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THE ROLES OF SEMANTIC RELATEDNESS AND NARRATIVE STRUCTURE IN
VISUAL NARRATIVES IN ASD

Elizabeth O'Donnell

Department of Communication Sciences and Disorders

The University of Vermont

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Abstract

Individuals with autism spectrum disorders (ASD) often struggle with narrative comprehension, possibly because of related impairments in semantic and syntactic processing. However, most studies have used linguistic narratives, making it difficult to isolate those processes because of potential interference from other language deficits. Therefore, visual narratives are an ideal modality for exploring narrative comprehension and the underlying roles of semantic and structural processing in ASD.

Previous work has shown impaired semantic processing for both linguistic and visual narratives in ASD (Coderre et al., 2018), but it remains to be seen whether impairments in structural sequencing abilities might also contribute to difficulties in narrative comprehension. To explore this, we replicated a previous study of sequential image comprehension (Cohn et al., 2012) in a population of adults with ASD and a control group of typically-developing (TD) adults. Stimuli were adapted from *Peanuts* comic strips and consisted of Normal sequences (containing both meaning between panels and narrative structure); Semantic-Only sequences (containing meaning but no structure); Structural-Only sequences (containing a narrative structure but no semantic relatedness); and Scrambled sequences (randomly-ordered panels with neither semantic relatedness nor narrative structure). We evaluated narrative processing by comparing the effect of sequence type on the N400 component of the event-related potential (ERP), and structural processing through the left anterior negativity (LAN) effect.

Preliminary data analysis showed similar N400 patterns between ASD and TD groups, suggesting visuo-semantic processing may be intact for individuals with ASD. This study also explored the possible presence of a LAN, which was not yet observable due to the sample size, and the effect of panel position on N400 amplitude.

Chapter 1: Introduction

Autism spectrum disorder (ASD) is a developmental disorder defined by deficits in social communication and interaction in addition to restricted and repetitive behaviors or interests (APA, 2013). Like other neurodevelopmental disorders, the symptoms of ASD may be present early in life but can be diagnosed at any point in the lifespan. People with ASD have a broad range of motor, sensory, cognitive and social abilities, which makes tracking prevalence difficult because social deficits and patterns may not be recognized as ASD until a child struggles to meet social or educational goals (Baio et al., 2018). In addition, the understanding that ASD encompasses a heterogenous range of impairments has led to ongoing refinement of tools and practices for diagnosis.

According to a 2018 report from the CDC's Autism and Developmental Disabilities Monitoring Network (ADDM), approximately 1 in 59 children 8 years old have been diagnosed with ASD (Baio et al., 2018). The ratio of males to females diagnosed with ASD is currently in the range of 2-4:1 (Baio et al., 2018; Lai et al., 2013) with estimates ranging from 6-8:1 in samples with an average IQ or higher (Fombonne, 2009). Although there may be a biological discrepancy behind the skewed ratio of occurrences, females may be under-identified or "missed" in samples due to changing or male-biased diagnostic criteria (e.g., weighting restrictive and repetitive behaviors over social-communication difficulties), even though both groups demonstrate similar levels of ASD symptoms (Baio et al., 2018; Duvekot et al., 2016; Dworzynski, Ronald, Bolton, & Happé, 2012).

While language impairment is no longer a criterion for a diagnosis, people with ASD frequently suffer from deficits or differences in language processes and use. For example, individuals with ASD commonly use language in a one-sided, non-reciprocal manner to achieve

a personal goal, rather than for social purposes (Fine & Bartolucci, 1994). According to some estimates, more than 15% of people diagnosed with ASD are non-verbal at the age of 9 (Gotham et al. 2010). However, even individuals with strong verbal communication skills often have deficits in higher-level language processes including semantics, syntax, and narrative production and comprehension (Groen, Zwiers, van der Gaag, & Buitelaar, 2008).

Many theories have been suggested to explain the higher-order language deficits that characterize ASD. For instance, the weak central coherence theory (WCC) suggests that people with ASD have superior local or detail-focused processing, often at the expense of global processing, and that this bias diminishes their ability to integrate contextual information (Happé & Frith, 2006; Jolliffe & Baron-Cohen, 2000). With poor global coherence, individuals with ASD have difficulty establishing causal connections and integrating smaller pieces of information together (Jolliffe & Baron-Cohen, 2000).

In addition, higher-level language deficits could be related to neurobiological differences in ASD. Neuroimaging studies have reported a different distribution of activation in brain areas involved in language in ASD (Just, Cherkassky, Keller, & Minshew, 2004). On tasks of sentence comprehension, an ASD group displayed more activation in Wernicke's area (left latero-superior temporal gyrus) and less activation in Broca's area (left inferior frontal gyrus) than a control group of verbal IQ-matched individuals (Just et al., 2004). Because Broca's area has been associated with language processes including semantic integration, this finding suggests that individuals with ASD struggle to integrate the meaning of individual words. In addition, the functional connectivity or synchronization between Wernicke and Broca's areas in this study was consistently lower for the ASD group, suggesting disordered language in ASD is related to a

lower degree of integration and connectivity, particularly in long-range pathways that are critical for language (Just et al., 2004).

Individuals with ASD often struggle with semantic processing (i.e., understanding the meaning of a word or stimulus). As a higher-level language process, linguistic or lexico-semantic processing requires long-range communication across areas of the language network in the frontal cortex and temporo-parietal brain areas (Coderre, Chernenok, Gordon, & Ledoux, 2017; Sahyoun, Belliveau, Soulieres, Schwartz, & Mody, 2010; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996). In contrast, visuo-semantic processing, or semantic processing of visual, non-lexical stimuli such as images, may be centralized in occipito-parietal and temporo-parietal areas, requiring shorter communication pathways (Sahyoun et al., 2010). Because the long-range pathways of lexico-semantic processing may suffer from underconnectivity (Just et al., 2004), individuals with ASD may have stronger visuo-semantic processing due to the proximity of the recruited areas.

Regardless of presenting language ability, the linguistic skills of children diagnosed with ASD might be underestimated due to the characteristics of language-based tests and the demands of the testing situation. For instance, linguistic skills are often assessed through standardized testing in a one-on-one situation, thus requiring competency in social interaction as well as functional language skills. In addition, it is hard to isolate a specific language skill from more global language and cognitive processes to determine which skills are atypical. For example, Coderre et al. (2018) found impaired comprehension of both linguistic and non-linguistic modalities, suggesting deficits cannot be attributed solely to the linguistic domain. The goal of this thesis is to develop a more complete understanding of language deficits in ASD, and in particular, how semantics and narrative structure are processed in a visual narrative. With a

stronger comprehension of the language deficits present in ASD, we will hopefully be able to design better interventions that more directly target the language construct at hand.

Chapter 2: Literature Review

Language processing

Language processing requires many higher-level language or metalinguistic skills. These complex systems transcend basic vocabulary and grammar and involve deeper understanding, reasoning, and analysis of abstract language. One of these domains is semantics, or the study of meaning and relationships between stimuli. In language, semantics often describes the meaning of a word or phrase and its relations to others within a text. For example, some words have multiple meanings (e.g., “bug” can refer to an insect, an illness, a listening device, an obsessive interest, or bothering), and others have multiple words for the same meaning (e.g., a flower is yellow, but hair is blonde). Linguistic semantics is concerned with all possible meanings of a word, and how the interpretation of a selected word influences the context. However, semantics can also be conceptualized non-linguistically, such as understanding the meaning of a picture. For the purpose of this study, semantic processing refers to the understanding and integration of the meaning of all stimuli, whether it is a word, sentence, picture, or sequence of images (Coderre et al., 2017).

Another branch of linguistics is syntax (grammar), or the set of rules that arranges sentences by combining words into phrases. Like semantics, syntax is not limited to the phrase or sentence level and can be applied to a narrative at the discourse level. Syntax allows for differentiation of coherent sentences from strings of scrambled words by imposing a hierarchical grammatical structure.

Semantics and syntax are independent language components, and while they are both present in coherent sentences, they can be studied in isolation. In his 1957 book *Syntactic Structures*, linguist Noam Chomsky proposed an example of syntax without semantics in the

sentence, “Colorless green ideas sleep furiously”. Although the sentence is grammatically correct, it is semantically meaningless. Likewise, semantics can exist separately from syntax, as exemplified by strings of semantically-related words or a sentence with scrambled word order.

Language processing also occurs on the narrative level. In linguistic form, a narrative is a spoken or written sequence of events (i.e., a story). Narrative comprehension refers to the combination of language skills and processes, including the interaction of semantic information (e.g., how characters and themes fit together), and the narrative structures that organize it (Coderre et al., 2018).

