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## Cross-Modal Examinations Of Narrative Structural Processing In Autism.

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CROSS-MODAL EXAMINATIONS OF NARRATIVE STRUCTURAL PROCESSING IN  
AUTISM.

A Thesis Presented

by

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## ABSTRACT

Understanding the structure, or narrative arc, of a story is critical for narrative comprehension, whether a narrative is presented verbally (e.g., written or spoken stories) or pictorially (e.g., comics). Previous work finds that autistic adults<sup>1</sup> show reduced sensitivity to narrative structure in comics, which could help explain oft-reported differences in narrative comprehension by autistic individuals. Here, we extend that work to explore structural processing in written and pictorial narratives and compare between modalities. In an electroencephalography (EEG) study with autistic and non-autistic adults, we manipulated the presence of narrative grammar in comics and written stories. “Structural Only” narratives contained narrative structure but no comprehensible meaning. These were created by shuffling sentences (in written narratives) or comic panels (in visual narratives) across stories but maintaining their relative positions. “Scrambled” narratives were created by shuffling sentences/panels across stories and positions, thus eliminating both structure and meaning. Neural responsiveness to narrative structure was examined by subtracting Structural Only ERP amplitudes from Scrambled amplitudes and comparing the resulting difference wave across levels of autistic traits as measured by the Autism Quotient (AQ) questionnaire. Analyses showed effects of level of autistic traits in both modalities, with higher AQ participants exhibiting more negative amplitudes across conditions compared to low AQ participants. In response to both written and visual narratives, analyses revealed positive correlations between AQ and Scrambled – Structural Only difference wave amplitudes. This association indicates that, with higher AQ scores, the amplitudes of the difference waves became less negative, indicating differential sensitivity to and processing of narrative grammar with higher levels of autistic traits. These findings suggest that autistic traits affect the processing of narrative grammar regardless of modality, which could contribute to overall narrative comprehension differences in this population.

1. Identity-first language (e.g., “autistic individuals”) is used in this document as opposed to person-first language (e.g., “individuals with autism”) to reflect the preferences of the adult autistic community (Bottema-Beutel et al., 2021; Keating et al., 2022).

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## TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	ii
LIST OF TABLES .....	vi
LIST OF FIGURES .....	vii
CHAPTER 1: INTRODUCTION.....	1
1.1. Narrative Structure across Modalities.....	1
1.1.2. Linguistic Narrative Structure .....	2
1.1.2. Visual Narrative Structure .....	4
1.2. Neural Measurement of Narrative Structural Processing .....	6
1.2.1. Event related potentials.....	7
1.2.2. ERP Studies of Structural Processing in Linguistic Narratives.....	8
1.2.3. ERP Studies of Structural Processing in Visual Narratives.....	11
1.3 Structural Processing in Autism .....	12
1.3.1. Structural Processing of Linguistic Narratives in Autism .....	12
1.3.2. Structural Processing of Visual Narratives in Autism.....	14
1.4 Visual Ease Assumption .....	15
1.5 Current Study .....	16
CHAPTER 2: METHODOLOGY .....	18

2.1 Research Design .....	18
2.1.1. Stimuli.....	18
2.1.2. Participants .....	21
2.1.3. Experimental Procedure.....	22
2.2 Statistical Analyses .....	23
CHAPTER 3: RESULTS.....	25
3.1 Linguistic Narratives.....	25
3.1.1. Overall ANOVAs .....	25
3.1.2. Difference Waves .....	29
3.1.3. Summary.....	32
3.2. Visual Narratives .....	33
3.2.1. Overall ANOVAs .....	33
3.2.2. Difference Waves .....	40
3.2.3. Summary.....	45
CHAPTER 4: DISCUSSION.....	47
4.1. Linguistic Narrative Processing in Autism .....	47
4.1.1. Overall ERP Data .....	47
4.1.2. Scrambled – Structural Only Difference Waves .....	48

4.2. Visual Narrative Processing in Autism.....	52
4.2.1. Overall ERP Data .....	52
4.2.2. Scrambled – Structural Only Difference Waves .....	54
4.3 Narrative Structural Processing Across Modalities .....	57
4.4. Implications for the Visual Ease Assumption.....	57
4.5. Limitations and Future Directions .....	59
4.6. Conclusions.....	61
REFERENCES .....	63
APPENDIX.....	68

## LIST OF TABLES

<b>Table</b>	<b>Page</b>
Table 1: Demographic information.....	22
Table 2: ANOVAs on ERP amplitude in the linguistic modality.....	27
Table 3: ANOVAs on difference waves in the linguistic modality.....	30
Table 4: ANOVAs on ERP amplitude in the visual modality.....	35
Table 5: ANOVAs on difference waves in the visual modality.....	42

## LIST OF FIGURES

<b>Figure</b>	<b>Page</b>
Figure 1: A written narrative with labeled narrative structure.....	3
Figure 2: Structural categories of a visual narrative (Cohn, 2014).....	5
Figure 3: Narrative categories and constituents (Cohn & Bender, 2017).....	6
Figure 4: ERP for linguistically anomalous words (Osterhout et al., 1997).....	10
Figure 5: Overview stimuli in the current study.....	20
Figure 6: ERP waveforms for linguistic modality.....	26
Figure 7: Difference waves for linguistic modality.....	29
Figure 8: Scatterplot from 200-300 ms.....	31
Figure 9: Scatterplot from 600-700 ms.....	32
Figure 10: ERP waveforms for visual modality.....	34
Figure 11: Scatterplot from 200-300 ms (panel a) 300-400 ms (panel b).....	37
Figure 12: Difference waves for visual modality.....	41
Figure 13: Scatterplot from 200-300 ms (panel a) and 300-400 ms (panel b).....	43
Figure 14: Scatterplot from 600-700 ms.....	44
Figure 15: Scatterplot from 700-1000 ms.....	45

## **CHAPTER 1: INTRODUCTION**

Autism is a neurodevelopmental condition characterized by differences in social communication and sensory-motor behaviors (Lord et al., 2018). Though estimates vary according to diagnostic criteria, the prevalence of autism spectrum disorder (ASD) is estimated to be 1 in every 36 children in the United States (Maenner et al., 2023). Autistic individuals commonly exhibit language comprehension differences that are prominent in early childhood and are maintained through adulthood (Mouga et al., 2020). For autistic individuals, language processing difficulties generally arise not with single-word reading (which is often similar between autistic children and their non-autistic peers) but with more complex cognitive processes like comprehension at the sentence or narrative level (Minshew et al., 2002; Vale et al., 2022).

This pattern of comprehension difficulties in autism occurring only for more complex stimuli is also evident in the visual domain. Processing at the level of single images is often similar, if not superior, to that of non-autistic individuals (Samson et al., 2012), but for more complex visual stimuli like sequential images (e.g., comic strips), evidence suggests that higher-order cognitive processing like those necessary for understanding stories (“narrative comprehension”) are more difficult for autistic individuals (Coderre et al., 2018).

### **1.1. Narrative Structure across Modalities**

One of the most important cognitive processes involved in narrative comprehension is understanding the structure (e.g., syntax, grammar) of a story (Griffith & Ripich, 1988). Just as grammar and syntax are essential for understanding a sentence, narratives follow a structure (“narrative arc”) that imparts meaning by linking together thematic narrative

events (Stein & Glenn, 1975). Narrative structure is present in both linguistic narratives (e.g., written or spoken stories) and visual narratives (e.g., comics).

### **1.1.2. Linguistic Narrative Structure**

In a linguistic narrative, the sequential sentences in a story serve distinct roles in building a conceptual structure of meaning (Mandler & Murphy, 1983). Theoretical models of narrative structure distinguish narrative categories by identifying characters' goals within a formalistic "story grammar" (Stein & Glenn, 1975). Regardless of their modality (e.g., pictorial, written), narratives share a general canonical story structure: beginning, middle, and end (Dini et al., 2023). Various models agree that, in written and spoken stories, narrative grammar involves a description of the "Setting" followed by a sequence of events that make up an episode. An episode begins with an "Initiating Event" – an occurrence that influences the main character to action. The protagonist then establishes a "Goal" motivated by an "Internal Response" to the Initiating Event. The main character then "Attempts" to achieve it and then deals with the "Outcome" of the attempt. The story concludes with "Reactions" to the Outcome (Figure 1) (Griffith & Ripich, 1988; Peña et al., 2006; Stein & Glenn, 1975).

**Figure 1:** A written narrative from the current study demonstrating the Stien & Glenn’s narrative structure: Setting, Initiating Event, Internal Response, Goal, Attempts, Outcome, and Reactions.

<b>Setting</b>	<b>Initializing Event</b>	<b>Goal/Internal Response</b>	<b>Attempt</b>	<b>Outcome/Reaction</b>
Jeremy and Fido are sharing a popsicle.	Each of them takes a turn having a lick	Fido has started biting the popsicle on his turn instead of licking it.	It's Fido's turn, and he takes a giant bite.	Jeremy goes to take a lick and realizes the whole popsicle has been eaten.

A large body of psycholinguistic research supports the idea that written and spoken narratives have this intrinsic global structure that builds up as a story is read or heard – a concept articulated in Gernsbacher’s theory of a “Structure Building Framework” (Gernsbacher, 1990). According to the Structure Building Framework, the goal of narrative comprehension is to build coherent mental representations (“structures”). “Comprehenders” first lay foundations for their mental structures by taking in initializing information (e.g. Setting and Initializing Events) and subsequently develop mental structures by mapping on new information when it coheres or relates to previous information. Importantly, when the incoming information is not coherent with the structure one has built up to that point, comprehenders shift and build a new substructure (Gernsbacher, 1997). Gernsbacher argues that these processes and mechanisms are general and underlie nonlinguistic phenomena as well as linguistic (Gernsbacher, 1990).

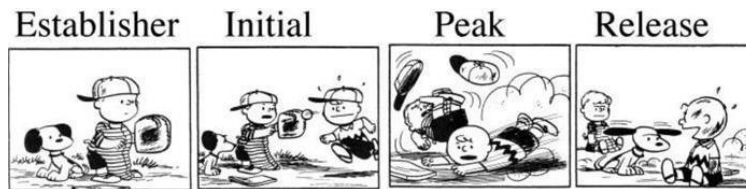
The importance of narrative grammar for building conceptual representations of stories has been confirmed in experimental work as researchers have manipulated the presence of story structure and used memory paradigms to examine the resulting patterns

of individuals' recall of stories. From these investigations, it is evident that narratives are recalled better when they follow the canonical story structure than when alterations were made to it or when the order of sentences was reversed or scrambled (Fitzgerald et al., 1985; Mandler & DeForest, 1979; Trabasso & van den Broek, 1985). Additionally, the more a canonical story structure is altered, the worse participants' recall or ability to reconstruct that story (Stein & Nezworski, 1978). These findings underscore the importance of building coherent mental representations of structure for understanding narratives.

### **1.1.2. Visual Narrative Structure**

Similar to linguistic narrative structure, each image in a visual story (e.g., comic strip) can be categorized according to its role in the global sequence of images (Cohn et al., 2012). Cohn's theory of Visual Narrative Grammar argues that comprehension requires more than understanding semantic connections between story units ("constituents") and posits that the structural components of a visual narrative sequence are analogous to the syntax of written and spoken narratives which group sentences into constituents based on characters' goal-directed events (Cohn & Bender, 2017). Individual images in a visual narrative sequence can be categorized as: Establishers, Initials, Peaks, and Releases (Figure 2). Image panels categorized as "Establishers" set up referential information (e.g., characters, setting) in a passive manner. Next, "Initials" may initiate or prepare the rising action in the story. The narrative arc climaxes in a "Peak", which marks the culmination of events in the narrative sequence. Finally, a "Release" resolves the events at the end of the sequence (Cohn et al., 2012).

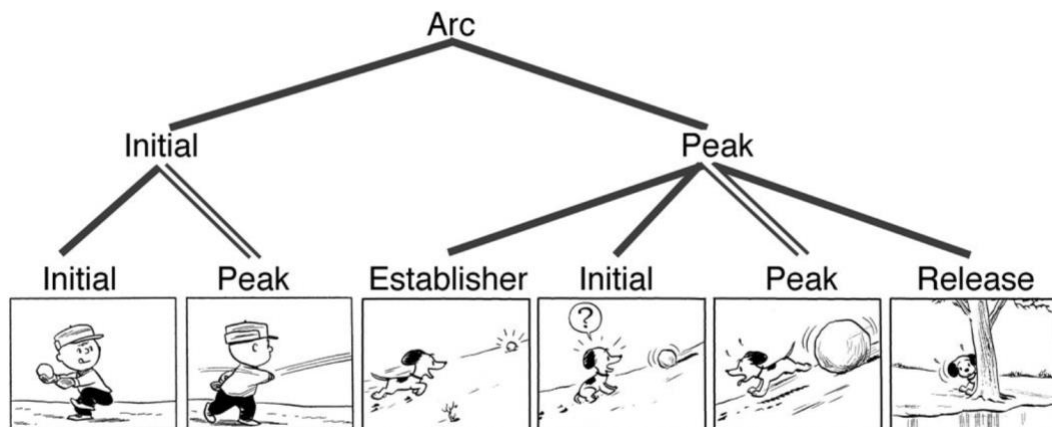
**Figure 2:** A Peanuts comic strip demonstrating the structural categories of a visual narrative: Establisher, Initial, Peak, and Release. (Image from Cohn, 2014).



Notably, the individual images in visual narratives do not always adhere strictly to this linear sequence. Sometimes, when viewing the panels in a visual narrative linearly, their associated grammatical categories may appear out of order (Figure 3). However, examining the larger, hierarchical structure of *groupings* of panels can reveal the canonical structure of the story because narrative categories do not just apply to panels, but also to whole constituents. For example, Figure 3 (taken from Cohn and Bender’s 2017 study of constituent structure in visual narratives) depicts a *Peanuts* comic strip in which Charlie Brown and Snoopy are playing in the snow. The first panel – showing Charlie reaching back with a snowball – is an Initial as it begins the events of the sequence. The second panel is a Peak, a mini-climax, depicting the completion of the action as Charlie throws the snowball. At a higher level of structure, these first two panels form their own constituent (an Initial) that commences the action of the second constituent (a Peak). The third panel, an Establisher, begins the second constituent of the narrative as it sets up a new interaction between Snoopy and the snowball. An Establisher panel following a Peak panel is technically in violation of the canonical narrative schema (E-I-P-R). However, it is evident that the narrative sequence does follow this overall schema when examining the constituents at a higher level (Cohn & Bender, 2017). The fourth panel is an Initial that starts a new event as Snoopy notices the snowball rolling towards him. Another climax

then occurs in the Peak, as Snoopy runs away from the snowball, which has grown to a frightening size. The final panel, showing Snoopy's reaction to the snowball as he hides behind a tree, is a Release or resolution of the action.

