Deshpande, H. D., & Kana, R. K. (2016). The impact of reading intervention on brain responses underlying language in children with autism. *Autism Research, 9*(1), 141–154. https://doi.org/10.1002/aur.1503.

Murdaugh, D. L., Maximo, J. O., & Kana, R. K. (2015). Changes in intrinsic connectivity of the brain's reading network following intervention in children with autism. *Human Brain Mapping, 36*, 2965–2979.

Nagai, M., Endo, N., & Kumada, T. (2007). Measuring brain activities related to understanding using near-infrared spectroscopy (NIRS). *Symposium on human interface and the management of information* (pp. 884–893). Berlin Heidelberg: Springer.

Nakazawa, J. (2016). Manga literacy and manga comprehension in Japanese children. In N. Cohn (Ed.). *The visual narrative reader* (pp. 157–184). London: Bloomsbury.

Nenadović, V., Stokić, M., Vuković, M., Đoković, S., & Subotić, M. (2014). Cognitive and electrophysiological characteristics of children with specific language impairment and subclinical epileptiform electroencephalogram. *Journal of Clinical and Experimental Neuropsychology, 36*(9), 981–991.

Nguyen, N. N., Leytham, P., Schaefer Whitby, P., & Gelfer, J. I. (2015). Reading comprehension and autism in the primary general education classroom. *The Reading Teacher, 69*(1), 71–76.

Nuske, H. J., & Bavin, E. L. (2011). Narrative comprehension in 4-7-year-old children with autism: Testing the Weak Central Coherence account. *International Journal of Language & Communication Disorders, 46*(1), 108–119.

Osaka, M., Yaoi, K., Minamoto, T., & Osaka, N. (2014). Serial changes of humor comprehension for four-frame comic Manga: An fMRI study. *Scientific Reports, 4*, 5828.

Pijnacker, J., Geurts, B., van Lambalgen, M., Buitelaar, J., & Hagoort, P. (2010). Exceptions and anomalies: An ERP study on context sensitivity in autism. *Neuropsychologia, 48*(10), 2940–2951.

Radvansky, G. A., & Zacks, J. M. (2014). *Event cognition.* Oxford, UK: Oxford University Press.

Richardson, B. (2000). Recent concepts of narrative and the narratives of narrative theory. *Style, 34*(2), 168–175.

Rozema, R. (2015). Manga and the autistic mind. *English Journal, 105*(1), 60–68.

Sahyoun, C. P., Soulières, I., Belliveau, J. W., Mottron, L., & Mody, M. (2009). Cognitive differences in pictorial reasoning between high-functioning autism and Asperger's syndrome. *Journal of Autism and Developmental Disorders, 39*(7), 1014–1023.

Sassenhagen, J., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2014). The P600-as-P3 hypothesis revisited: Single-trial analyses reveal that the late EEG positivity following linguistically deviant material is reaction time aligned. *Brain and Language, 137*, 29–39.

Schmithorst, V. J., Holland, S. K., & Plante, E. (2006). Cognitive modules utilized for narrative comprehension in children: A functional magnetic resonance imaging study. *NeuroImage, 29*, 254–266.

Strandburg, R. J., Marsh, J. T., Brown, W. S., Asarnow, R. F., Guthrie, D., & Higa, J. (1993). Event-related potentials in high-functioning adult autistics: Linguistic and nonlinguistic visual information processing tasks. *Neuropsychologia, 31*(5), 413–434.

Styslinger, M. E. (2012). Making meaning: Strategies for literacy learning. *Phi Delta Kappan, 94*(4), 40–45.

Tager-Flusberg, H. (1995). "Once upon a ribbit": Stories narrated by autistic children. *British Journal of Developmental Psychology, 13*, 45–59.

Tager-Flusberg, H., Paul, R., & Lord, C. (2005). Language and communication in autism. In F. Volkmar, R. Paul, A. Klin, & D. Cohen (Eds.). *Handbook of autism and pervasive developmental disorders* (pp. 335–364). (3rd ed.). New York: John Wiley & Sons.

Tager-Flusberg, H., & Sullivan, K. (1995). Attributing mental states to story characters: A comparison of narratives produced by autistic and mentally retarded individuals. *Applied Psycholinguistics, 16*(3), 241–256.

van de Meerendonk, N., Kolk, H. H. J., Vissers, C. T. W. M., & Chwilla, D. J. (2010). Monitoring in language perception: Mild and strong conflicts elicit different ERP patterns. *Journal of Cognitive Neuroscience, 22*(1), 67–82.

Van der Hallen, R., Evers, K., Brewaeys, K., Noortgate, W. Van den, & Wagemans, J. (2015). Global processing takes time: A meta-analysis on local-global visual processing in ASD. *Psychological Bulletin, 141*(3), 549–573.

van Petten, C., & Kutas, M. (1991). Influences of semantic and syntactic context on open- and closed-class words. *Memory & Cognition, 19*, 95–112.

Vermeulen, P. (2015). Context blindness in autism spectrum disorder: Not using the forest to see the trees as trees. *Focus on Autism and Other Developmental Disabilities, 30*(3), 182–192.

Walsh, R. (2007). *The rhetoric of fictionality: Narrative theory and the idea of fiction.* The Ohio State University Press.

West, W. C., & Holcomb, P. J. (2002). Event-related potentials during discourse-level semantic integration of complex pictures. *Cognitive Brain Research, 13*, 363–375.

Yarkoni, T., Speer, N. K., & Zacks, J. M. (2008). Neural substrates of narrative comprehension and memory. *NeuroImage, 41*, 1408–1425.

Zalla, T., Labruyère, N., Clément, A., & Georgieff, N. (2010). Predicting ensuing actions in children and adolescents with autism spectrum disorders. *Experimental Brain Research, 201*, 809–819.

Zwaan, R., & Radvansky, G. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162–185.