Measuring language processing using EEG

Electroencephalography (EEG) is a non-invasive method of monitoring the electrical activity of the brain through electrodes placed on the scalp. EEG measures fluctuations in voltage, producing a record of neural oscillations or “brain waves” of electrical activity at each electrode. Event-related potentials (ERPs) can be derived from EEG recordings and reflect the brain’s response to a specific stimulus over time as patterns of peaks and waves. Certain ERP components have been associated with semantic and structural processing, and we use these measurements in our current study of narrative comprehension in ASD. In addition, EEG is an ideal measure for examining the rapid stages of language processing because of its excellent temporal resolution.

N400. Described as a negative deflection in the waveform that peaks around 400 ms, the N400 ERP component has been associated with semantic processing (Kutas & Federmeier, 2011). In a coherent sentence, the N400 amplitude decreases with successive words, showing that as a sentence progresses, it becomes easier to integrate incoming information into the

established semantic context (Van Petten & Kutas, 1991). Sentences with final words that integrate easily with the preceding semantic context (e.g. “Finally, the climbers reached the top of the *mountain*”) show a reduced N400 in TD populations in response to the final word compared to sentences that end incongruently and are more difficult to integrate (e.g. “Finally, the climbers reached the top of the *tulip*”) (Pijnacker, Geurts, van Lambalgen, Buitelaar, & Hagoort, 2010). The “N400 effect” represents the difference in N400 amplitude elicited by stimuli of high congruency or semantic relatedness versus those with low congruency or semantic relatedness (Braeutigam, Swithenby, & Bailey, 2008; Kutas & Federmeier, 2011).

P600. Unlike the N400 for semantics, there is no single ERP component that demonstrates syntactic processing. The P600 ERP component or Late Positivity is a centro-parietally distributed positive deflection that peaks between 600 and 800ms following stimulus presentation (Osterhout & Holcomb, 1992). This waveform has been established as a measure of syntactic processing because it is evoked by syntactic ambiguities and syntactic violations in an otherwise normal sentence structure (Kuperberg, 2007). However, the P600 is also sensitive to semantic information, as shown by a larger P600 effect to syntactic violations when the context was more semantically constraining versus less semantically constraining (Gunter, Stowe, & Mulder, 1997).

LAN. The left anterior negativity (LAN) is another ERP component that occurs in response to syntactic violations. It appears most frequently between 300 and 500 ms after the onset of a stimulus, and the effect is often distributed over left, frontal electrode sites (Müntz, Matzke, & Johannes, 1997). In contrast to the P600, which is influenced by semantic relatedness, the LAN is sensitive to violations of syntactic structure even without a build-up of semantic context. The LAN reflects violations of syntactic expectancy (Molinaro, Barber, & Carreiras,

2011) or detection of a morphosyntactic violation (Friederici, 2002), and while it occurs around the same timeframe as the N400, it does not require semantic relatedness or a developed context.

Language processing in ASD

Deficits in language processing are common for individuals with ASD and are particularly prominent in higher-level processes such as semantics, syntax, and narrative comprehension (Groen et al., 2008). However, our understanding of the narrative comprehension abilities of people with ASD is relatively limited and incomplete.

Semantic processing in ASD. In comparison to TD individuals, individuals with ASD often show reduced or absent N400 effects for language-based semantic tasks (e.g., Pijnacker et al. 2010, Brautigam, 2008). For example, in a semantic priming task, McCleery et al. (2010) observed an N400 effect for linguistic stimuli (pairs of pictures and spoken words) in TD children but not in children with ASD, suggesting children with ASD were not as sensitive to the relationship between stimuli. In addition, individuals with ASD have shown reduced N400 effects to sentences that end with semantically incongruous words, suggesting deficits in using context for semantic integration (Braeutigam et al., 2008). Interestingly, in the presence of a reduced N400 for semantically incongruous sentences, some studies find an atypical late positivity, suggesting atypical methods of semantic integration that require more elaborate and less automatic processes (e.g., Pijnacker et al. 2010).

Syntactic processing in ASD. Compared to semantics, fewer studies have investigated syntax in ASD populations. Early studies suggested that ASD and TD populations do not differ in grammatical ability when matched for IQ or another mental age measure (Pierce & Bartolucci, 1977; Tager-Flusberg et al., 1990). These studies primarily used large-scale and general

measures of syntax including the Mean Length of Utterance (Brown, 1973) or the Index of Productive Syntax (Scarborough, 1990). However, other studies have argued that syntactic deficits are independent of cognitive skill or mental age, insisting that grammatical deficits do exist in ASD as assessed through total grammatical errors in spontaneous language samples (Wittke, Mastergeorge, Ozonoff, Rogers, & Naigles, 2017), tense and agreement omissions (Bartolucci, Pierce, & Streiner, 1980; Wittke et al., 2017), distinguishing personal and reflexive pronouns (Perovic, Modyanova, & Wexler, 2013), or relative clauses (Durrleman, Hippolyte, Zufferey, Iglesias, & Hadjikhani, 2015). In a population of people with ASD with impaired language skills, Kjelgaard and Tager-Flusberg (2001) found the same patterns of grammatical impairments characteristic of people with diagnoses of specific language impairment, leading to a differentiation between people with normal language (ALN) and impaired language (ALI) in autism. Another factor in syntactic impairment is a delay in language acquisition in childhood; Tager-Flusberg and Joseph (2005) found a small difference in grammatical impairment between adults with ASD with and without a history of language delay.

Narrative comprehension in ASD. Narrative sequences are central to most elements of everyday life, but for individuals with ASD, narrative comprehension can be challenging. Narrative comprehension requires a combination of semantic and structural or syntactic processing skills, which are both commonly impaired in ASD, as previously discussed. Studies of linguistic narrative comprehension suggest narrative production and comprehension deficits in areas including storytelling, episodic future thinking and mental time travel (Ferretti et al., 2018), connecting meaningful elements under a global theme (Vermeulen, 2014), making inferences, and ordering sentences in a scrambled narrative (Therese Jolliffe & Baron-Cohen, 2000), suggesting an impairment in global narrative coherence.

Non-linguistic processing in ASD

Because individuals with ASD often experience deficits in numerous linguistic domains central to narrative comprehension, the use of linguistic narratives may misrepresent narrative comprehension abilities. Some studies have suggested these deficits do not occur in visual modalities in ASD, such that individuals appear to have intact semantic processing when processing visual stimuli, and indicating a language-specific deficit in semantic processing (Kamio & Toichi, 2000; McCleery et al., 2010).

For example, in a semantic priming task comparing word-word and picture-word pairs, Kamio and Toichi (2000) found similar performance for the TD group on both modalities, but improved performance for the ASD group on the picture-word task, suggesting an advantage for visuo-semantic processing. As previously mentioned, lower connectivity of long-range lexico-semantic connections might also encourage a preference for visuo-semantic processing (Just et al., 2004; Sahyoun et al., 2010). It is thus possible that narrative comprehension difficulties are contingent on the linguistic modality of the narrative.

Non-linguistic narrative interventions in ASD. The theory of a language-specific deficit has led to the development of ASD interventions that use visual narratives instead of linguistic narratives. For instance, people with ASD often struggle with theory of mind, an important concept of perspective-taking and social cognition, and visual narratives may help to show similar concepts more clearly than through lexical narratives (Hutchins & Prelock, 2006, 2013). One example of visual narratives as an ASD intervention tool is Comic Strip Conversations, which combine stick-figure illustrations with conversation symbols into comics that depict what people think and feel, as well as what they say (Gray & Garand, 1993).

Visual narratives

Studies on narrative comprehension in individuals with ASD have almost exclusively used written or spoken linguistic narratives. However, because of a potential language-specific deficit, it is necessary to also evaluate processing in non-linguistic modalities. Analogous to linguistic narratives, visual narratives require both semantics and syntax to facilitate processing. For the purposes of this thesis, syntax in visual narratives will be referred to as *structure*. Using the visual narrative format of comic strips allows for the examination of semantic and structural processing without linguistic restrictions.

Semantics in visual narratives. The presence of a common theme or semantic field that connects the panels to each other helps the reader to establish a context and infer elements of the narrative that are not illustrated. For example, to generate the setting of a horse race, individual panels might depict a horse's head and legs, a jockey, and spectators (Saraceni, 2003). Semantic processing in visual narratives also includes recognizing changes in time, characters, spatial location, or other elements that influence the meaning of individual panels and the sequence (Cohn, Paczynski, Jackendoff, Holcomb, & Kuperberg, 2012).

Structure in visual narratives. When understanding how sequential images tell a story, a reader must also take into consideration the narrative structure. Visual Language Theory is a framework for the structure and cognition of the visual language used in comics based on the idea that sequential images require a "narrative grammar" (Cohn, 2018). Cohn's theory of Visual Narrative Grammar (VNG) functions to structure images by assigning categorical and hierarchical roles to individual units. This approach examines the role each panel plays relative to the global sequence, in contrast to approaches that focus on the relations between adjacent images such as changes in character, spatial location, and time (Cohn, 2013; McCloud, 1993).