**Figure 3:** Structure of a visual sequence with narrative categories and constituents (Image from Cohn & Bender, 2017).



## 1.2. Neural Measurement of Narrative Structural Processing

Structural processing of narratives can be isolated and studied by manipulating the presence of narrative grammar in visual and written stories. Studies examining structural processing have isolated narrative grammar by presenting syntactically legal but nonsensical sentences (Van Petten & Kutas, 1991). In visual narratives, structural processing has been studied using comic strip sequences where panels index grammatical categories but are not linked in meaning (Cohn et al., 2012). Detection of, or sensitivity to, narrative syntax can be assessed by presenting these structurally isolated narratives while recording electrophysiological responses in the brain using electroencephalography (EEG) (Coderre et al., in preparation; Cohn et al., 2012; Van Petten & Kutas, 1991). EEG

measures the electrical activity of large populations of synchronously firing neurons in the cortex using electrodes placed directly on the scalp (Light et al., 2011). Because of its high temporal resolution and non-invasive nature, EEG is a favorable option for measuring the perceptual and cognitive operations that underlie complex higher-order processes like narrative comprehension.

### **1.2.1. Event related potentials**

Event-related potential (ERP) experimental designs leverage the temporal precision of EEG by collecting millisecond-by-millisecond scalp-recorded changes in electrical activity that occur in response to stimuli (Osterhout et al., 1997). Many time-locked trials of the same type are averaged together to yield an ERP (Kaan, 2007). ERP studies are particularly useful for examining language comprehension as the underlying processes that occur rapidly and in succession can be examined without participants having to make conscious, subjective reports of their processing and understanding. Recording the precise timing of language comprehension can facilitate differentiation of the neurocognitive processes involved in the comprehension of both linguistic and non-linguistic information (Regel et al., 2014). ERP studies have shown that violations of linguistic structure and visual narrative structure elicit left anterior negativities (LANs) which fall between 300 and 500ms and late positivities such as P600 effects – positive peaks from 600–800ms (Cohn et al., 2012; Friederici, 2002; Osterhout et al., 1997). These effects will be discussed in more detail below.

### **1.2.2. ERP Studies of Structural Processing in Linguistic Narratives**

To our knowledge, no prior studies have isolated and examined narrative structural processing of written stories at an electrophysiological level. However, ERP studies of structural processing at the sentence level are plentiful. A seminal ERP study by Van Petten & Kutas (1991) investigated the impact of semantic and structural context for the processing of words in sentences. The authors developed stimuli that could be presented during EEG recording to isolate and examine the syntactical processing that occurs while reading. “Congruent” sentences were both syntactically well-structured and semantically meaningful. A Congruent sentence used in the study read, “Everything she owned was in a paper bag”. “Syntactic” sentences were generated by taking Congruent sentences and shuffling open-class words (i.e., nouns, adjectives, verbs) of the same class between sentences while maintaining the position of closed-class words (i.e., prepositions, pronouns, conjunctions). These Syntactic sentences followed grammatical laws but were nonsensical. A Syntactic sentence used in the study read, “He went out of right food and had to go to the black bed”. “Random” sentences were generated by taking Syntactic sentences and shuffling words around regardless of class, so resulting sentences were neither syntactically legal nor semantically meaningful. A Random sentence used in the study read, “Every opened the gripped they stepping kind steel pine”. Sentences of each condition (Congruent, Syntactic, Random) were randomly intermixed and presented to participants one word at a time in the center of a screen during EEG recording. ERPs elicited by open- and closed-class words in each of the three conditions were averaged according to ordinal position within the sentence (Van Petten & Kutas, 1991).

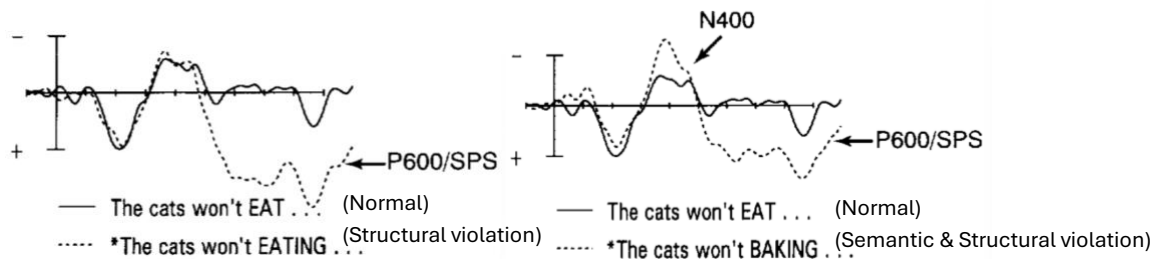
Open-class words in Congruent sentences, but not Syntactic or Random sentences, elicited an N400 component – a negative peak around 400ms often associated with semantic context – indicating that this component is responsive to semantic information but largely insensitive to syntactic structure. The modulation of N400 amplitude in response to semantic congruity is termed the “N400 effect” and is typically localized over centro-posterior sites for linguistic stimuli (Kutas & Federmeier, 2011). From 300-500 ms post stimulus, Van Petten & Kutas (1991) also reported amplitude differences between Syntactic and Random sentences for closed-class words (which carry structural information) regardless of ordinal position, with words from Random sentences eliciting the most negative amplitudes. These findings support the idea that syntactic and semantic phenomena elicit distinct patterns of brain activity and suggests that separable syntactic and semantic processes are involved in sentence comprehension (Van Petten & Kutas, 1991).

Another early negativity – the N300 effect – is worth mentioning in the context of semantic processing. Though most commonly observed in response to pictorial tasks (West & Holcomb, 2002), the N300 is thought to also be sensitive to expectancy for semantic similarity between linguistic stimuli, and may reflect forward-looking processing (i.e., prediction and anticipatory processing) (Franklin et al., 2007).

Two additional ERP components have been linked to syntactic processing. The P600 effect is a later positivity that can be elicited in response to a range of structural anomalies but is often produced when context builds up a coherent syntactic and semantic context that is subsequently violated (Osterhout et al., 1997). A 1995 study by Osterhout and Mobley examined the role of the P600 in syntactic processing and argued that this late

positivity reflects backward-looking post-semantic processing (Osterhout & Mobley, 1995). Backward-looking processes include integration, re-interpretation and index updating. Interestingly, linguistic stimuli that are both semantically and syntactically anomalous can elicit both the N400 effect and the P600 effect within the same epoch of activity (Figure 4; Osterhout et al., 1997). Interactions between syntax and semantics during sentence comprehension within the latency range of the N400 component have also been identified, typically localized within the left hemisphere (Palolahti et al., 2005). Finally, another ERP response to syntactic anomalies is the LAN – a negative-going wave between 200 and 500 ms over a localized left anterior region of the scalp – which is thought to reflect structural processing. It is argued that the LAN is correlated with morphosyntactic errors (i.e., subject-verb agreement) while the P600 correlates with a broader range of outright syntactic violations and anomalies (i.e., scrambled sentences) (Friederici, 2002; Osterhout et al., 1997).

**Figure 4:** Event-related potentials and effects elicited by linguistically anomalous words encountered during sentence comprehension (Figure from Osterhout et al., 1997).



### 1.2.3. ERP Studies of Structural Processing in Visual Narratives

A 2012 ERP study by Cohn et al. adopted the design of the Van Petten & Kutas (1991) study and manipulated visual narratives (*Peanuts* comic strips) to contain both semantics and structure (“Normal” sequences; analogous to Congruent sentences); narrative structure but no semantic relatedness between panels (“Structural Only” sequences; analogous to Syntactic sentences); or neither semantics nor structure (“Scrambled” sequences; analogous to Random sentences). Cohn et al. (2012) observed that Normal sequences elicited the smallest N300 and N400 effects compared to the Structural Only and Scrambled sequences. With smaller N300/N400 amplitudes reflecting easier semantic integration, this finding indicates that the presence of narrative structure in Structural Only sequences was not enough to reduce the amplitude of the N400 effect. This finding supports the claim that, while semantic information plays an integral role in the processing of sequential images, it does so in combination with narrative grammar (Cohn, 2014). Additionally, Cohn et al. (2012) found that, around 300-500 ms, Structural Only sequences elicited a small LAN relative to a larger LAN for Scrambled sequences. Notably, this left anterior effect was associated with a measure of participants’ comic reading expertise such that the more experience participants had, the larger the difference between these brain responses. The study by Cohn et al. (2012) provided initial evidence that the same ERP components that are elicited by manipulations of narrative semantics and structure in linguistic stimuli – the N300, N400, and LAN – are evoked by visual narrative stimuli. These findings support the claim that, like with written narratives, neural processing of structure within a visual narrative sequence is separate from the semantic processing. Recent ERP studies of visual narrative comprehension have replicated these

findings (Cohn, 2020) and have expanded to include investigations of visual narrative processing in autism (Coderre et al., 2018; Coderre et al., in preparation).

### **1.3 Structural Processing in Autism**

Though abilities vary widely across individuals with autism, understanding the cognitive mechanisms driving difficulties for those who struggle with narrative comprehension is important for designing and administering effective interventions and supports. Specifically, autistic individuals may exhibit differences in how they process narrative structure, which could lead to comprehension difficulties in some individuals. Previous studies have examined differences in the structural processing of linguistic and visual narratives in autistic individuals, but no studies to date have directly compared structural processing of narratives between modalities in autism.

#### **1.3.1. Structural Processing of Linguistic Narratives in Autism**

Many studies of syntactic processes in autism have examined language production or performance on standardized syntactic tasks rather than assessing comprehension directly. Studies have shown that, when asked to tell or retell a story, autistic individuals commonly demonstrate reduced syntactic complexity (Banney et al., 2015; Capps et al., 2000; Norbury & Bishop, 2003); fewer story grammar elements including narrative structure and setting (Banney et al., 2015); fewer pronominal references (Colle et al., 2008; Rumpf et al., 2012); more ambiguous references and pronouns (Banney et al., 2015; Norbury & Bishop, 2003; Novogrodsky, 2013; Suh et al., 2014); and less coherent stories (Diehl et al., 2006; Losh & Gordon, 2014; Rollins, 2014; Tager-Flusberg, 1995). Though

production is distinct from comprehension, accurate narrative production of stories requires accurate understanding of story structure (Coderre et al., 2018). As such, these findings could suggest differences in structural processing of narratives among autistic individuals.

Two studies examining comprehension of linguistic syntax using grammaticality judgement tasks found differences in accuracy detecting morphosyntactic violations (i.e., changes in word order or agreement) between autistic and non-autistic children. Eigsti & Bennetto (2009) found that autistic children performed lower than IQ-matched children for three particular types of morphology errors. Ambridge et al. (2015) found that autistic children showed smaller rating differences between grammatical and ungrammatical sentences compared to IQ-matched non-autistic peers. Additionally, a study by Durrleman et al. (2015) found that autistic adults without intellectual disability or history of language delay show difficulty detecting syntax at the sentence level. These studies suggest that differences in comprehension of and sensitivity to grammar exist in autism in childhood and adulthood alike.

ERP studies of syntactical processing in autism are limited, especially at the level of narrative structural processing. Examining how neural responsiveness to structure differs in autism at the sentence level can provide insight into the patterns we can expect during narrative structural processing. Tsai et al. (2013) used an ERP design to explore recognition of syntactic errors in Chinese-English bilingual participants, both with and without Asperger's syndrome. The authors reported challenges in recognizing and interpreting sentences in Chinese among autistic individuals, as evidenced by stronger and more prolonged event-related synchronization in the delta frequency band relative to non-

autistic participants. Additionally, Koolen et al. (2013) investigated EEG responses in autistic adults while monitoring for orthographic (“local”) and/or syntactic (“global”) errors in written sentences. Neurotypical participants showed P600 effects at specific scalp sites in response to syntactic errors, while autistic participants displayed a broader distribution of P600 effects. Though examinations of structural processing of linguistic narratives in autism are limited and predominantly focused on production or sentence-level effects, these studies suggest that differences in syntactic processing may contribute to differences in language processing in autism.

### **1.3.2. Structural Processing of Visual Narratives in Autism**

Structural processing during visual narrative comprehension was directly examined in a recent ERP study by Coderre et al. (in preparation) that replicated the study design from Van Petten & Kutas (1991) and Cohn et al. (2012). The study found that increasing levels of autistic traits were associated with smaller differences between Scrambled and Structural-Only conditions during the N300 and N400 time windows. Coderre et al. argue that, although these are early effects for structural processing, the small differences between these conditions may suggest a reduced sensitivity to narrative grammar in individuals with higher levels of autistic traits. Coderre et al. further propose that these findings may reflect a bottom-up processing style in autism. This would corroborate a tendency towards more backwards-looking, bottom-up processing in autism compared to more predictive, forward-looking top-down processing (Kubinski et al., under review; Palolahti et al., 2005). Bottom-up processing describes a cognitive approach that involves taking in initial sensory input (i.e., analyzing the words’ features) and gradually

assembling meaning by relating observed details to existing mental representations. In contrast, during top-down processing, prior knowledge, context, and expectations are used to anticipate and predict meaning of presented stimuli. Because visual narrative grammar is proposed to offer a top-down structure that organizes and facilitates semantic understanding (Cohn, 2014), reduced top-down influences in autism would lessen facilitation from, or sensitivity to, narrative structure, which could impact overall comprehension (Coderre et al., in preparation). A reduced sensitivity to grammar in the visual domain is in line with investigations of structural processing of linguistic stimuli for autistic individuals.

#### **1.4 Visual Ease Assumption**

As differences and difficulties in language processing and comprehension among autistic individuals are well documented in the linguistic domain, visual stimuli are often leveraged in many clinical assessments and interventions in an attempt to bypass linguistic processing demands. There is a common belief that visual processing is a strength among autistic individuals, adding to the popularity of visual approaches to interventions – such as using pictures, diagrams and comic strips – in a hope to ameliorate challenges with language comprehension. Some research has shown that autistic individuals exhibit enhanced functional resource allocation in brain regions associated with imagery and visual processing (Kaldy et al., 2016; Samson et al., 2012). Findings like these relate to the processing of single images but have been extrapolated to support the use of *any* visualization technique to build skills in other areas (Coderre, 2020). This assumption that

pictures are generally easier to understand than language for autistic individuals has been labeled the *Visual Ease Assumption* (VEA).

There is no evidence to suggest that processing of sequential images, such as visual narratives, is enhanced in autism, and yet they are commonly utilized used to both support and assess various cognitive abilities in autism (Coderre, 2020). Investigations of narrative comprehension across visual and linguistic narratives have shown that comprehension is equally affected across modalities in autism (Coderre et al., 2018). This finding suggests that the challenge lies not with written language, but with general comprehension. If narrative comprehension is difficult regardless of modality, then it is likely that shared cognitive and neural processing mechanisms are recruited for narrative comprehension and are causing these differences in autism in both visual and linguistic domains.

### **1.5 Current Study**

The current study proposes that, in contradiction to the VEA, structural processing is an amodal cognitive function that underlies both visual and linguistic narrative comprehension and contributes to challenges in overall narrative comprehension seen in autism. We replicated the methods of Cohn et al. (2012) and Coderre et al. (in preparation) in the visual modality, using Normal, Structural Only, and Scrambled visual narrative sequences (Figure 5). We built on these studies by isolating structural processing in linguistic narratives and constructing an analogous stimulus set consisting of Normal, Structural Only, and Scrambled written narratives (Figure 5). The objective of this project was to isolate and examine the structural processing subfunction of narrative comprehension by comparing Normal, Structural Only, and Scrambled narrative sequences

between visual and linguistic modalities, using similar stimuli to those featured in studies of structural processing of visual narratives (Cohn et al., 2012) and linguistic stimuli (Van Petten & Kutas, 1991). Our hypotheses involved examining interactions between structural processing and level of autistic traits across modalities. We expected to replicate the findings from Cohn et al. (2012), with Scrambled sequences eliciting the largest amplitudes, followed by Structural Only, and Normal sequences, respectively. And, as reported by Coderre et al. (in preparation), we expected that higher levels of autistic traits would be correlated with smaller differences between Structural Only and Scrambled narratives, indicating a reduced sensitivity to narrative structure across modalities. Because the VEA proposes that the use of visual stimuli should alleviate narrative processing difficulties in autism, observing these predicted effects would offer further evidence against the VEA.

## CHAPTER 2: METHODOLOGY

### 2.1 Research Design

#### 2.1.1. Stimuli

In this study, visual narrative stimuli consisted of 6-panel sequences generated from *Peanuts* comics. As in Cohn et al. (2012), visual stimuli were manipulated to isolate structural processing by shuffling panels across *Peanuts* comic strips. The visual stimuli that were employed in this design have been used in published studies, and their narrative qualities have been empirically verified through previous investigations of structural processing in non-autistic populations (Cohn, 2020; Cohn et al., 2012; Cohn & Bender, 2017). No text was included in the stimuli to avoid linguistic influences on processing. Reducing the probability of episodic memory effects, Cohn et al. (2012) selected six-panel sequences that were tested for familiarity and were normed for coherence relations across panels in each condition. Selected visual narratives maintained similar numbers of characters per panel across scenarios, if not the identical characters (see Cohn et al., 2012 for details). Linguistic narratives consisted of 5-sentence narratives that were based on prior ERP studies examining comprehension of visually-presented written stories that were three sentences in length (Camblin et al., 2007). Written narratives for the current study were longer and were kept as similar as possible to visual narratives by modeling sentences and story progression based on that of sequential panels from selected *Peanuts* comic strips.

Three sequence types were utilized to isolate structural processing of linguistic and visual narratives in this study (Figure 5). Normal narratives had sentences (in written stimuli) or comic panels (in visual stimuli) that were linked in meaning and that followed

the canonical structure of narratives described above (Figure 1; Figure 2). Structural Only narratives contained a narrative structure with consecutive events fitting the Establisher, Initial, Peak, and Release categories, but with no meaningful semantic relatedness between the comic panels or sentences. These Structural Only stimuli were created by shuffling sentences or comic panels across stories while maintaining their relative positions within the narrative. Scrambled narratives contained neither meaning nor narrative structure. The Scrambled narratives were created by shuffling sentences or panels across stories and positions such that story components did not share a semantic theme and were not ordered in a canonical narrative arc.

**Figure 5:** Examples of the four conditions and sequences, including an overview of the presence or absence semantic relatedness and narrative structure in each condition.

Condition	Narrative Structure	Semantic Relatedness	Stimuli					
<b>Normal</b>	+	+	<b>Establisher</b>	<b>Establisher</b>	<b>Initial</b>	<b>Peak</b>	<b>Release</b>	
			Jeremy and Fido are sharing a popsicle.	Each of them takes a turn taking a lick.	But Fido has started biting the popsicle on his turn, instead of licking it.	It's Fido's turn, and he takes a giant bite.	Jeremy goes to take a lick and realizes the whole popsicle has been eaten.	
<b>Structural</b>	+	-	<b>Establisher</b>	<b>Establisher</b>	<b>Initial</b>	<b>Peak</b>	<b>Release</b>	<b>Release</b>
			It's autumn, so the ground is covered in dry leaves.	He gets the milk out of the fridge and pours it on his cereal.	In the afternoon, it starts to rain.	Next to the tree, he sees a shiny new bike with a big bow on it.	To get to school, Phillip will have to ride his bike, and fast!	
<b>Scrambled</b>	-	-	<b>Initial</b>	<b>Peak</b>	<b>Release</b>	<b>Initial</b>	<b>Establisher</b>	
			But he is pretty forgetful.	Phillip runs right into Jeremy.	The sun is already shining brightly through the blinds.	He sees Phillip skateboarding straight towards him.	Phillip and Jeremy are playing frisbee in the backyard.	

### 2.1.2. Participants

Participants included 21 adults aged 18-65 with and without autism diagnoses. Adults were used in this study because narrative comprehension skills in childhood are variable by age, grade, and educational experience (Melzi & Caspe, 2017). As differences in narrative comprehension often persist into adulthood, studying these subtleties of narrative comprehension in adulthood allowed us to be more certain that our findings are related to differences specific to autistic traits rather than transient developmental stages and delays. Rather than separating participants into autistic and non-autistic groups, we measured sensitivity to narrative structure against self-reported levels of autistic traits as measured by the Autism Quotient (AQ; Baron-Cohen et al., 2001) questionnaire. Only participants with a score greater than 85 on the Sentence Comprehension subscale of the Wide-Ranging Achievement Test (WRAT-5; Davis & Francis, 2020) were included in analyses, as this preliminary study will examine structural processing in individuals without reading impairments. Demographic information is presented in **Error! Reference source not found.** Individuals with histories of neurological conditions were also excluded. All participants self-reported normal or corrected-to-normal vision. Participants were recruited from the community and local organizations that serve autistic adults.

**Table 1:** Demographic information for the participants included in the study. Means, standard deviations, and ranges are reported for each variable.  $N = 21$ .

<b>Variable</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Range</b>
<i>Age</i>	23.95	11.74	18 - 65
<i>Autism Quotient</i>	18.62	11.32	5 - 41
<i>WRAT Sentence Comp</i>	116.67	6.09	94 - 131
<i>VLFI</i>	8.31	4.90	2.75 - 23.25

### **2.1.3. Experimental Procedure**

Participants first attended a screening session during which assessments were administered to measure cognitive functions related to narrative comprehension. All participants completed assessments of level of autistic traits (AQ score), baseline sentence comprehension abilities (Sentence Comprehension subscale of the WRAT-5), and familiarity and proficiency with reading visual narratives (The Visual Language Fluency Index, VLFI; Cohn, 2020).

During two separate sessions, the Normal, Structural Only and Scrambled narratives were presented in random order on a computer monitor while participants' EEG data were recorded at 500 Hz using an EGI GES 400 amplifier, 128-channel Hydrocel nets, and NetStation (version 5.4.2.). In one session participants viewed all visual narratives, and in the other participants viewed all linguistic narratives. EEG recording lasted around 1 hour, including net application and breaks. In visual narratives, panels appeared in sequence, one by one, for 1500 milliseconds (ms) each with a 350 ms inter-stimulus interval (ISI). Presenting panels one at a time minimized eye movements, which can cause artifacts in the EEG data. The panels were black and white against a white background. In

linguistic narratives, the first four sentences were presented one sentence at a time, and participants were able to read in a self-paced format by clicking a button to advance to each following sentence in the narrative. This design was modeled after the study by (Camblin et al., 2007) in which the first two sentences of the narrative appeared on the screen in their entirety, and participants pressed a button after they had completed reading these two sentences to advance to the last sentence. Upon pressing the button, the critical sentence was presented one word at a time, with a presentation duration of 400 ms per word and a 400 ms ISI. All words were presented at the center of the screen. Participants were instructed to read each visual and linguistic narrative for comprehension. On 20% of trials, comprehension questions were presented to ensure attention. The Normal, Structural Only and Scrambled conditions consisted of 24 narratives each in each modality. ERP responses were averaged over the last panel in each visual narrative and over every word in the last sentence of each linguistic narrative.

## **2.2 Statistical Analyses**

Using EEGLab and Matlab, EEG data was preprocessed by performing filtering with a 0.1-50 Hz bandpass filter, re-referencing, epoching, and eye movement artifact correction using independent component analysis (ICA). Bad channels were identified and replaced via interpolation. ERP amplitudes were evaluated at 9 electrode clusters at left, midline, and right lateralities within frontal, central, and parietal sites to allow for a broad scalp representation.

Amplitudes were averaged over the final panels in visual narratives and over all words in the last sentence of each linguistic narrative to compare the processing of Normal,

Scrambled and Structural Only narratives by condition and across levels of autistic traits. Repeated-measures ANOVAs were performed on the average ERP amplitudes for each modality separately. For linguistic narratives, repeated-measures ANOVAs included factors of *Condition* (Normal, Structural Only, Scrambled), *Site* (frontal, central, parietal), and *Laterality* (left, midline, right) as within-subjects factors, and *AQ* and *Sentence Comprehension* (as measured by the WRAT-5) as between-subjects continuous variables. For visual narratives, repeated-measures ANOVAs included factors of *Condition* (Normal, Structural Only, Scrambled), *Site* (frontal, central, parietal), and *Laterality* (left, midline, right) as within-subjects factors, and *AQ* and *VLFI* scores as between-subjects continuous variables. Additionally, difference waves were generated by subtracting the ERPs from the Structural Only condition from those from the Scrambled condition. To identify main effects and interactions, repeated-measures ANOVAs were performed on the difference wave amplitudes for each modality separately, with within-subjects factors of *Site* (frontal, central, parietal), and *Laterality* (left, midline, right) as within-subjects factors, and *AQ* and *WRAT/VLFI* scores as between-subjects continuous variables.