Visual narrative categories. Cohn has proposed a model that formalizes the narrative structure of sequential images into five distinct core categories that describe the relation of an image to the global narrative sequence (Cohn, 2013; Cohn et al., 2012). For example, in a six-panel comic strip, each image is classified under a core category depending on its role within the strip. The sequence in Figure 1 opens with an Establisher panel, which introduces the scene without any action occurring (e.g. displaying a setting of a frozen pond). Next, an Initial panel begins the event, depicting an action that prepares for the main event by initiating tension (e.g. an excited Snoopy is running). A Prolongation panel can extend the tension of the initial panel by continuing the action (e.g. Snoopy jumps towards the pond). In a Peak panel, the previous events reach a climax and maximum tension (e.g. Snoopy slips on the ice). Often, the Peak will interrupt the initial event in some way, altering the viewer's expectations. The Peak is the most important panel because it influences the meaning of the entire sequence and provides a context for the panels to come. In the case of Figure 1, the Peak is followed by a second Prolongation, which continues the action of the Peak but releases tension (e.g. Snoopy slides on the ice). The final category is the Release, which completely resolves narrative tension from the Peak and often depicts the outcome of the events (e.g. Snoopy, frustrated, walks away from the pond).

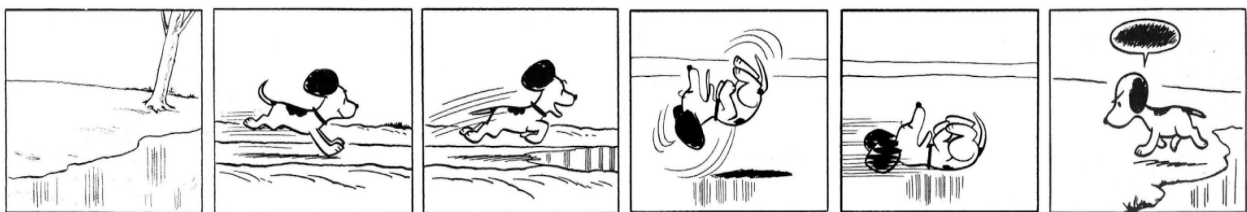


Figure 1: A Peanuts comic strip.

A panel's categorization depends on not only the content of the image, but also the constraints and context of the global sequence. Because of this, a sequence does not need to follow an exact order such as the one presented in Figure 1, and a panel might belong to different

categories depending on its place in the sequence. The roles of the categories are determined through the bottom-up semantic content and top-down sequential context of the images, but they are not descriptors of meaning (Cohn, 2013; Cohn, 2014). Because of this, it is possible for one image to function within multiple categories depending on the sequence. Within Visual Language Theory, VNG is separate from meaning, much like the earlier example of Chomsky's demonstration that semantics and syntax are separable in language. This creates a possibility for a sequence of images to have a narrative structure without semantic or local relations between the individual panels (Cohn et al., 2012).

Visual narratives in ASD

Superficially, images seem simple to understand because they are generally representative of their meaning, in contrast with words or characters, which are symbolic. However, other studies have shown that narrative processing deficits persist for individuals with ASD even when visual stimuli are used. Studies of narrative retellings from children with ASD using wordless picture books have also documented impairments. In comparison to TD children, Tager-Flusberg (1995) found that children with ASD used minimal causal language and had trouble interpreting the character's thoughts or emotional states even when looking at non-linguistic materials. In addition, their narratives were significantly shorter and less grammatically complex than the narratives produced by TD children, indicating that impairments in narrative production could arise in part from impaired comprehension. Similarly, Coderre et al. (2018) found that individuals with ASD showed impaired narrative comprehension compared to TD individuals for both linguistic and visual narratives.

The current study

The purpose of the current study is to evaluate the contributions of semantic and structural processing to visual narrative comprehension in individuals with ASD. Although some studies have shown that semantic processing of single pictures is intact in individuals with ASD compared to TD controls (Coderre et al., 2017), it is not clear whether these results can be equated to semantic processing at the narrative level. In narratives, Coderre et al. (2018) found reduced N400 effects for both linguistic and non-linguistic narratives, suggesting deficits in semantic processing and narrative comprehension that are independent of modality. It also remains to be seen whether visual narrative comprehension difficulties might arise from impairments in structural processing, since there have been no studies investigating the processing of visual narrative structure in ASD.

We replicated a previous study of sequential image comprehension (Cohn et al., 2012) in a population of adults with ASD and TD adults. The stimuli, described in the next section, allowed us to explore semantic and structural processing individually in visual narratives. Because of previously-established impairments in visuo-semantic processing of narratives in ASD (Coderre et al., 2018), we expected to see reduced N400 effects for the ASD group in comparison to the TD group and a reduced or absent LAN as measures of semantic and structural processing. This thesis provides a preliminary insight into the contributions of semantic and structural processing to visual narrative comprehension in ASD.

Chapter 3: Methods

Construction of stimuli

We replicated the ERP experiment (Experiment #2) of Cohn et al. (2012) and used stimuli created for the original experiment. Comic strip sequences were generated from panels from the *Complete Peanuts* volumes 1-6 by Charles Shultz. *Peanuts* comics were chosen by Cohn et al. (2012) for a number of reasons. First, there is a large anthology to draw from, and many people are familiar with the content of the series. In addition, there are repeated characters and situations, creating consistent semantic fields. Standard *Peanuts* comic strips are four panels long, so novel six-panel sequences were created from existing strips to eliminate familiarity with particular strips (Cohn et al., 2012).

Novel comic strips were created to form four experimental conditions (Cohn et al., 2012). First, strips in the Normal condition contained both semantics and structure (i.e., there was a common meaning that continued through each panel following a canonical story arc described by the categories of VNG; Figure 2a). Second, Semantic-Only strips contained a common semantic theme (e.g. Snoopy playing baseball), but no narrative structure (i.e., the panels did not follow a canonical narrative arc; Figure 2b). Structural-Only strips featured a narrative structure, with panels belonging to Cohn's core narrative categories (Cohn, 2013) in relation to the global narrative structure (e.g. a sequence of panels belonging to the Establisher, Initial, Peak, and Release categories), but no semantic relationships between panels (Figure 2c). Finally, Scrambled strips were arranged with neither a narrative structure nor a semantic field to provide context or coherence.

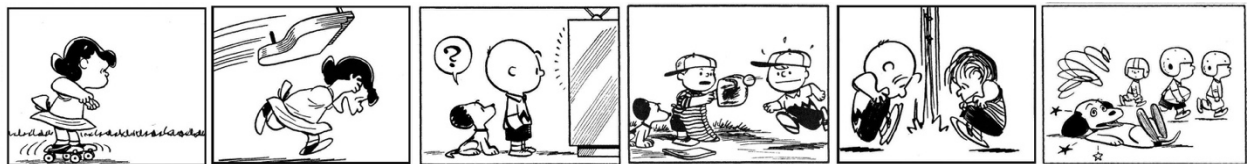
a. Normal sequences



b. Semantic Only sequences



c. Structural Only sequences



d. Scrambled sequences



Figure 2: Four conditions of comic strip stimuli.

Cohn et al. (2012) also included an experiment for target panel monitoring (Experiment #1) with a hypothesis that the combination of semantic relatedness and narrative structure in a context facilitate processing of a target image. Expanding from the linguistic tasks of Marslen-Wilson and Tyler (1980), Cohn predicted participants would respond fastest to target panels in the Normal sequences and slowest to panels in Scrambled sequences, with Semantic and Structural sequences falling in between due to partial expectations of the context. Therefore,

each quartet of strips features a shared target panel (e.g., the fourth panel in Figure 2a-d). Our current study does not include monitoring for a specific panel because of the potential for an explicit task to interfere with overall comprehension of the sequences, but the target panels remain included in the stimuli.

Participants

Ten adolescents and adults with ASD ($M = 23.9$) were recruited for this study from the University of Vermont campus and surrounding Burlington community. Examiners obtained written consent forms from all participants, including written assent from children or individuals who are not their own legal guardian and an accompanying consent form from their parents or guardians. In addition, a control group of ten TD age-matched subjects ($M = 22$) was tested on the same screening and experimental tasks.

During an initial screening visit, participants completed screening questionnaires including the Edinburgh Handedness Inventory and a documentation of personal health and language history. The Autism Quotient (AQ) was completed to assess five areas of social skill, communication, attention switching, attention to detail, and imagination (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). In addition, because sequential image comprehension may be affected by comic reading expertise, examiners administered the Visual Language Fluency Index (VLFI), a measure of comic “fluency” determined by expertise in comic reading comprehension and production (Cohn et al., 2012). Examiners also administered the Peabody Picture Vocabulary Test, Fourth Edition, of receptive vocabulary (Dunn & Dunn, 2007), the Kaufman Brief Intelligence Test, Second Edition, of verbal and non-verbal intelligence (Kaufman & Kaufman, 2004), and forward and backward digit span tasks as

baseline measures. By matching participants on verbal and non-verbal intelligence, any findings can be more directly attributed to differences in language processing in ASD and not to impaired verbal abilities or differences in intelligence. Participants with ASD also completed the Autism Diagnostic Observation Schedule, Second Edition (Lord et al., 2012). Demographic information can be found in Table 1.