## **CHAPTER 3: RESULTS**

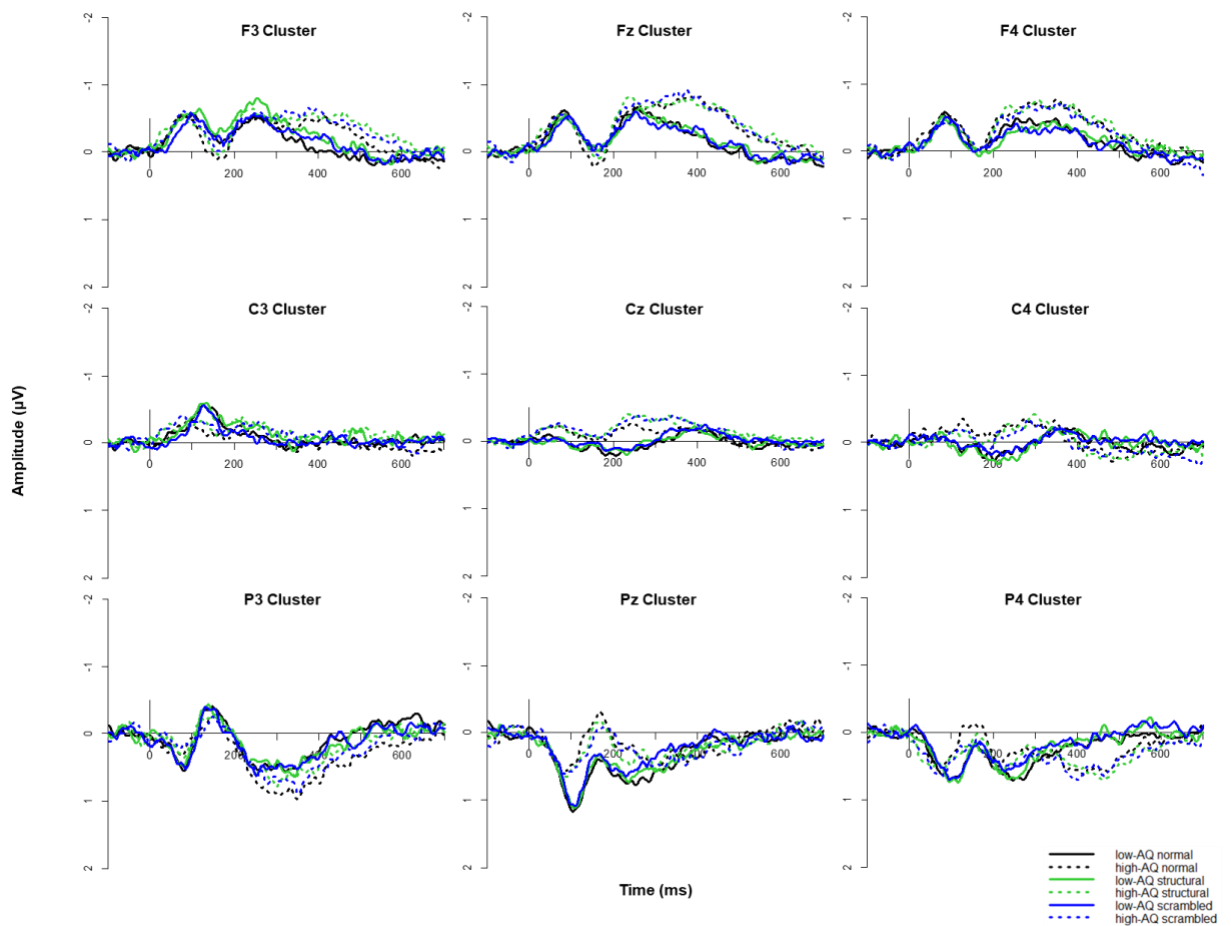
### **3.1 Linguistic Narratives**

#### **3.1.1. Overall ANOVAs**

ERP waveforms in response to linguistic narrative stimuli were analyzed at every word in the final sentence from -100 ms to 700 ms (Figure 6). Using a median split, participants were divided into either the “high AQ” group (scores above 17 on the AQ questionnaire) and the “low AQ” group (scores below 17 on the AQ questionnaire). This grouping via median split was utilized purely for visualization purposes to examine directions of trends with lower vs higher levels of autistic traits. All statistical analyses were performed against a continuum of AQ scores rather than dichotomous groupings. Visual inspection of the ERP waveforms for participants with low versus high levels of autistic traits suggests an effect of AQ on ERP amplitude such that high AQ participants exhibited stronger negativities regardless of condition at frontal sites from approximately 300-600 ms. At right and midline central sites, it appears that high AQ participants exhibited slightly stronger negative amplitudes from approximately 200-350 ms. A negative deflection was present from 200-300 ms in most sites representing the onset of the N300 ERP component. Normal, Structural Only and Scrambled sequences trended closely together for both low and high AQ groups. Slight separation between conditions is visible at midline central sites (starting around 200 ms) and left frontal sites (starting around 300 ms). To explore these effects statistically, the effects of condition (Normal, Structural Only, Scrambled), sentence comprehension (score on the Sentence Comprehension subscale of the WRAT), and level of autistic traits (AQ score) were examined using repeated-measures ANOVAs in five 100 ms time windows: 200-300 ms,

300-400 ms, 400-500 ms, 500-600 ms, and 600-700 ms. The full results are shown in Table 2; only interactions of AQ and/or Sentence Comprehension and Condition are discussed in the text. Alternative ANOVA tables listing mean square error estimates and degrees of freedom are included in the appendix (See page 63).

**Figure 6:** ERP waveforms for Normal, Structural Only and Scrambled conditions at nine electrode clusters across the scalp. For visual comparison, participants were grouped into “high AQ” and “low AQ” based on a median split. Negativity is plotted upwards.



**Table 2:** *F*-values for the repeated-measures ANOVAs on the ERP amplitude in each analysis window, with two continuous between-subjects factors of *AQ* (level of autistic traits) and *Sentence Comp* (score on Sentence Comprehension subsection of the WRAT) and within-subjects factors of *Condition* (Normal, Structural Only, Scrambled), *Site* (frontal, central, parietal), and *Laterality* (left, midline, right). Interactions of *AQ* and *Condition* are highlighted in bold. Asterisks indicate statistically significant results ( $. = p < 0.10$ ;  $* = p < 0.05$ ;  $** = p < 0.01$ ;  $*** = p < 0.001$ ).

Main effects and interactions	Time Windows (ms)				
	200-300	300-400	400-500	500-600	600-700
AQ	1.05	0.72	0.21	0.00	0.08
Sentence Comp	1.33	0.83	1.29	1.90	1.65
AQ * Sentence Comp	0.13	0.01	0.48	0.93	0.03
Condition	3.66 *	4.30 *	2.82	3.98 *	1.28
<b>AQ * Condition</b>	0.17	0.67	0.77	0.55	1.31
Sentence Comp * Condition	3.281 *	0.40	0.38	0.11	0.31
<b>AQ * Sentence Comp * Condition</b>	4.22 *	1.18	1.85	0.91	0.65
Site	20.93 ***	17.25 ***	8.26 **	0.86	0.75
AQ * Site	0.12	1.58	4.61 *	1.70	0.48
Sentence Comp * Site	0.46	0.15	0.01	0.08	0.39
AQ * Sentence Comp * Site	1.85	0.99	0.80	0.09	0.27
Laterality	0.22	1.84	1.11	0.34	1.56
AQ * Laterality	0.24	0.15	0.44	0.49	0.61
Sentence Comp * Laterality	0.69	0.57	0.51	0.27	0.01
AQ * Sentence Comp * Laterality	1.31	0.07	0.35	0.47	0.18
Condition * Site	0.37	0.04	0.23	0.73	0.78
<b>AQ * Condition * Site</b>	0.14	0.80	0.48	0.03	0.11
Sentence Comp * Condition * Site	0.54	0.31	0.24	0.37	0.43
<b>AQ * Sentence Comp * Condition * Site</b>	0.63	0.69	1.04	0.43	1.32
Condition * Laterality	1.49	1.21	0.27	0.32	0.41
AQ * Condition * Laterality	1.06	0.56	0.25	0.75	0.84
Sentence Comp * Condition * Laterality	0.42	1.54	1.37	0.44	0.34
<b>AQ * Sentence Comp * Condition * Laterality</b>	0.74	1.43	0.46	0.11	0.54
Site * Laterality	0.76	0.54	0.52	1.02	0.93
AQ * Site * Laterality	0.06	0.21	0.17	0.51	0.52
Sentence Comp * Site * Laterality	0.78	0.58	0.55	0.58	0.27
AQ * Sentence Comp * Site * Laterality	0.81	0.67	0.78	0.43	0.27
Condition * Site * Laterality	0.97	1.00	0.51	0.76	0.80
<b>AQ * Condition * Site * Laterality</b>	2.62 *	0.83	0.71	0.71	0.65
Sentence Comp * Condition * Site * Laterality	0.74	0.53	0.60	0.18	0.42
<b>AQ * Sentence Comp * Condition * Site * Laterality</b>	1.45	1.19	0.93	0.50	0.32

**200 – 300 ms.** Repeated-measures ANOVA on this time window revealed an interaction of *AQ*, *Sentence Comprehension*, and *Condition* ( $F(2,34) = 4.22, p < 0.05$ ). However, follow-up analyses found no significant main effects or interactions of *AQ* and *Sentence Comprehension* for any condition (all  $p$ 's  $> 0.12$ ). There was an interaction of

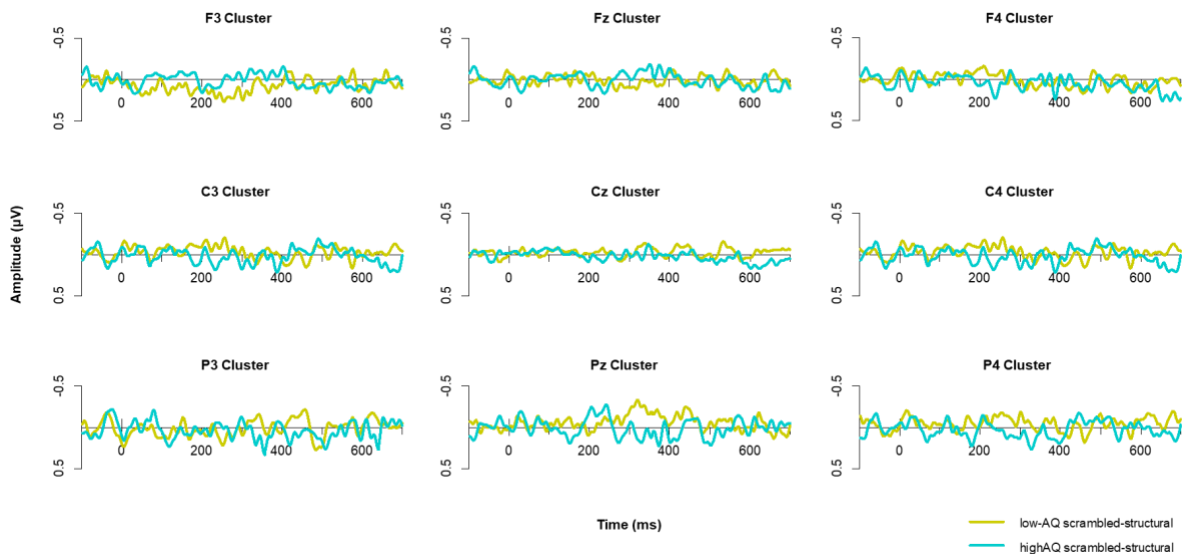
AQ, Condition, Site, and Laterality ( $F(8,136) = 2.62, p < 0.05$ ). On follow-up, there was a significant interaction of Condition and Laterality at frontal sites ( $F(4,76) = 2.73, p < 0.05$ ) as well as a trend of an effect of Condition in the left hemisphere ( $F(2,38) = 3.01, p = 0.06$ ). However, there were no interactions between AQ, Condition, and Laterality at any site (all  $p$ 's  $> 0.18$ ) nor interactions between AQ, Condition, and Site at any laterality (all  $p$ 's  $> 0.16$ ).

**300 – 700 ms.** There were no main effects of, or interactions with, either AQ or Sentence Comprehension and Condition in the remaining time windows.

### 3.1.2. Difference Waves

To closely examine differences between conditions, difference waves between Structural Only and Scrambled conditions were used to directly isolate structural processing in linguistic narratives in the absence of semantics. Difference waves were constructed by subtracting the Structural Only amplitudes from the Scrambled amplitudes at each time point and electrode cluster (see Figure 7). Repeated-measures ANOVAs were performed on the same 100 ms time windows starting at 200 ms and ending at 700 ms post stimulus presentation. The full results are presented in Table 3. Only significant main effects of, or interactions with, AQ are discussed in the text.

**Figure 7:** Difference waves for the Scrambled – Structural Only contrast at each of the nine electrode clusters across the scalp with participants grouped into “high AQ” and “low AQ” based on a median split. Negativity is plotted upwards.



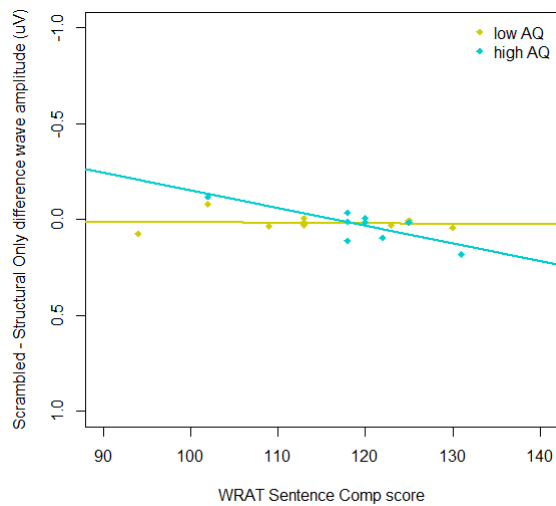
**Table 3:** *F*-values for the repeated-measures ANOVAs on the Scrambled – Structural Only difference waves in each analysis window, with two continuous between-subjects factors of *AQ* (score on assessment of autistic traits) and *Sentence Comp* (score on sentence comprehension subscale of WRAT) and within-subjects factors of *Site* (frontal, central, parietal) and *Laterality* (left, midline, right). Main effects of, or interactions with, *AQ* are highlighted in bold. Asterisks indicate statistically significant results (. =  $p < 0.10$ ; \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.001$ ).

Main effects and interactions	Time Windows (ms)				
	200-300	300-400	400-500	500-600	600-700
<b>AQ</b>	0.00	1.74	0.97	0.92	<b>3.54 .</b>
Sentence Comp	6.85 *	0.89	0.93	0.00	0.01
<b>AQ * Sentence Comp</b>	<b>14.99 **</b>	2.92	0.03	0.17	0.31
Site	0.78	0.03	0.14	0.22	0.72
<b>AQ * Site</b>	0.01	1.58	0.27	0.05	0.13
Sentence Comp * Site	0.19	0.71	0.39	0.33	0.28
<b>AQ * Sentence Comp * Site</b>	1.52	0.60	1.14	0.79	1.07
Laterality	1.24	0.83	0.25	0.32	0.06
<b>AQ * Laterality</b>	0.73	0.23	0.28	0.02	0.19
Sentence Comp * Laterality	0.62	0.33	0.09	0.63	0.64
<b>AQ * Sentence Comp * Laterality</b>	0.10	0.17	0.41	0.06	1.18
Site * Laterality	0.43	0.19	0.40	0.62	0.31
<b>AQ * Site * Laterality</b>	0.55	0.46	0.47	0.18	0.48
Sentence Comp * Site * Laterality	0.82	0.21	0.83	0.33	0.59
<b>AQ * Sentence Comp * Site * Laterality</b>	1.75	1.68	1.14	0.81	0.26

**200 – 300 ms.** Repeated-measures ANOVA on the Scrambled – Structural Only difference wave from 200-300 ms revealed an interaction of *AQ* and *Sentence Comprehension* ( $F(1,17) = 14.99, p < 0.01$ ). To visualize this, we divided the participants into “high *AQ*” and “low *AQ*” groups based on a median split. Follow-up correlations identified a positive correlation between WRAT *Sentence Comprehension* score and difference wave amplitude ( $r = 0.79, p = 0.01$ ) across all sites and hemispheres for the high *AQ* group only (see Figure 8). The positive correlation between *Sentence Comprehension* score and difference wave amplitude indicates that as *Sentence Comprehension* score

increases, the amplitude of the difference wave increases (becomes less negative) for participants with high levels of autistic traits. For the low AQ group, there were negligible associations of Sentence Comprehension score with difference wave amplitude ( $r = 0.08$ ,  $p = 0.82$ ).