	<i>TD group (n=10)</i>	<i>ASD group (n=10)</i>	<i>Group difference</i>
Age	22 (17-27)	23.9 (16-28)	0.35
PPVT	121.9 (109-136)	110.9 (93-132)	0.0536 .
KBIT			
Verbal	123.9 (104-141)	110.8 (89-135)	0.0646 .
Non-verbal	111.5 (74-130)	102.9 (79-120)	0.2237
Combo	121(93-137)	108.1 (82-132)	0.092
VLFI	7.93 (2-15.1)	13.4 (1.5-17.4)	0.13
Digit Span			
Forward	12.9 (10-16)	10.5 (8-14)	0.02 *
Backward	9.7 (5-14)	8.6 (5-12)	0.34
Autism Quotient	16 (12-25)	27.9 (17-39)	0.0007 ***
ADOS-2			
SA+RBB		13.55 (9-20)	
CSS		7.11 (5-10)	

Table 1: Participant characteristics for the TD and ASD groups. Means and ranges for are reported for each measure. All participants fell within the “normal” range (scores >70) for verbal and nonverbal abilities (PPVT and KBIT). Because the ADOS-2 is an ASD diagnostic tool, only the ASD group completed the test. ADOS-2 scores are reported for Social Affect and Restricted and Repetitive Behaviors (SA+RBB) and Calibrated Severity Scores (CSS). One participant was not available to complete the ADOS-2; they are excluded from the mean and range scores

reported ($n = 9$) for that measure. The ‘group difference’ column shows the results of independent-samples t tests on each measure. Although there are statistically significant or trending group differences for PPVT, verbal KBIT, and forward digit span measures, subsequent analysis including these as covariates showed no difference in results. Asterisks indicate statistically significant results ($*p < 0.05$; $**p < 0.01$; $***p < 0.001$), and a period indicates a trend toward significance.

Procedure

Participants were fitted for a net according to the circumference of their head. With a wax pencil, examiners marked a reference point on the scalp at the midpoint of the lines between the nasion and inion and the preauricular points. The net was soaked in an electrolyte solution of water, potassium chloride, and baby shampoo to improve the signal and remove scalp oils. After initial placement, each electrode was adjusted and re-wet to ensure it was contacting the scalp properly.

Because this experiment used 129-channel nets, it was often not possible to achieve an impedance of under 50 k Ω for all electrodes. The shape of a participant’s head or their hair occasionally prevented electrodes from making good contact with the scalp, especially around the ears. Impedances were checked after net application before initiating the experiment and electrodes were re-wet every 20 minutes throughout the session.

Participants sat in a separate room from the computers and experimenters with the joining door open. The overhead lights were left on to minimize a flashing effect caused by the white panels appearing on a black background and resulting eye blinks. The experiment was presented using E-Prime 2.0, build 2.0.10.356, and data was recorded using NetStation 5.

To start the experiment, participants read the following instructions presented on the screen.

“In this study you will be asked to watch short stories based on the Peanuts comics. The stories consist of several comic panels. You will first see a “Ready?” screen to begin each story. Press any button to begin the story. You will then see each panel one at a time in the center of the screen. Please try to remain still, try not to move your eyes, and try to blink only during the blank screen in between the panel presentations. After every story, you will be asked to judge whether the story “made sense” or not. After the final panel you will see a question mark as a prompt. Press 1 if the story DID make sense. Press 2 if the story DID NOT make sense. On some trials you will also be asked a comprehension question. Press 1 for YES. Press 2 for NO. Press any button to start the practice trials.”

Experimenters also reviewed the instructions with the participants and presented an opportunity to ask questions. Ten practice strips familiarized participants with the format of the experiment before they began the experimental trials.

The experiment consisted of six blocks of 40 trials each for a total of 240 trials and lasted between 50 and 75 minutes. Four sets of stimuli were created for counterbalancing to prevent participants from seeing repeated panels in different strips or conditions. Across all blocks of the experiment, participants viewed 60 trials of each condition. For each trial, participants were first showed a black screen with “READY?” displayed in white letters. After pressing a button to initiate the trial, participants viewed a white fixation cross for 500 ms, followed by the six panels of the sequence. All panels were black and white and displayed on a black background, and each was viewed for 1350 ms with 300 ms ISI. After the final panel, participants were shown a red question mark to prompt them to answer, “Did that story make sense?” Upon pressing a button, the next trial initiated. After some trials, participants were shown a comprehension question (e.g., “Did Snoopy catch the leaf?”) to assess overall accuracy of comprehension.

Data preprocessing

Data were preprocessed using EEGLab (version 14.1.1b) and Matlab (version 2017a). The data were filtered using 0.1–50 Hz bandpass filtering and segmented into epochs time-locked to the onset of each panel. Segments started 100ms before panel onset and extended to 1500ms following panel presentation. Channels with an average voltage of $\pm 30\mu\text{V}$ were replaced and interpolated. Correction for artifacts was performed using a 32-dimension independent component analysis (ICA). Following ICA decomposition, the topographic plots and ERP waveforms for each component were displayed and reviewed, and components contributing to movement, eye-blinks, ECG, or other noise artifacts were removed. Segments were then baseline corrected and re-referenced to the average of the mastoid sites. Each trial was reviewed individually and any remaining bad trials containing noise were selected for removal.

Statistical Analysis

ERP amplitude was evaluated using R version 3.5.0. Electrode clusters were centered at the left frontal (F3), midline frontal (Fz), right frontal, (F4), left central (C3), midline central (Cz), right central (C4), left parietal (P3), midline parietal (Pz), and right parietal (P4) regions across the scalp. We used these sites to provide a broad scalp representation and include any effects that may be missed by analysis of specific regions. For ERP analysis, ANOVAs were performed with factors of condition (Normal, Semantic, Structural, and Scrambled), site (frontal, central, and parietal), and laterality (left, midline, and right) as within-subject factors and group (TD and ASD) as a between-subjects factor to explore main and interaction effects of each factor. Panel position was added as an exploratory factor in secondary ANOVA analysis, averaging over all panels in the strip for each condition. Statistical analysis was performed at

300-400, 400-600, and 600-900 ms following stimulus onset, consistent with the time windows used by Cohn et al. (2012).

To assess story coherence, participants were asked to respond to the question “Did that story make sense?” after each strip was presented. Correct responses were defined as pressing “1” for the Normal condition and “2” for all other conditions, and those responses were assigned a coherence rating of 1. For incorrect responses, trials were assigned a coherence rating of 0. To evaluate behavioral performance and response accuracy, we performed ANOVAs on the average coherence rating of each condition. Follow-up *t*-tests confirmed ANOVA results by comparing each group by condition. Accuracy of comprehension question responses were assessed similarly with ANOVAs and independent-sample *t*-tests. All trials, even those with incorrect behavioral responses, were included in the analysis.

Chapter 4: Results

ERP data

Effects of sequence type on ERPs. Averaged across all panels, a significant negative deflection was observed beginning between approximately 400 and 600 ms, consistent with an N400. TD ERP waveforms are depicted in Figure 3 and ASD waveforms in Figure 4.

TD results mirrored the findings of Cohn et al. (2012). In the TD group, the greatest N400 negativity was seen in the Scrambled condition, closely followed by the Structural condition. The Normal condition evoked the smallest N400 effect, and the Semantic condition elicited N400s larger in amplitude than the Normal condition but smaller than the Scrambled or Structural conditions. ASD results showed similar patterns of negativity by condition, although the N400 effect appeared noticeably smaller as depicted by clustered electrode waveforms in Figure 4 than the TD group amplitudes at the same site.

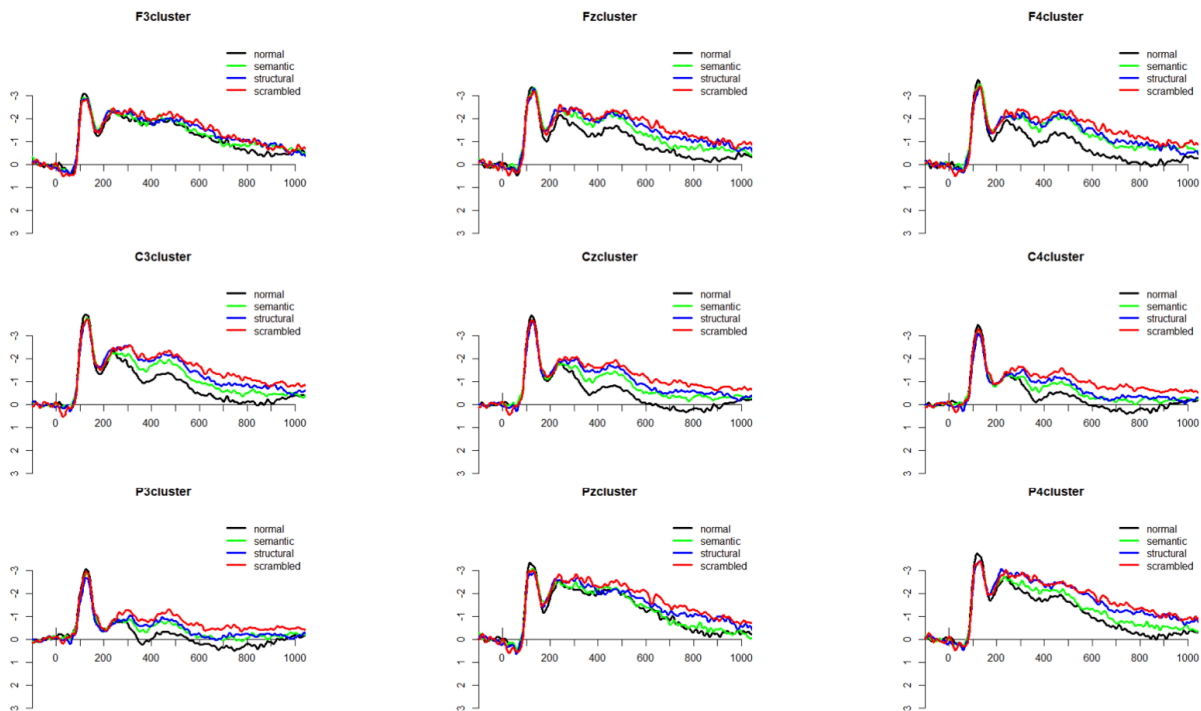


Figure 3: ERP waveforms for the TD group at each of nine clustered electrode sites.

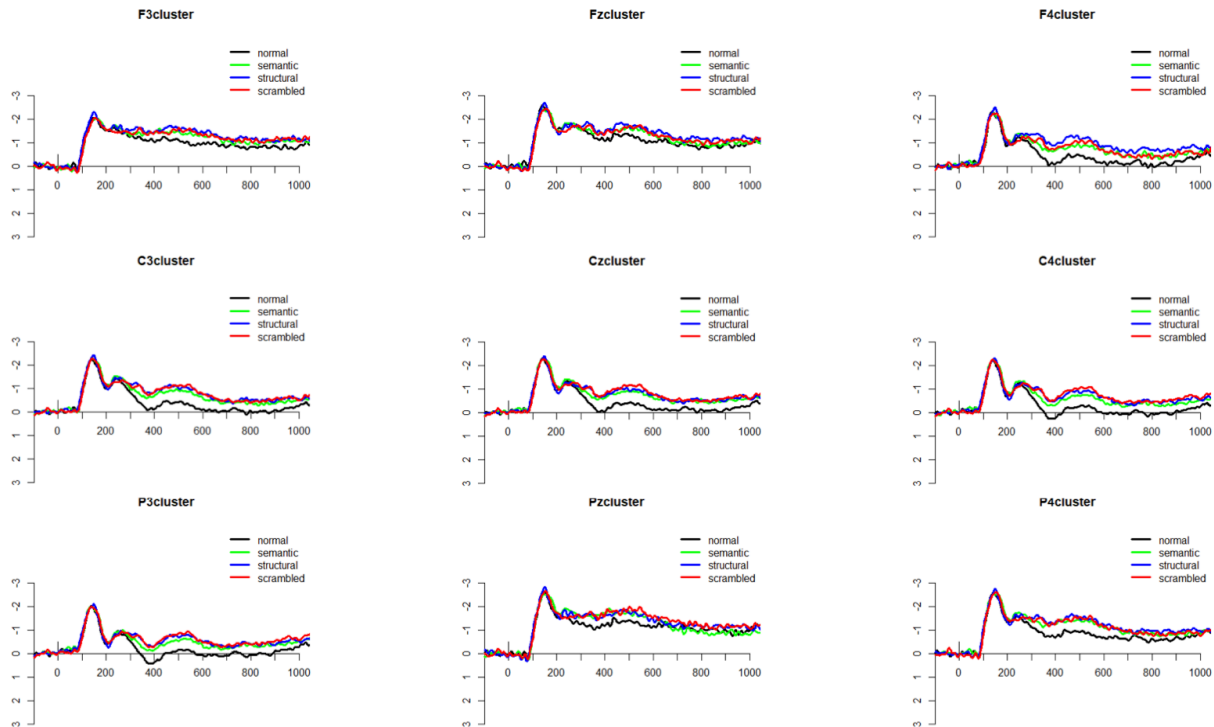


Figure 4: ERP waveforms for the ASD group at each of nine clustered electrode sites.

A series of 4 (condition) x 3 (site) x 3 (laterality) x 2 (group) ANOVAs at 300-400, 400-600, and 600-900 ms showed main effects of condition, site, and laterality. These time frames were chosen to provide a comparable and consistent analysis with the methods of Cohn et al. (2012). Interactions involving group and condition were of primary interest. There were no group x condition interactions at 300-400 or 400-600 ms. A trend of group x condition x site was observed from 600-900 ms ($F(6,108) = 2.274, p = 0.0417$). This trend was first explored in an additional ANOVA by site, showing no significance at any site, and second by independent-samples *t*-tests comparing condition by group, which also showed no significance.

A main effect of condition was observed at 300-400 ms ($F(3,54) = 7.873, p = 0.00019$), 400-600 ms ($F(3,54) = 12.136, p = 3.51e-06$), and 600-900 ms ($F(3,54) = 8.205, p = 0.000136$), which we examined further using *t*-tests. Paired-samples *t*-tests in the TD group showed a

significant difference in means between each possible pairing of conditions (e.g. Normal vs. Semantic, Normal vs. Structural, Normal vs. Scrambled), showing that the experimental conditions were different. Interestingly, the ASD group showed significant differences between all conditions except for the Structural vs. Scrambled pairing. The distinction between Structural vs. Scrambled conditions in the TD group suggests that the TD group was sensitive to the presence of narrative structure without semantics. In contrast, the ASD group did not show a difference in Structural vs. Scrambled conditions, suggesting narrative structure in the absence of semantics did not facilitate processing for people with ASD.

Scrambled - Semantic and Scrambled - Structural difference waves

Topographic maps show the EEG field and plot electrical activity on a two-dimensional image of the top of the head and map. Figures 5 and 6 show differences in waveform negativity between Scrambled minus Semantic and Scrambled minus Structural conditions as plotted across the scalp. By comparing the Scrambled condition, which has neither semantics nor structure, to the Semantic and Structural conditions, we were able to isolate the activation and increased negativity resulting from semantic or structural processing alone. In the Scrambled - Semantic comparison (Figure 5), the TD group showed significant frontal negativity (dark blue) beginning in 300-400 ms and extending throughout the timeframes. In contrast, the ASD group appeared to show almost no difference in Scrambled and Semantic negativity. Similarly, in the Scrambled - Structural comparison (Figure 6), the TD group showed increased fronto-central activation peaking around 600-800 ms and the ASD group did not appear to show a difference in activation between Scrambled - Structural conditions. The Scrambled - Structural difference waves were also plotted by amplitude, as seen in Figure 7. These results were based on visual analysis of the

topoplots in Figures 5 and 6 and the difference waves in Figure 7, and they were not yet confirmed through statistical analysis. Although initial ANOVAs showed no effect of group or interactions of group and condition, the TD and ASD groups appeared to show differing activation in this contrast of plotted activation.

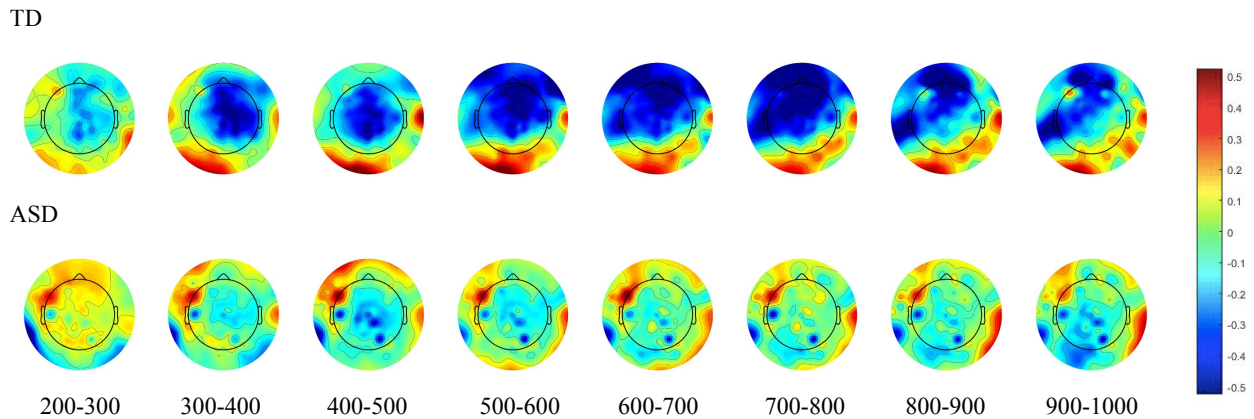


Figure 5: Topographic plot of Scrambled minus Semantic difference waves.