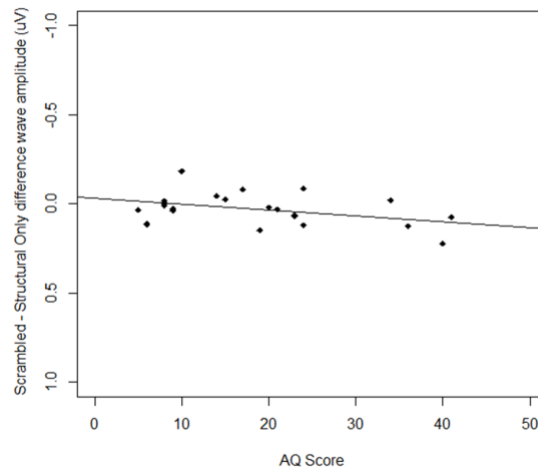
**Figure 8:** Scatterplot from 200-300 ms comparing scores on the Sentence Comprehension subscale of the WRAT against Scrambled – Structural Only difference wave amplitudes. Participants are divided into “high AQ” and “low AQ” groups based on a median split. Negativity is plotted upwards.



**300 – 600 ms.** There were no significant main effects of, or interactions with, AQ in this these time windows.

**600 – 700 ms.** In this time window there was a trend of an interaction of AQ ( $F(1,17) = 3.54$ ,  $p = 0.08$ ). Follow up analysis revealed a positive correlation ( $r = 0.41$ ,  $p = 0.06$ ) such that higher AQ scores were associated with slightly less negative difference wave amplitudes (Figure 9).

**Figure 9:** Scatterplot from 600-700 ms comparing AQ score and difference wave amplitude over all sites and hemispheres. Negativity is plotted upwards.



### 3.1.3. Summary

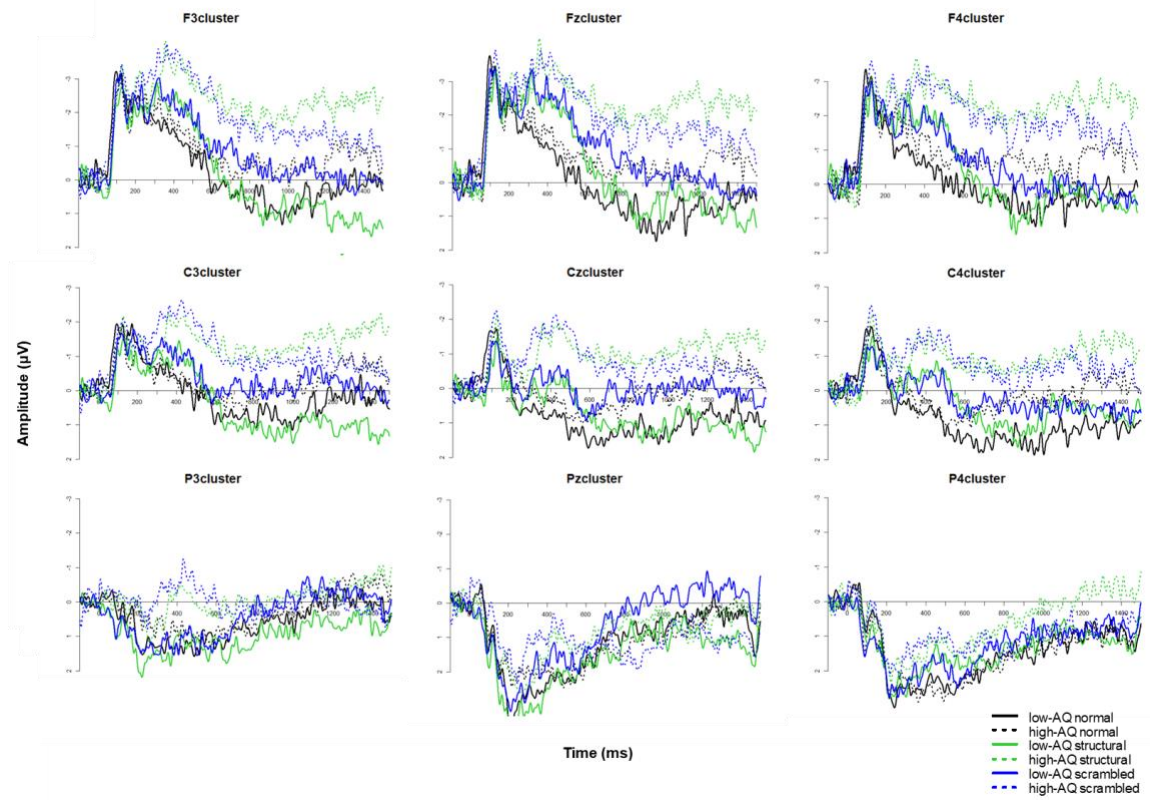
In the linguistic modality, significant interactions of AQ and Condition on overall ERP amplitude were only evident in the earliest time window (200-300 ms). However, upon follow-up, no interactions were significant. Direct comparisons between the Structural Only and Scrambled conditions revealed that sentence comprehension abilities (as measured by the WRAT) interacted with level of autistic traits in this early time window (200-300 ms). Stronger sentence comprehension abilities were associated with increased (less negative) difference wave amplitude (i.e. smaller differences between Scrambled and Structural Only conditions) for participants with higher levels of autistic traits but not for participants with lower levels. In the latest time window (600-700 ms), there was an effect of AQ such that higher levels of autistic traits correlated with less negative difference wave amplitudes.

## 3.2. Visual Narratives

### 3.2.1. Overall ANOVAs

ERP waveforms in response to visual narrative stimuli were analyzed at the presentation of the final panel from -100 ms to 1000 ms (Figure 10). Visual inspection of the ERP waveforms for participants with low versus high levels of autistic traits suggests an effect of AQ on ERP amplitude such that high AQ participants exhibited stronger negativities regardless of condition at all frontal and central sites from approximately 300 ms onward. Normal sequences tended to elicit the smallest negative amplitudes. Structural Only and Scrambled sequences trended closely together at early time windows but separated at later time windows. Interestingly, Structural Only sequences appeared to have the most negative ERP amplitudes in the high AQ group while Scrambled sequences tended to have the most negative ERP amplitudes in the low AQ group. To explore these effects statistically, the effects of condition (Normal, Structural Only, Scrambled), proficiency with reading visual narratives (VLFI score), and level of autistic traits (AQ score) were examined using repeated-measures ANOVAs in eight 100 ms time windows from 200 ms to 1000 ms: 200-300 ms, 300-400 ms, 400-500 ms, 500-600 ms, 600-700 ms, 700-800 ms, 800-900 ms, and 900-1000 ms. The full results are shown in Table 4; only interactions of AQ and/or VLFI and Condition are discussed in the text. Alternative ANOVA tables listing mean square error estimates and degrees of freedom are included in the appendix (See page 63).

**Figure 10:** ERP waveforms for Normal, Structural Only and Scrambled conditions at nine electrode clusters across the scalp. For visual comparison, participants were grouped into “high AQ” and “low AQ” based on a median split. Negativity is plotted upwards.



**Table 4:** *F*-values for the repeated-measures ANOVAs on the ERP amplitude in each analysis window, with two continuous between-subjects factors of *AQ* and *VLFI* and within-subjects factors of *Condition*, *Site*, and *Laterality*. Interactions of Group and Condition are highlighted in bold. Asterisks indicate statistically significant results ( $. = p < 0.10$ ;  $* = p < 0.05$ ;  $** = p < 0.01$ ;  $*** = p < 0.001$ ).

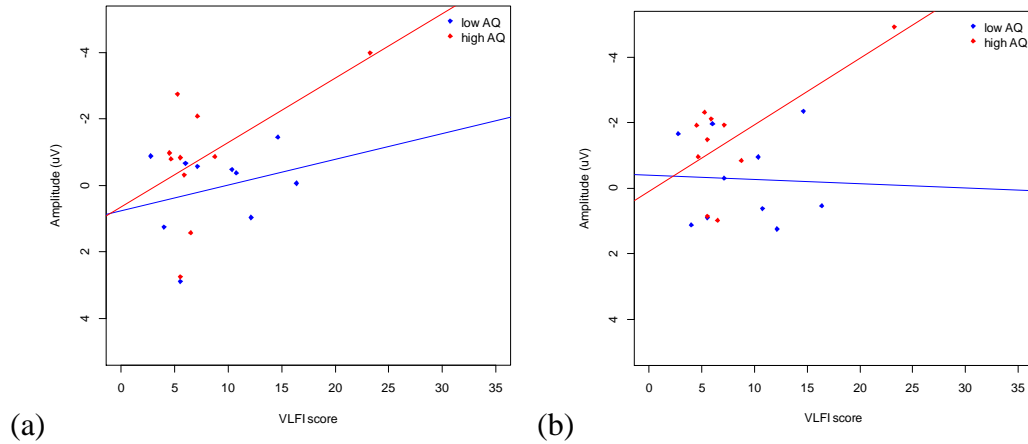
Main effects and interactions	Time Windows (ms)							
	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000
AQ	0.15	1.15	1.9	0.92	0.94	0.94	1.06	3.50.
VLFI	0.15	0.00	0.3	0.05	0.17	0.41	0.98	2.17
AQ * VLFI	0.16	0.87	2.2	1.48	1.03	2.56	3.23.	3.94.
Condition	4.20*	14.94***	19.75***	13.01***	9.47***	7.04**	3.24.	5.32**
<b>AQ * Condition</b>	1.72	3.96*	5.70**	5.11*	3.12.	3.72*	5.05*	5.07*
VLFI * Condition	17.06***	8.28**	4.60*	1.61	1.95	0.32	0.16	0.04
<b>AQ * VLFI * Condition</b>	8.37**	4.67*	1.6	0.92	2.34	1.88	0.55	0.47
Site	105.95***	81.39***	90.05***	50.52***	23.55***	14.18***	8.64***	5.66**
AQ * Site	0.05	0.16	0.5	0.50	0.66	1.33	2.97.	3.99*
VLFI * Site	0.55	0.84	2.2	2.23	0.89	0.49	0.36	0.19
AQ * VLFI * Site	0.78	0.96	1.5	1.30	0.43	0.35	0.28	0.40
Laterality	10.04***	8.90***	6.75**	5.82**	1.82	1.66	1.55	1.01
AQ * Laterality	0.25	0.86	1.0	0.25	0.04	0.19	0.26	0.18
VLFI * Laterality	0.20	0.03	0.0	0.10	0.21	0.17	0.03	0.20
AQ * VLFI * Laterality	0.48	1.27	0.8	0.69	0.38	0.45	0.44	0.52
Condition * Site	2.71*	6.00***	4.75**	4.08**	3.77**	3.73**	1.63	1.97
<b>AQ * Condition * Site</b>	0.43	0.54	0.4	0.58	1.10	1.09	0.79	1.15
VLFI * Condition * Site	2.387 .	1.57	1.0	0.60	0.87	1.03	1.38	2.12.
<b>AQ * VLFI * Condition * Site</b>	1.36	0.76	0.7	0.23	0.15	0.90	0.72	0.95
Condition * Laterality	2.078.	2.09.	1.0	0.83	0.32	0.17	0.16	0.49
<b>AQ * Condition * Laterality</b>	0.63	0.89	1.4	1.16	0.72	0.52	1.02	1.12
VLFI * Condition * Laterality	0.82	1.13	1.0	0.42	0.15	0.16	0.5	0.44
<b>AQ * VLFI * Condition * Laterality</b>	1.56	0.89	0.8	0.66	0.57	0.43	0.58	0.53
Site * Laterality	10.39***	5.77***	4.34**	4.40**	3.46*	4.47**	3.39*	3.33*
AQ * Site * Laterality	0.45	0.64	0.7	0.39	0.28	0.57	1.37	2.35.
VLFI * Site * Laterality	0.40	0.11	0.1	0.10	0.24	0.32	0.45	0.23
AQ * VLFI * Site * Laterality	0.28	0.19	0.2	0.32	0.26	0.27	0.35	0.45
Condition * Site * Laterality	1.17	2.69**	0.8	0.86	1.03	0.96	0.78	1.03
<b>AQ * Condition * Site * Laterality</b>	0.51	0.71	0.7	0.90	0.58	0.89	1.06	1.37
VLFI * Condition * Site * Laterality	1.17	1.33	0.8	1.07	0.98	0.94	1.16	1.31
<b>AQ * VLFI * Condition * Site * Laterality</b>	0.95	0.75	0.8	0.62	0.50	0.79	0.95	0.90

**200 – 300 ms.** In this time window, there was an interaction of AQ, VLFI, and Condition ( $F(2,34) = 8.37, p < 0.01$ ) which arose from an interaction of AQ and VLFI ( $F(1,185) = 6.05, p < 0.05$ ) in the Scrambled condition (Table 3). Participants were divided into “high AQ” and “low AQ” groups based on a median split to visualize this interaction. Follow-up correlational analyses in the Scrambled condition identified a statistical trend such that higher VLFI scores were associated with slightly more negative ERP amplitudes

over all electrode clusters for the high AQ group only ( $r = -0.56, p = 0.09$ ; Figure 11a). This negative correlation was not approaching significance for the low AQ group ( $r = -0.28, p = 0.44$ ). There were no significant main effects of, or interactions with, AQ and VLFI in the Structural Only and Normal conditions at this time window (all  $p$ 's  $> 0.36$ ).

**300 – 400 ms.** Results from the overall ANOVA (Table 3) showed a significant interaction of AQ, VLFI, and Condition ( $F(2,34) = 4.67, p < 0.05$ ) which arose from an interaction of AQ and VLFI in both the Scrambled condition ( $F(1,185) = 12.39, p < 0.001$ ) and Structural Only condition ( $F(1,185) = 4.29, p < 0.05$ ). There were no significant main effects of, or interactions with, AQ in the Normal condition at this time window ( $p$ 's  $> 0.85$ ). In the Scrambled condition, higher VLFI scores were associated with more negative ERP amplitudes for the high AQ group ( $r = -0.68, p < 0.05$ ) but not the low AQ group ( $r = 0.04, p = 0.90$ ; Figure 11b). On follow-up, the Structural Only condition did not elicit significant correlations between VLFI and ERP amplitudes for either the high AQ group ( $r = -0.02, p = 0.96$ ) nor the low AQ group ( $r = 0.21, p = 0.56$ ).

**Figure 11:** Scatterplot from 200-300 ms (panel a) 300-400 ms (panel b) comparing VLFI score against ERP amplitudes over all sites and hemispheres in the Scrambled condition. Participants are divided into “high AQ” and “low AQ” groups based on a median split. Negativity is plotted upwards.



From 300-400 ms, there was also an interaction between AQ and Condition ( $F(2,34) = 3.96, p < 0.05$ ) that arose from significant main effects of AQ in both the Scrambled ( $F(1,185) = 11.01, p < 0.01$ ) and Structural Only ( $F(1,185) = 4.25, p < 0.05$ ) conditions. Negative correlations of AQ with ERP amplitude occurred in both the Scrambled condition ( $r = -0.26, p = 0.25$ ) and the Structural Only condition ( $r = -0.39, p = 0.08$ ), such that increasing AQ scores were associated with more negative amplitudes. There was no main effect of AQ in the Normal condition at this time window ( $p = 0.85$ ).

**400 – 500 ms.** The significant interaction between AQ and Condition ( $F(2,34) = 5.70, p < 0.01$ ) was maintained in this time window and arose from significant main effects of AQ in both the Scrambled ( $F(1,187) = 19.97, p < 0.001$ ) and Structural Only ( $F(1,187) = 10.82, p < 0.01$ ) conditions. As in the previous time window, there was a negative correlation of AQ with ERP amplitude in both the Scrambled ( $r = -0.49, p < 0.05$ ) and the Structural Only conditions ( $r = -0.43, p = 0.05$ ), such that increasing AQ scores were

associated with more negative amplitudes. There was no main effect of AQ in the Normal condition at this time window ( $p = 0.71$ ).

**500 – 600 ms.** The significant interaction between AQ and Condition ( $F(2,34) = 5.11, p < 0.05$ ) remained present and arose from significant main effects of AQ in both the Scrambled ( $F(1,187) = 16.32, p < 0.001$ ) and Structural Only ( $F(1,187) = 5.78, p < 0.05$ ). Continuing the pattern evident from 300 – 500 ms, there was a significant negative correlation of AQ with ERP amplitude in the Scrambled ( $r = -0.44, p < 0.05$ ) and the Structural Only ( $r = -0.30, p = 0.19$ ) conditions, such that increasing AQ scores were associated with more negative amplitudes. There was no main effect of AQ in the Normal condition at this time window ( $p = 0.56$ ).

**600 – 700 ms.** There was a trend of a significant interaction between AQ and Condition ( $F(2,34) = 3.12, p = 0.06$ ) that arose from significant main effects of AQ in both the Scrambled ( $F(1,187) = 7.33, p < 0.01$ ) and Structural Only ( $F(1,187) = 5.78, p < 0.001$ ) conditions. As in previous time windows, there were negative correlations of AQ with ERP amplitude in both the Scrambled condition (although not statistically significant:  $r = -0.30, p = 0.18$ ) and the Structural Only condition ( $r = -0.40, p = 0.07$ ), such that increasing AQ scores were associated with more negative amplitudes. There was no main effect of AQ in the Normal condition at this time window ( $p = 0.98$ ).

**700 – 800 ms.** There was a significant interaction between AQ and Condition ( $F(2,34) = 3.72, p < 0.05$ ) that arose from a significant main effect of AQ in the Structural Only condition alone ( $F(1,187) = 23.58, p < 0.001$ ). In the Structural Only condition, there was a significant negative correlation of AQ with ERP amplitude ( $r = -0.43, p < 0.05$ ), such that, as in previous time windows, increasing AQ scores were associated with more

negative amplitudes. There were no main effects of AQ in the Normal or Scrambled conditions at this time window ( $p$ 's > 0.26)

**800 – 900 ms.** In this time window there continued to be a significant interaction between AQ and Condition ( $F(2,34) = 5.05, p < 0.05$ ) which arose from a significant main effect of AQ in the Structural Only condition alone ( $F(1,187) = 30.77, p < 0.001$ ). In the Structural Only condition, there was a significant negative correlation of AQ with ERP amplitude ( $r = -0.47, p < 0.05$ ), such that, as in previous time windows, increasing AQ scores were associated with more negative amplitudes. There were no main effects of AQ in the Normal or Scrambled conditions at this time window ( $p$ 's > 0.15)

**900 – 1000 ms.** The significant interaction between AQ and Condition ( $F(2,34) = 5.07, p < 0.05$ ) was maintained in this time window and arose from significant main effects of AQ in both the Structural Only ( $F(1,187) = 48.59, p < 0.001$ ) and Normal ( $F(1,187) = 7.45, p < 0.01$ ) conditions. There were significant negative correlations of AQ with ERP amplitude in both Structural Only ( $r = -0.56, p < 0.01$ ) and Normal conditions (although not statistically significant:  $r = -0.26, p = 0.25$ ), such that increasing AQ scores were associated with more negative amplitudes. There was no main effect of AQ in the Scrambled condition at this time window ( $p = 0.56$ ).

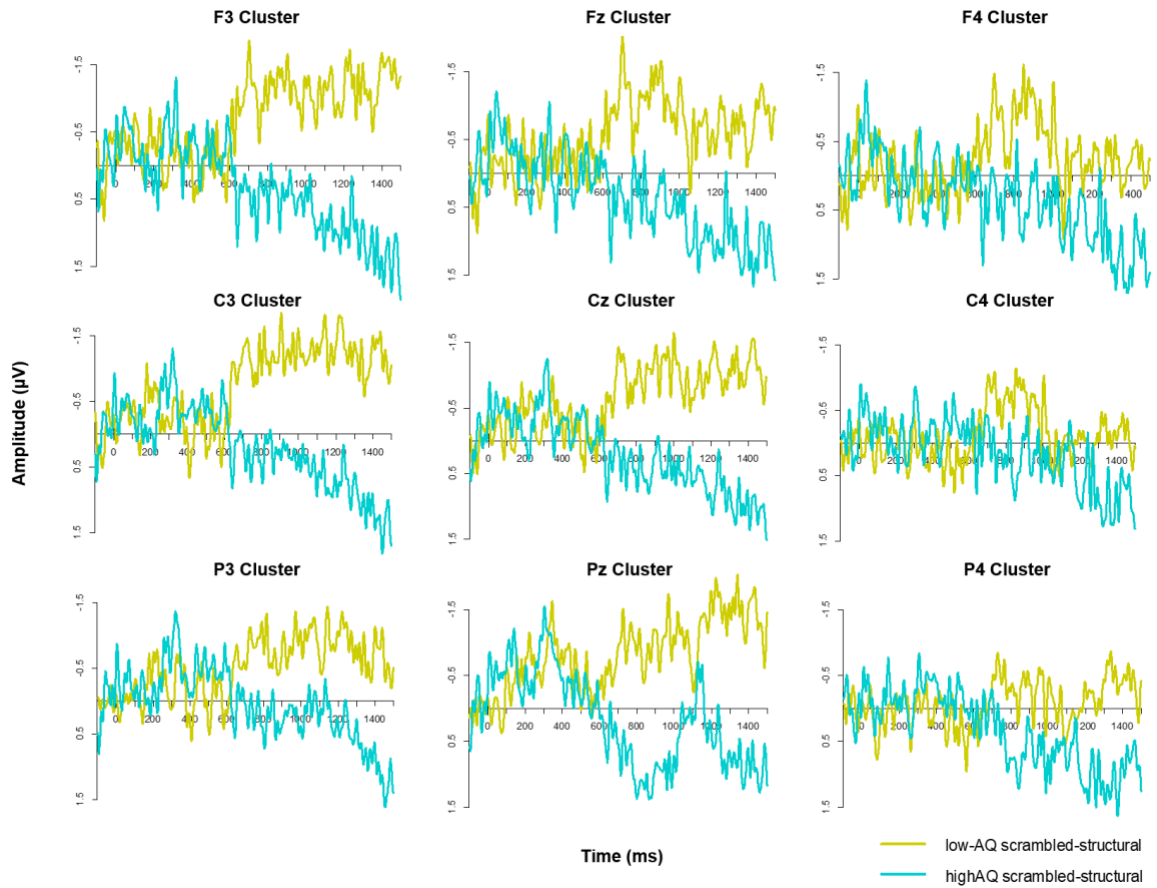
To briefly summarize the effects of the overall ANOVA, interactions of AQ and VLF1 occurred in the Scrambled condition only, and only in the earliest time windows (200-400 ms): greater visual language fluency was associated with more negative Scrambled ERP amplitudes for participants with higher AQ, whereas this effect was mitigated for participants with lower AQ. AQ also interacted with condition from 300-1000 ms. Over all conditions, negative correlations were observed, such that higher levels

of autistic traits were associated with more negative amplitudes. This reflects the overall patterns that we noted during visual inspection: high-AQ participants tended to show more negative amplitudes overall compared to low-AQ participants. However, there were differences in the timing of this effect between conditions: the Structural Only condition showed a sustained effect, such that effects of AQ were significant from 300-1000 ms; the Scrambled condition showed effects of AQ from 300-600 ms; and the Normal condition showed effects of AQ from 900-1000 ms.

### **3.2.2. Difference Waves**

Structural processing was isolated by directly contrasting the Scrambled condition with the Structural Only condition using difference waves (Figure 12). To examine the effects of AQ on Scrambled – Structural Only difference wave amplitude statistically, we ran repeated-measures ANOVAs with *AQ* and *VLF1* as between-subjects factors and *Site* (frontal, central, parietal) and *Laterality* (left, midline, right) as within-subjects factors (Table 5).

**Figure 12:** Difference waves for the Scrambled – Structural Only contrast at each of the nine electrode clusters across the scalp with participants grouped into “high AQ” and “low AQ” based on a median split. Negativity is plotted upward.



**Table 5:** F-values for the repeated-measures ANOVAs on the Scrambled – Structural Only difference waves in each analysis window, with a AQ and VLFI as continuous variables and within-subjects factors of Site and Laterality. Main effects of, or interactions with, AQ are highlighted in bold. Asterisks indicate statistically significant results (. =  $p < 0.10$ ; \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.0001$ ).

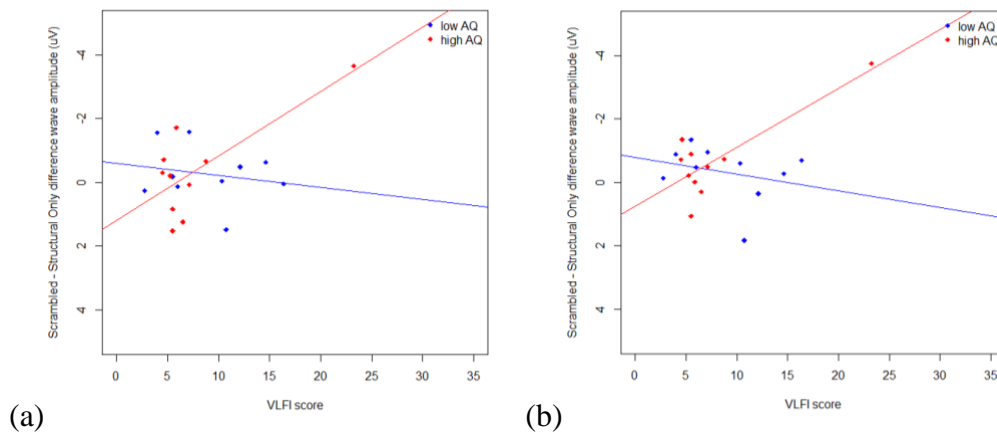
Main effects and interactions	Time Windows (ms)							
	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000
AQ	0.73	1.19	2.26	<b>3.44.</b>	0.40	<b>6.62*</b>	<b>16.49***</b>	<b>15.32**</b>
VLFI	<b>26.26***</b>	<b>11.46**</b>	<b>20.86***</b>	<b>5.59*</b>	<b>5.61*</b>	0.90	0.49	0.12
<b>AQ * VLFI</b>	<b>4.44 .</b>	2.54	1.12	1.87	<b>4.37 .</b>	0.18	0.58	0.35
Site	1.48	3.22 .	0.64	0.02	0.24	0.21	1.62	0.45
<b>AQ * Site</b>	0.05	0.43	0.35	0.46	0.27	0.91	0.37	0.42
VLFI * Site	<b>5.39 **</b>	<b>4.45 *</b>	1.59	1.16	1.33	2.09	2.711 .	2.70 .
<b>AQ * VLFI * Site</b>	<b>2.79 .</b>	<b>2.67 .</b>	1.74	0.46	0.13	1.91	1.24	0.34
Laterality	1.94	2.07	0.95	0.60	0.31	0.19	0.25	0.62
<b>AQ * Laterality</b>	0.42	1.02	1.87	1.07	0.43	0.39	0.77	0.93
VLFI * Laterality	0.85	0.77	0.79	0.64	0.34	0.32	0.79	0.75
<b>AQ * VLFI * Laterality</b>	0.78	1.06	0.93	1.17	1.39	0.88	0.96	0.85
Site * Laterality	1.32	2.37 .	0.32	0.55	0.23	0.23	0.37	0.44
<b>AQ * Site * Laterality</b>	0.40	0.31	0.37	0.66	0.59	1.41	1.53	1.62
VLFI * Site * Laterality	0.61	0.63	0.26	0.17	0.12	0.17	0.30	0.60
<b>AQ * VLFI * Site * Laterality</b>	0.74	1.05	1.17	0.93	0.43	0.96	1.38	1.40

**200-300ms.** Repeated-measures ANOVA on the Scrambled – Structural Only difference wave from 200-300 ms revealed a trend of an interaction of AQ, VLFI, and Site ( $F(2,34) = 2.79, p = 0.08$ ) which arose from a significant interaction of AQ and VLFI at parietal sites ( $F(1,17) = 7.05, p < 0.05$ ) but not at frontal or central sites (all  $p$ 's  $> 0.13$ ). To examine this interaction, participants were divided into “high AQ” and “low AQ” groups based on a median split and the interaction of AQ and VLFI was assessed at parietal sites (Figure 13a). Follow-up correlations identified a significant negative correlation between VLFI score and difference wave amplitude for the high AQ group at parietal sites ( $r = -0.75, p = 0.01$ ). For the low AQ group, there was a slight positive correlation between VLFI and difference wave amplitude ( $r = 0.19, p = 0.60$ ).