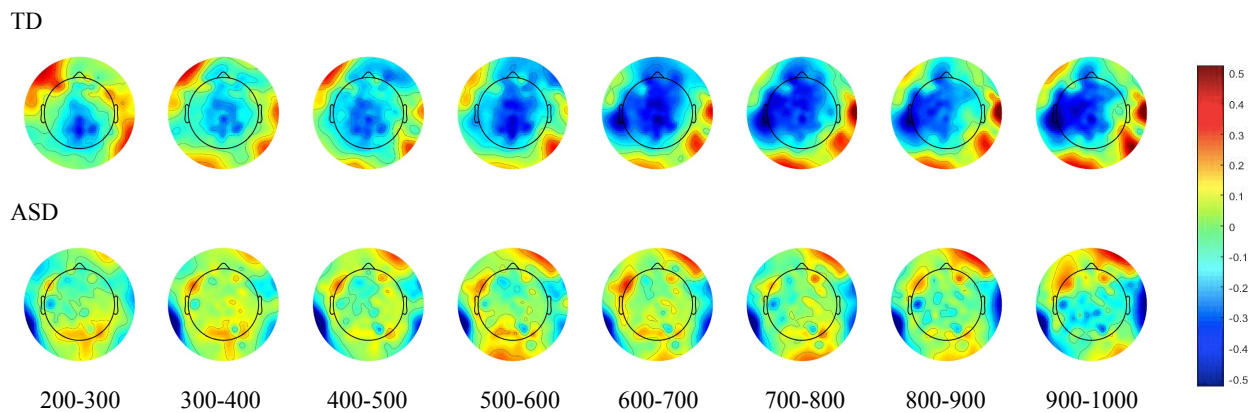


Figure 6: Topographic plot of Scrambled minus Structural difference waves.

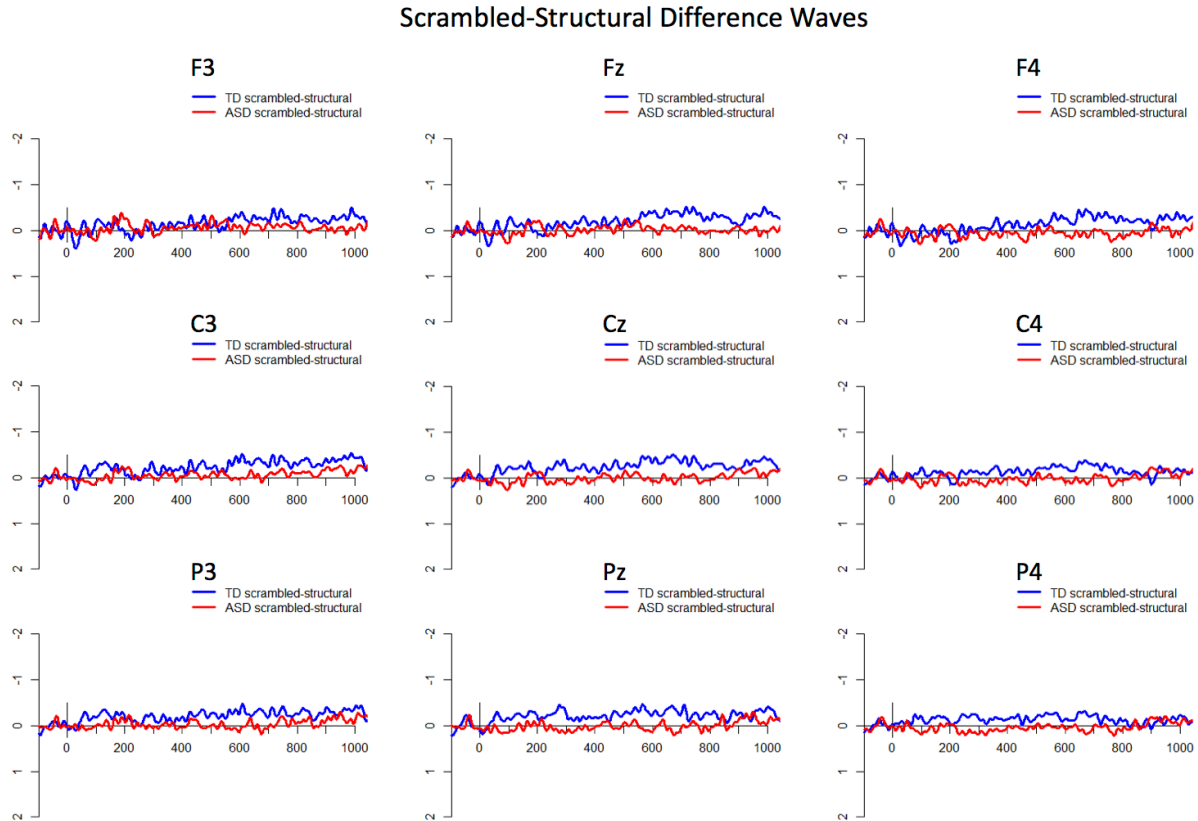


Figure 7: Amplitude of Scrambled minus Structural difference waves. TD is represented in blue; ASD by red.

Effects of visual narrative fluency on comprehension

To assess the effect of visual narrative fluency on comprehension, we correlated participants' scores on the VLFI with Scrambled - Structural difference wave amplitude. An independent samples *t*-test showed no significant difference in average VLFI score between groups ($p = 0.13$), although the ASD group had a higher average score and larger range ($M = 13.4$; range = 2.13-30) in comparison to the TD group ($M = 7.9$, range = 2-15.13). Pearson's correlations were performed to correlate the average ERP amplitude of the difference between the Scrambled and Structural conditions with the average VLFI score of each group. However,

there was no effect of VLFI score on amplitude, as shown by p -values of $p > 0.05$ and insignificant correlation coefficients for both groups across the 300-400, 400-600, and 600-900 ms time frames.

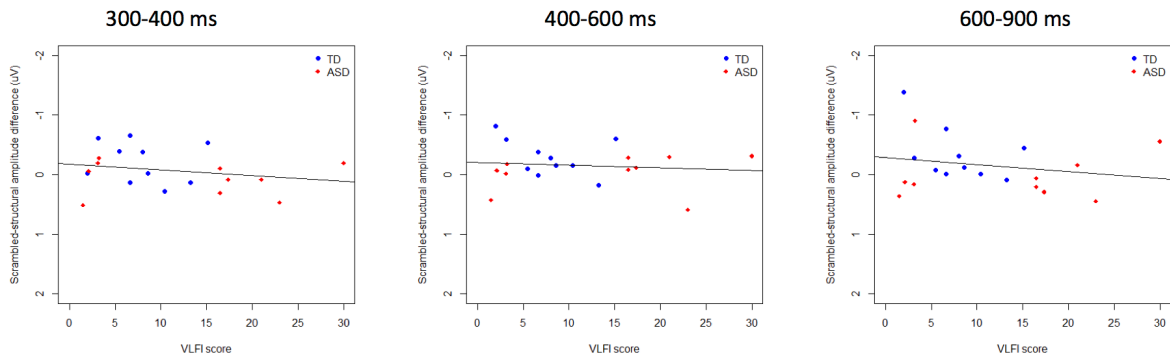


Figure 8: Scatterplots showing correlations between average difference in Scrambled - Structural amplitude and VLFI score.

Panel analysis

We also ran secondary analyses investigating if panel position across the sequence (1-6) influenced ERP amplitude in the 300-400, 400-600, and 600-900 ms time windows. Preliminary visual analysis showed a clear decrease in N400 amplitude across panels in the Normal condition (Figure 9). This is the typical pattern seen in studies of coherent visual narratives (Cohn et al., 2012; Van Petten & Kutas, 1991), showing that as a semantic and structural context develops, integration of stimuli becomes easier. In contrast, no consistent change in N400 amplitude was shown by the Semantic, Structural, or Scrambled conditions. Both TD and ASD groups showed similar patterns of attenuation. The attenuation observed in the Normal condition due to panel position showed the joint facilitation of semantic relatedness and narrative structure in developing a context and establishing coherence, while all other conditions failed to establish referential relationships.