**300-400ms.** There was a trend of an interaction of AQ, VLFI, and Site ( $F(2,34) = 2.67, p = 0.08$ ) which arose from a significant interaction of AQ and VLFI at parietal sites ( $F(1,17) = 7.91, p < 0.05$ ) but not at frontal and central sites (all  $p$ 's  $> 0.25$ ). As in the

previous time window, there was a significant negative correlation between VLFI score and Scrambled – Structural Only difference wave amplitude for the high AQ group at parietal sites ( $r = -0.82, p < 0.001$ ; Figure 13b). For the low AQ group, there was a slight positive correlation between VLFI and difference wave amplitude ( $r = 0.27, p = 0.45$ ).

**Figure 13:** Scatterplot from 200-300 ms (panel a) and 300-400 ms (panel b) comparing VLFI score against Scrambled – Structural Only difference wave amplitude at parietal sites. Participants are divided into “high AQ” and “low AQ” groups based on a median split. Negativity is plotted upwards.



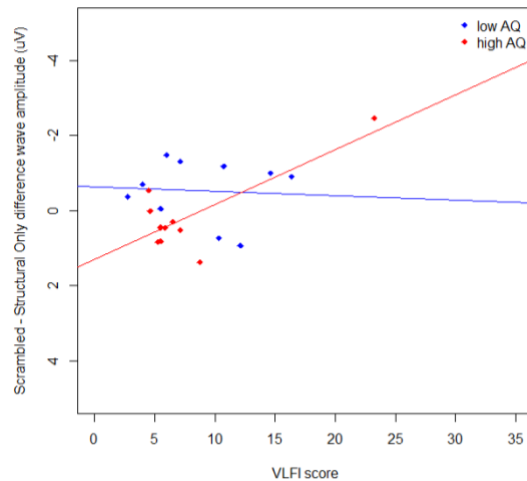
**400-500ms.** There were no significant main effects of, or interactions with, AQ in this time window.

**500-600ms.** There was a trend toward a significant main effect of AQ overall ( $F(1, 17) = 3.44, p = 0.08$ ), with higher AQ scores correlating with slightly more negative Scrambled – Structural Only difference wave amplitudes ( $r = -0.35, p = 0.12$ ). There were no interactions with AQ in this time window that approached significance (all  $p$ 's  $> 0.19$ ).

**600-700ms.** There was a trend toward a significant interaction between AQ and VLFI  $F(1,17) = 4.37, p = 0.05$ ). Follow-up correlations identified a significant negative correlation between VLFI score and Scrambled – Structural Only difference wave amplitude across all sites and hemispheres for the high AQ group ( $r = - 0.78, p < 0.01$ ;

Figure 14). There was a negligible correlation between VLFI and difference wave amplitude for the low AQ group ( $r = 0.06$ ,  $p = 0.86$ ).

**Figure 14:** Scatterplot from 600-700 ms comparing VLFI score against Scrambled – Structural Only difference wave amplitude over all sites and hemispheres. Participants are divided into “high AQ” and “low AQ” groups based on a median split. Negativity is plotted upwards.



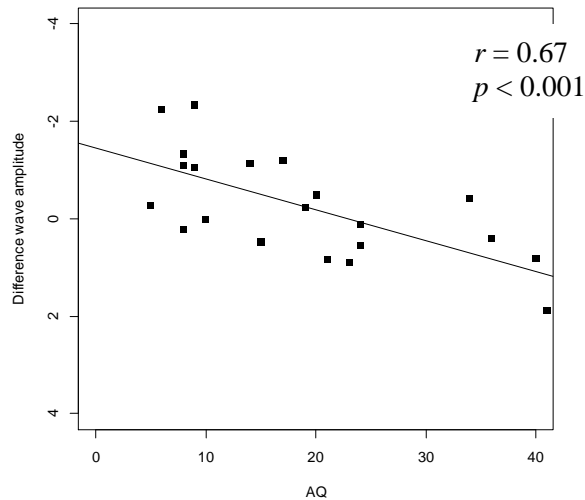
**700-800ms.** There was a significant main effect of AQ overall ( $F(1, 17) = 6.62$ ,  $p < 0.05$ ). Follow-up correlation analyses identified a significant positive correlation between AQ and Scrambled – Structural Only difference wave amplitude ( $r = 0.52$ ,  $p < 0.05$ ), indicating that as AQ score increases, the amplitude of the difference wave increases (i.e., becomes less negative; Figure 15).

**800-900ms.** As in the previous time window, there was a significant main effect of AQ overall ( $F(1, 17) = 16.49$ ,  $p < 0.001$ ). Follow-up correlation analyses identified a strong, significant positive correlation between AQ and Scrambled – Structural Only difference wave amplitude ( $r = 0.69$ ,  $p < 0.001$ ), indicating that as AQ score increases, the amplitude of the difference wave becomes less negative (Figure 15).

**900-1000ms.** The significant main effect of AQ was maintained in the final time window ( $F(1, 17) = 15.32$ ,  $p < 0.01$ ). Follow-up correlation analyses identified a strong,

significant positive correlation between AQ and Scrambled – Structural Only difference wave amplitude ( $r = 0.68, p < 0.001$ ), indicating that as AQ score increases, the amplitude of the difference wave becomes less negative (Figure 15).

**Figure 15:** Scatterplot from 700-1000 ms comparing AQ score and Scrambled – Structural Only difference wave amplitude over all sites and hemispheres. Negativity is plotted upwards.



### 3.2.3. Summary

In the visual modality, interactions of AQ and VLF1 occurred in earlier time windows. In the overall ANOVA, we observed interactions from 200-300 ms in the Scrambled condition only, such that greater visual language fluency was associated with more negative Scrambled ERP amplitudes for participants with higher AQ, whereas this effect was mitigated for participants with lower AQ. This effect was also picked up in the difference wave analyses, which identified interactions of AQ and VLF1 occurred from 200-400 ms over parietal sites: increasing visual language fluency was associated with more negative Scrambled-Structural Only difference waves in participants with higher

levels of autistic traits, whereas this effect was opposite (and not statistically significant) in participants with lower levels of autistic traits.

Overall effects of AQ were also evident in both the overall ANOVAs and the difference-wave comparisons. In the overall ANOVA, greater levels of autistic traits were associated with more negative ERP amplitudes from 300-600 ms in the Scrambled condition; from 300-1000 ms in the Structural Only condition; and from 900-1000 ms in the Normal condition. In the difference waves, effects of AQ occurred from 500-600 ms and 700-1000 ms. In the earlier time window (500-600 ms), higher levels of autistic traits were associated with more negative Scrambled-Structural Only difference wave amplitude, whereas in the later time window (700-1000 ms), this effect was flipped such that higher levels of autistic traits were associated with less negative difference waves.

## **CHAPTER 4: DISCUSSION**

This study aimed to isolate and examine the role of structural processing in narrative comprehension across modalities and explore how sensitivity to narrative grammar is associated with autistic traits. Electrophysiological methods were utilized to record temporally precise neural activity in response to visual and linguistic narrative stimuli that were manipulated to isolate narrative structure. This cross-modal design facilitated examinations of a key cognitive subfunction that underlies visual and linguistic narrative comprehension alike – structural processing – and addressed the Visual Ease Assumption that is prevalent in assessment of and intervention for autism.

### **4.1. Linguistic Narrative Processing in Autism**

#### **4.1.1. Overall ERP Data**

This study is the first to isolate and examine narrative structural processing of written stories at an electrophysiological level. We hypothesized that isolating canonical narrative structure (via Structural Only stimuli) and removing narrative structure (via Scrambled stimuli) in written stories would elicit ERP waveforms that parallel findings from sentence-level studies of syntactical processing in the absence of semantics. In participants with low levels of autistic traits, we expected to see late ERP components like the P600 or LAN in response to Scrambled but not Structural Only narratives, in line with examinations of structural processing at the sentence level in non-autistic populations (Friederici, 2002; Osterhout et al., 1997; van Petten & Kutas, 1991). Surprisingly, ERP waveforms for Normal, Structural Only and Scrambled conditions trended closely together

for both low and high AQ participants. Visual inspection of these waveforms indicated some effect of autistic traits on narrative processing, as high AQ participants showed greater negativities for all conditions, especially at frontal sites from 300-600ms. There appeared to be a temporal shift in this effect for high AQ participants wherein observed negativities in ERP waveforms appeared at earlier time windows at more parietal sites and later time windows at frontal sites (Figure 6). Since larger ERP amplitudes are typically interpreted as reflecting more effortful processing, this could suggest that, overall, processing of written narratives is different, and perhaps more difficult, for those with higher levels of autistic traits. Statistically significant interactions of AQ and Condition on overall ERP amplitude were only evident in the earliest time window (200-300ms). However, these interactions did not remain significant when followed up. This could suggest that the effects of AQ and condition on overall ERP amplitude could be too subtle by the final sentence in the narrative.

#### **4.1.2. Scrambled – Structural Only Difference Waves**

Direct comparisons between the Structural Only and Scrambled conditions revealed significant effects that may have been overshadowed in the overall ANOVA. Analyses of Scrambled-Structural Only difference waves showed that sentence comprehension abilities (as measured by the WRAT) interacted with level of autistic traits in the earliest time window (200-300 ms). Interestingly, stronger sentence comprehension abilities were associated with less negative difference wave amplitude (i.e., smaller differences between Scrambled and Structural Only conditions) for participants with higher levels of autistic traits but not for participants with lower levels. At first glance, this may

seem to contradict our predictions: we had expected better sentence comprehension abilities to be associated with greater sensitivity to narrative structure (i.e., greater difference waves), whereas this observed effect seems to suggest the opposite (a reduced sensitivity to narrative structure, or smaller difference waves). However, this effect is surprisingly early for structural processing, which typically affects later ERP components.

One possibility is that this earlier effect may be an N300. Although the N300 is more commonly elicited by visual stimuli (e.g., Cohn, 2020; Cohn et al., 2012), it has been reported for linguistic stimuli as well (e.g., Franklin et al. 2007). Franklin et al. (2007) observe an anterior N300 that they specifically link to forward-looking semantic expectancy processes. Coderre et al. (2017) also observe a frontal N300 effect in response to semantically related pairs of words for non-autistic participants but not autistic participants. One possible explanation for our observed interactions of AQ and sentence comprehension in this time window, therefore, is that among those with higher levels of autistic traits, greater sentence comprehension abilities lead to more forward-looking semantic processing strategies. An outstanding question that stems from this explanation would be why the low-AQ group do not show a similar modulation by sentence comprehension. Here, it may be that there was less variability in sentence comprehension abilities among those with lower autistic traits, making the interaction of AQ and WRAT scores less apparent in the ERP data. Another question is why this effect was most apparent for the Scrambled-Structural Only difference waves as opposed to all conditions; one would think that such forward-looking processing strategies might affect semantic processing for all types of narratives. Here, it may be that the Scrambled stimuli specifically triggered such forward-looking processes in higher-comprehension

participants based on narrative incongruity. Because we analyzed ERPs at all words in the final sentence, participants had likely already noticed that the narratives did not make sense; perhaps the high-AQ/high-comprehension participants picked up on this more than the high-AQ/low-comprehension participants and adjusted their processing strategies accordingly. Although further research is needed to replicate and explore these findings, our preliminary data suggest that effects of reading ability (and specifically sentence comprehension ability) may have an earlier effect on narrative processing than anticipated and may interact with autistic traits in interesting ways.

In the latest time window (600-700ms), we observed effects of AQ such that higher levels of autistic traits correlated with less negative difference wave amplitudes. Visual inspection of the difference waves for high AQ participants show some small positive difference waves at later time windows across all sites and hemispheres. As difference waves were calculated by subtracting Structural Only from Scrambled amplitudes, this suggests that Structural Only conditions may have elicited more negative amplitudes than Scrambled conditions at these later time windows for high AQ participants. This finding contradicts that of previous research, which has found that linguistic stimuli that follow grammatical rules and lack semantic meaning (Structural Only stimuli) elicited less negative amplitudes than stimuli that lack both grammar and semantics (Scrambled stimuli) (van Petten & Kutas, 1991).

One possibility is that participants with high levels of autistic traits were indeed sensitive to narrative structure in written narratives, but that the lack of structure in Scrambled narratives caused participants to cognitively “check out” prior to the final sentence at which we analyzed neural responses. Such a lack of attentiveness to Scrambled

narratives could elicit less negative/more positive amplitudes for this condition compared to the Structural Only condition, which participants were still actively trying to interpret based on the presence of narrative structure.

Alternatively, it is possible that the positive Scrambled – Structural Only difference wave amplitudes at later time windows reflect a P600 effect in the high-AQ group. This would be in line with other ERP findings from studies of language comprehension in autism (e.g., Pijnacker et al., 2010). Though not directly targeting structural processing, a study by Pijnacker et al. (2010) found that autistic participants exhibited smaller N400 effects and larger late positive components (e.g., P600 effects) in response to semantically anomalous sentences when compared with non-autistic participants. It has been theorized that autistic individuals are less likely to recruit integration mechanisms in early time windows relative to non-autistic individuals (leading to smaller N400 amplitudes), and instead rely on later re-analysis and integration processes (leading to larger positive amplitudes at later time windows). In the current study, it is possible that individuals with higher levels of autistic traits *are* sensitive to narrative structure but are processing that structure using different neural mechanisms than those with lower levels of autistic traits. This would also fit with other research suggesting that autistic individuals rely on more bottom-up cognitive processing strategies compared to the more top-down processing strategies that non-autistic participants employ (Coderre et al., 2017; Coderre et al., in preparation; Kubinski et al., under review). Earlier negativities, such as N400 effects, are typically thought of as being more forward-looking and top-down, whereas later positivities like the P600 effect are thought of as more backwards-looking and bottom-up. If participants with higher levels of autistic traits are showing enhanced P600 effects in the

absence of both structural and semantic context, this could indicate that they are using a more bottom-up strategy than participants with lower levels of autistic traits. The correlation of AQ and difference wave amplitude was only approaching significance in our dataset, so this interpretation should be made lightly given the small effect and limited sample size. Nevertheless, these preliminary analyses seem to suggest that autistic individuals are sensitive to narrative structure but may be using different cognitive processes to understand it.