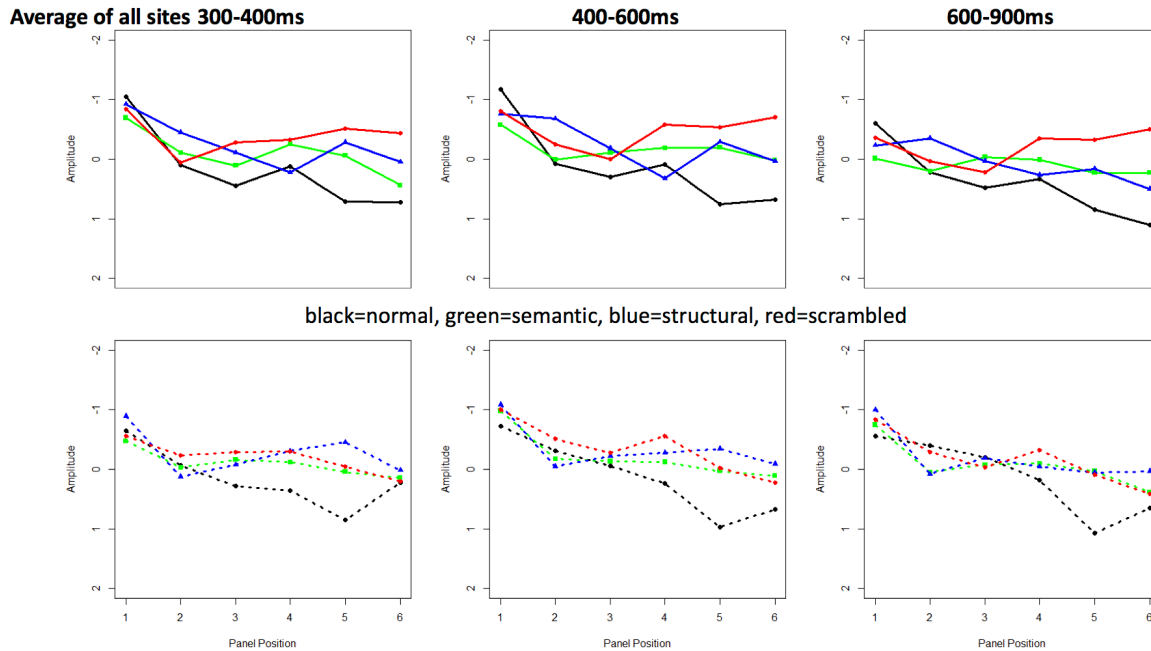


Figure 9: Amplitudes evoked by panels in each sequence position for each sequence type, collapsed across all sites. (Normal= black, Semantic = green, Structural = blue, Scrambled = red)

Behavioral data

Coherence ratings. Participants were asked to rate the coherence of each comic strip panel during the experiment by pressing Button 1 if the strip made sense and Button 2 if the strip did not make sense. Correct responses (1 for Normal only, 2 for all other conditions) were assigned a coherence rating of 1. Coherence ratings are shown in Figure 10 for each group by condition.

A 2 (group) x 4 (condition) ANOVA for coherence ratings showed main effects of condition for each group but no group by condition interactions. Cohn et al. (2012) found that participants were most accurate in rating Normal sequences ($M = 0.92$), less accurate in judging Scrambled ($M = 0.89$) and Structural ($M = 0.87$) sequences, and least accurate in judging

Semantic sequences ($M = 0.70$). We would expect to see a similar pattern in our TD sample. For both groups, Normal, Scrambled, and Structural conditions were all rated highly accurately. As in Cohn et al. (2012), the Semantic condition was rated the least accurately, likely due to participants detecting semantic relatedness or a “theme” between the panels and incorrectly rating the strip as “making sense”. Although there was no statistical significance between groups as shown with the 2 x 4 ANOVA and independent-samples t -tests, the TD group was slightly more accurate than the ASD group for each condition.

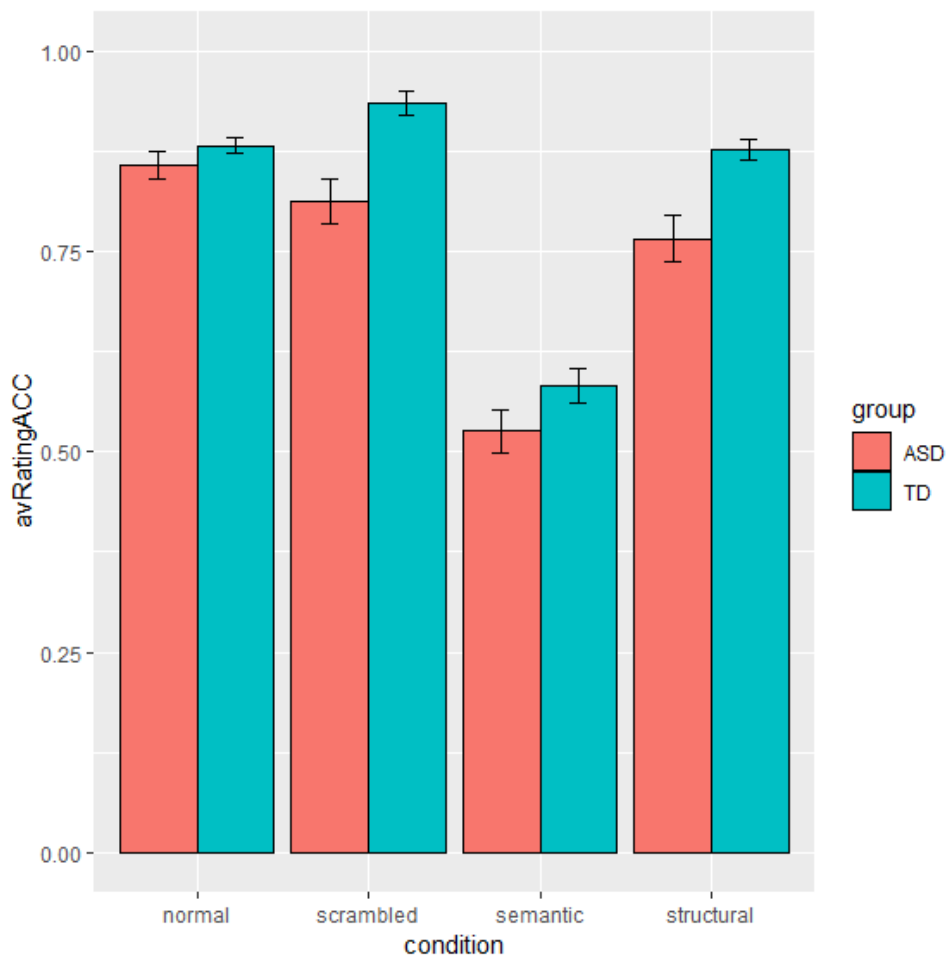


Figure 10: Story coherence ratings for each condition and group.

Comprehension question accuracy. Behavioral response accuracy was also measured through analysis of responses to comprehension question (Figure 11). Surprisingly, there was no

effect of group or condition, and no interactions of group and condition, as examined through a 2 (group) x 4 (condition) ANOVA and independent-samples *t*-tests. Our results showed that for the Scrambled, Semantic, and Structural conditions, the TD group was slightly more accurate than the ASD group in judging each condition, although not statistically significant in overall ANOVA analyses. For the Normal condition however, the ASD group was slightly more accurate than the TD group. Based on Cohn et al. (2012), we would expect around 75% of the comprehension questions to be answered correctly; however, our inclusion of all participants instead of limiting the sample to participants with a score of 80% or greater correct responses as in Cohn et al. (2012) likely influenced the overall pattern of comprehension question accuracy.

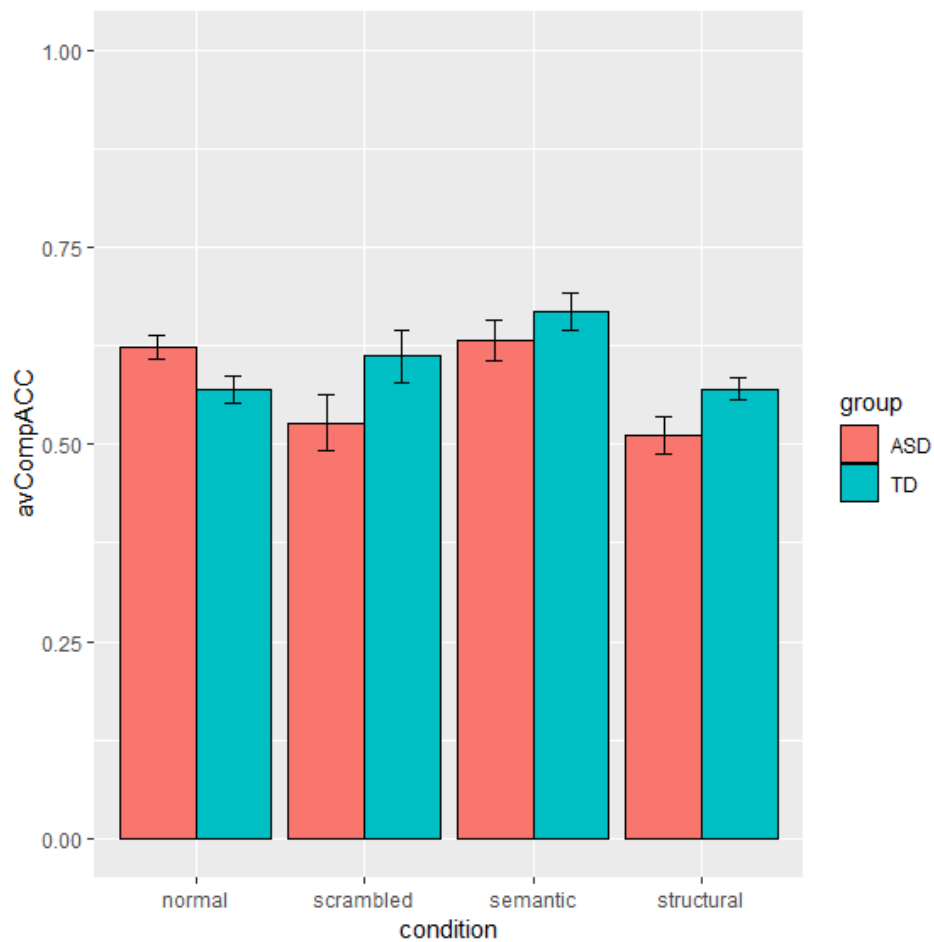


Figure 11: Comprehension question response accuracy for each condition and group.

Chapter 5: Discussion

In this experiment, we explored the roles of semantic relatedness and narrative structure by presenting sequences of coherent visual narratives with both semantic relatedness and narrative structure (Normal), a semantic field but no narrative structure (Semantic), narrative structure but no semantic relatedness (Structural), or random images with no semantics or structure (Scrambled). As predicted, patterns in ERP amplitude for the TD group mirrored the findings of Cohn et al. (2012), with the Scrambled and Structural conditions producing the most negative N400 amplitudes, the Semantic condition producing slightly smaller amplitudes, and the Normal condition producing the least negative amplitudes. The ASD group showed similar patterns in ERP waveform amplitude. Although statistical analysis showed no main effects of group or group by condition interactions, likely due to the small sample size and preliminary nature of the data, small differences in difference wave topography as observed visually indicated a slight difference in sensitivity to the components of semantics and structure in each group.

Effects of narrative structure in combination with semantic relatedness

Normal sequences showed an advantage for processing over Structural sequences through an increased N400 negativity to Structural sequences. Because both conditions have a narrative structure, this confirmed that semantic relatedness (which is present in Normal strips but not Structural strips) additionally facilitated processing of visual narratives. Similarly, N400s were increased in the Semantic sequences in comparison to the Normal sequences, which showed that in the presence of semantics, a narrative structure (which is present in Normal strips but not Semantic strips) was also advantageous in the semantic processing of panels. By showing

decreasing N400 amplitude over subsequent panels in the strip for the Normal condition exclusively, preliminary panel analysis also indicated the advantages of a combination of semantic relatedness and narrative structure for stimulus integration. Analogous to the findings of Van Petten and Kutas (1991), semantic processing of upcoming pictures was facilitated more by a context built through the combination of semantics and structure than semantics or structure alone.

Narrative structure without semantic relatedness

The contrast between the Structural and Scrambled conditions tested participants' use of narrative structure in the absence of semantic relatedness. ERP waveforms and paired-samples *t*-tests showed a significant difference in means in the TD group between the Structural and Scrambled conditions, indicating facilitated cognitive processing in the Structural condition. However, the ASD group did not show a significant difference between the Structural and Scrambled conditions in a similar *t*-test, potentially indicating that the ASD group was not sensitive to the presence of structure without semantic relatedness. Although the Scrambled - Structural difference waves did not show a statistical difference between groups, topography as observed visually showed a slight difference in activation between the TD and ASD groups (Figure 6). The TD group appeared to show more negativity than the ASD group, suggesting a higher sensitivity to narrative structure in isolation in the TD group. Although we do not see statistically significant group differences, because narrative comprehension requires the combination of many elements like structural processing, slight differences in structural processing as observed visually in this sample may indicate a future trend towards impaired processing of structure in visual narratives in ASD.

Examining the effect of visual narrative fluency on comprehension also involved comparing the Structural and Scrambled conditions. We correlated the Scrambled - Structural difference wave amplitude with VLFI scores to investigate if people with higher levels of fluency or familiarity with visual narratives were more sensitive to the presence of narrative structure. Cohn et al. (2012) found significant correlations between comic reading fluency and the magnitude of Scrambled - Structural N400 differences, reasoning that frequent comic readers have more experience and exposure to visual narrative structure and thus an advantage in processing narrative structure in isolation, as in the Structural condition. Participants who were not experienced with visual narratives showed a smaller difference between the Scrambled and Structural conditions, suggesting they were not sensitive to narrative structure without semantics. We did not observe similar patterns in our preliminary analysis of visual narrative fluency in either the TD or ASD group, and the *p*-values of Pearson's correlations were not significant.

As discussed, the LAN ERP component is measure of syntactic processing that is sensitive to narrative structure without semantics. The presence of this waveform would support results of structural processing without semantics by showing a difference in Structural and Scrambled amplitudes. Because the ERP waveforms of the TD group closely mirror the findings of Cohn et al. (2012), we would expect to see a LAN in the TD group. However, we did not observe an LAN in either group. Although these ERP and topography group differences were not significant in an overall ANOVA, this trend suggests that the TD group used narrative structure to facilitate processing on a small level even in the absence of semantic relatedness, while the ASD group was less sensitive to narrative structure alone to provide any context or aid in comprehension.

Limitations

The primary limitation facing the current study was sample size. This preliminary analysis used a sample size of 10 participants with ASD and 10 TD controls. The ERP waveforms shown and discussed in this study represented the average of all participants within a group. Because participant waveforms are not uniform due to unique differences in brain activity and the limits of our recording techniques, a larger sample will be beneficial in the future to achieve a data collection that is more representative of the population. In addition, the small sample size was likely a contributing factor to the absence of significant main effects and interactions of group, which require a larger sample to be statistically significant.

While some ERP components like the N400 are visible even in single participants, the LAN is a small component that is not easily detectable. However, we did not observe a LAN in either group, which suggests that the current sample size affected the emergence of this processing component. The sample size also influenced the effects of visual narrative fluency on comprehension as shown by correlations that were not significant between VLF1 score and the difference in Scrambled and Structural amplitude.

Another factor that potentially contributes to our findings is the demographics of our population. Almost all of our participants in both TD and ASD groups were current undergraduate students or recent graduates, and most had completed at least one year of post-secondary education. As mentioned, people with ASD have a broad spectrum of abilities and difficulties in fields of social interaction, communication, and behavior. The requirements of our experiment (e.g. meeting with unfamiliar researchers; remaining still for one hour while wearing a wet and uncomfortable EEG net on the scalp and face) inadvertently restricted our sample to people who were able to do those tasks, excluding some members of the ASD community. This

sample of college-aged students is not necessarily representative of the entire population, so it is difficult to generalize from these results.

Future research should continue to explore structural processing of visual narratives in ASD. Attention has been previously given to visuo-semantic processing in ASD (e.g., Coderre et al., 2017; Kamio & Toichi, 2000). However, this is the first study to explore visual narrative grammar in ASD. It was not designed to be a comprehensive analysis of structural processing in ASD and measures of structural processing were indeed limited (i.e., we did not observe a LAN; we did not inquire post-experiment if participants had detected a narrative structure.) A more thorough analysis of visual narrative grammar in ASD should be done to provide a foundation for future research into structural processing in visual narratives in ASD.

Conclusions

This experiment mirrored the findings of Cohn et al. (2012), showing similar patterns in N400 amplitude and ERP waveforms for both TD and ASD groups. While not statistically significant, a visual variation in Scrambled - Semantic and Scrambled - Structural difference wave topography suggests that people with ASD may be slightly less sensitive to the presence of semantics and structure in isolation to facilitate narrative processing. Similar to processing verbal language, comprehension of sequential images requires the combination of semantic relatedness and narrative structure to develop context and coherence across a sequence. Although statistically significant findings were limited by the current sample size, similarities in ERP waveform patterns for both TD and ASD groups showed comparable use of semantics and structure to facilitate processing in visual narratives.

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