## **4.2. Visual Narrative Processing in Autism**

### **4.2.1. Overall ERP Data**

Visual inspection of the ERP waveforms in response to visual narrative stimuli showed that, for participants with *low* levels of autistic traits, presence of narrative grammar, even in the absence of semantic context, tended to have a facilitatory effect on processing relative to narratives that lack both grammar and meaning. This effect was especially evident at frontal and central sites where ERP amplitudes for the Structural Only condition trended closely with those of the Normal condition while larger negative amplitudes were elicited by Scrambled sequences for the low AQ group. This pattern corroborated results from non-autistic participants in previous investigations of visual narrative structural processing, in which Normal sequences elicited the least negative amplitudes followed by Structural Only then Scrambled sequences (Cohn et al., 2012; Coderre et al., in preparation). In contrast, the facilitatory effect of narrative structure – evidenced by Structural Only and Normal conditions eliciting similar ERP amplitudes – was not evident for participants with higher levels of autistic traits. Rather, there appeared

to be large differences between Normal and Structural Only conditions with Normal sequences eliciting the least negative ERP amplitudes, followed by Scrambled, then Structural Only sequences, respectively. The finding that Structural Only sequences elicited the most negative amplitudes for participants with higher levels of autistic traits was not in line with overall ERP patterns from previous examinations of structural processing of visual narratives in autism (Coderre et al., in preparation).

A recent investigation into structural processing of visual narratives in autism by Coderre et al. (in preparation) which utilized a larger sample ( $n = 40$ ) found that, for participants with high levels of autistic traits, Structural Only and Scrambled sequences trended closely together and separated only slightly at later time windows with Scrambled sequences having the most negative ERP amplitudes. We expected to see this pattern for participants with higher levels of autistic traits in the current study, as similar ERP waveforms between Structural Only and Scrambled conditions would suggest that high AQ participants were less sensitive to narrative grammar and that the presence of narrative structure alone did not have a facilitative effect. Both the wide separation between Structural Only and Scrambled conditions in later time windows and the flipped effect of Structural Only sequences eliciting the most negative amplitudes for high AQ participants in this sample were surprising as they contradict our hypotheses and previous findings that individuals with higher levels of autistic traits exhibit reduced sensitivity to visual narrative structure.

#### **4.2.2. Scrambled – Structural Only Difference Waves**

This separation between Scrambled and Structural Only ERP amplitudes was examined using difference waves calculated by subtracting Structural Only amplitudes from Scrambled amplitudes. In previous studies, greater negativities were elicited by the Scrambled condition than by the Structural Only condition across all levels of autistic traits (Coderre et al., in preparation). Accordingly, a larger negative difference wave would suggest greater discrimination between Scrambled and Structural sequences while a less negative difference wave would suggest similar neural responsiveness to both Scrambled and Structural sequences and therefore reduced sensitivity to structural processing.

In the current study, analyses indeed revealed significant positive correlations between AQ and Scrambled – Structural difference wave amplitudes in later time windows (700-1000 ms), indicating that lower AQ scores were associated with larger negative difference wave amplitudes and higher AQ scores were associated with less negative (more positive) difference wave amplitudes. For low AQ participants, greater negativities were elicited by the Scrambled condition than by the Structural Only condition, and the large negative difference waves exhibited by these participants suggest discrimination between Scrambled and Structural Only sequences and sensitivity to narrative grammar. However, for high AQ participants, greater negativities were elicited by the Structural Only condition than by the Scrambled condition. As a result, the more positive difference waves exhibited by these participants do not necessarily suggest reduced sensitivity to structural processing with greater levels of autistic traits. Rather, it is possible that individuals with higher levels of autistic traits *are* sensitive to narrative structure but recruit different neural mechanisms to process structure than those with lower levels of autistic traits.

As we proposed for the linguistic narratives, it is possible that high AQ participants exhibit less negative (more positive) amplitudes in response to Scrambled sequences than we expected because, at this point in the narrative, they have cognitively “checked out” and are not exerting as much cognitive effort to integrate the information at the final panel in the narrative. If this is true, it would still suggest that high AQ participants are sensitive to narrative structure if they are exhibiting this effect for Scrambled but not Structural Only sequences. An alternative explanation could be that the Scrambled narratives elicit a P600 effect wherein absence of both structural and semantic context is reflected in more positive waveforms relative to structurally intact conditions later on in processing. As discussed in reference to the linguistic modality, enhanced positivity at later time windows for those with higher levels of autistic traits has been observed in other ERP findings from studies of language comprehension in autism (e.g., Pijnacker et al., 2010). While Coderre et al. (in preparation) found reduced sensitivity to narrative grammar with higher levels of autistic traits overall, in this prior study the high-AQ group did show a difference wave that was positive at parietal sites from 400-600ms, suggesting a late positivity effect. Coderre et al. (in preparation) also entertain the idea of a P600 effect in high-AQ participants, similar to what we propose here. This would again suggest that individuals with higher levels of autistic traits *are* sensitive to narrative structure but are processing that structure using different neural mechanisms than those with lower levels of autistic traits. Importantly, the differential processing appears to be a more backward-looking re-analysis procedure driven by bottom-up mechanisms (eliciting a larger P600 effect) rather than a forward-looking top-down effect (as evident by the lack of differences

earlier in processing), as proposed by prior studies (Coderre et al., 2017; Coderre et al., in preparation; Kubinski et al., under review).

We also observed interactions of AQ and VLFI in surprisingly early time windows, just as we did in the linguistic modality (where we observed interactions of AQ and WRAT only in the 200-400 ms time window). In the visual modality, from 200-400 ms, increasing visual language fluency was associated with more negative Scrambled-Structural difference waves in participants with higher levels of autistic traits, whereas this effect was opposite (and not as strong) in participants with lower levels of autistic traits. The direction of this effect, such that greater visual language fluency leads to more negative difference waves, is in line with previous findings by Cohn et al. (2012). However, it is interesting that this effect only occurred in participants with higher levels of autistic traits. It could be that the different types of narrative structural processing being employed by the higher-AQ participants, as discussed above, were more susceptible to influences of VLFI compared to those employed by the lower-AQ participants. The timing of this effect is also notable since, as in the linguistic narratives, it is surprisingly early. This again raises the possibility that this is the N300 component. The N300 is more commonly elicited by visual stimuli and is thought to be related to processes of object identification in pictorial stimuli, specifically relatively fast semantic activation of the features of objects (Sitnikova, West, Kuperberg, & Holcomb, 2006; McPherson & Holcomb, 1999). As in the linguistic narratives, it may be that higher-AQ participants are employing different strategies for earlier semantic processing of the stimuli in Scrambled compared to Structural conditions, which is leading to the similar interactions of autistic traits with fluency at the N300 time window.

### **4.3 Narrative Structural Processing Across Modalities**

To conclude, over both linguistic and visual narratives we see some similar patterns emerging between modalities in this preliminary data sample. Effects of fluency (both sentence comprehension abilities in the linguistic domain and visual language fluency in the visual domain) interacted with autistic traits in relatively early time windows, and specifically at the N300 component. These interactions could point to differences in processing strategies between individuals with higher and lower levels of autistic traits. Across both modalities we also observed similar effects of AQ such that greater levels of autistic traits were associated with less negative/more positive differences between Scrambled and Structural Only sequences. In both modalities these differences tended towards more positive waveforms for Scrambled sequences compared to Structural Only sequences, raising the possibility of an enhanced P600 effect in the higher-AQ participants. As the P600 has been linked to more bottom-up re-integration processes, this could suggest fundamental differences in the way that narrative structure is processed in individuals across the autism spectrum.

### **4.4. Implications for the Visual Ease Assumption**

The long-standing belief that images are easier to understand than language and should therefore be utilized to overcome difficulties with verbal communication – the *Visual Ease Assumption* (VEA) – continues to influence approaches to assessment and support in the autism field (Coderre, 2020). Yet, a growing body of research on narrative processing argues that similar cognitive mechanisms underly both visual and linguistic

narrative comprehension (Coderre et al., 2018; Cohn, 2014b; Cohn et al., 2012; West & Holcomb, 2002). Contradicting the VEA, the findings of the current study suggest that one cognitive subfunction of narrative comprehension – structural processing – is similarly affected in both visual and linguistic modalities. The similar pattern of results between visual and linguistic modalities supports the idea that structural processing is an amodal subfunction of narrative comprehension. Across modalities, greater levels of autistic traits were associated with less negative differences between narratives with and without canonical narrative structure in the absence of semantics. These findings suggest that presenting narratives in a visual format does not ameliorate processing differences between autistic and non-autistic individuals. In fact, the most prominent associations between autistic traits and structural processing differences were evident in the visual modality. This study builds on the existing evidence that differences in narrative comprehension in autism are not limited to verbal language. Rather, autistic traits seem to affect the processing of and sensitivity to narrative grammar regardless of modality, which may contribute to overall narrative comprehension differences in autism.

As structural processing was similarly affected across modalities, it is likely that the VEA does not hold true at the level of narrative comprehension. If narrative comprehension difficulties in autism stem from domain-general differences in cognitive mechanisms like structural processing, the use of visual narratives to measure abilities and improve skills in the autism field is misguided. Though visual supports are beneficial in some instances (e.g., picture exchange communication systems such as PECS, which may facilitate communication for non-speaking individuals), generally assuming that opting for

visual formats will bypass challenges with complex processes like narrative comprehension is unsubstantiated (Coderre, 2020).

#### **4.5. Limitations and Future Directions**

As this is a preliminary study with a small sample size, the applications of our findings are somewhat limited. There is likely insufficient power to be able to extrapolate the results to explain narrative processing in autism generally. However, this project is part of a larger study of narrative comprehension in autism that is still in the process of data collection. These preliminary analyses will be replicated with a larger sample of approximately 160 participants in the final dataset which will incorporate additional covariates such as working memory and executive function, strengthening the generalizability of results. Additionally, analyzing our results against a continuum of autistic traits rather than dichotomizing participants into groups or having diagnoses of autism/ASD confirmed using the Autism Diagnostic Observation Schedule (ADOS) limits the claims that can be made about the nature of autism more generally. Though the Autism Quotient questionnaire is not a clinical diagnostic measure for autism, it has been established as a valid measure of autistic traits and has the advantage of picking up on traits that may be missed using behavioral assessments like the ADOS, as many adults have learned to mask their observable autistic behaviors (Ruzich et al., 2015; Woodbury-Smith et al., 2005). We feel that the advantages of including participants who may not have access to formal diagnoses and reflecting the range of profiles that exist within the autism spectrum make this a worthwhile approach.

Notably, the paradigm utilized in this study may not have been the optimal approach for assessing sensitivity to narrative structure, particularly in the linguistic modality. Because our study is modeled after previous examinations of visual narrative structure in autistic and non-autistic populations, we can be fairly confident that our design is sensitive to differences in structural processing (Coderre et al., in preparation, Cohn, 2020; Cohn et al., 2012). However, we have not found any previous studies assessing processing of written narrative structure at an electrophysiological level. Although the van Petten & Kutas (1991) study examined ERP markers of syntactic processing, this study manipulated structure at the sentence level, not the narrative level. We therefore modeled our examinations of linguistic narrative processing after the existing visual paradigm to allow for more direct comparison across modalities. The analytic approach we used for linguistic stimuli – averaging over every word in the final sentence – was based on an ERP study of lexical *semantic* processing which utilized three-sentence-long written narratives (Camblin et al., 2007). As a result, this approach may not be optimal for picking up on differential structural processing over a longer timescale in response to manipulations of narrative grammar in our five-sentence-long stimuli. Perhaps examining earlier sentences in the narrative would show clearer differences between conditions in the linguistic modality.

The study by van Petten & Kutas (1991) found differences between Syntactic and Random sentences during presentation of closed-class words (e.g., prepositions, conjunctions, articles) that establish grammatical structure within a sentence. It is possible that transition words and phrases within a linguistic narrative (e.g., “One day,” “Suddenly,” “Finally,”) could play a functionally similar role of carrying structural information in

written stories. Examining ERPs time-locked to these words or phrases could allow for observation of a more pronounced response to narrative structure. It would be interesting to examine ERPs in response to transition words and phrases in normal narrative at various ordinal positions to see how narrative structural processing builds over the course of a story. This approach could then be utilized to compare between Structural Only and Scrambled narratives to isolate structural processing in the absence of semantics and elucidate differences correlated to varying levels of autistic traits. It is difficult to record time-locked EEG responses over the entirety of a written narrative because words would need to be presented one at a time (in standard rapid serial visual presentation (RSVP) format, which minimizes EEG artifacts arising from eye movements) to establish a standardized time window for the ERPs. Presenting the narratives auditorily could allow for easier standardization of when each word is presented. However, the consequence of this approach would be a less analogous design to that of the visual modality. Nevertheless, it would be beneficial to create a more sensitive paradigm for assessing linguistic narrative comprehension to thoroughly examine the evidence for the VEA.

#### **4.6. Conclusions**

The current study replicated and extended the work of Cohn et al. (2012) and Coderre et al. (in preparation) by exploring the modulation of narrative structural processing by autistic traits in both visual and linguistic modalities. Our results suggest that autistic traits do modulate the processing of narrative structure. Specifically, greater levels of autistic traits were associated with less negative/more positive differences between Scrambled and Structural Only sequences across modalities. These preliminary findings

suggest that individuals with higher levels of autistic traits *are* sensitive to narrative structure and may enlist different cognitive processes to understand this structure than individuals with fewer autistic traits. This differential processing of narrative structure may lead to differences in overall narrative comprehension seen in autism. This study also contradicts the Visual Ease Assumption by suggesting that differences in structural processing are present in visual and linguistic narratives alike.

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## APPENDIX

### Visual Modality – Alternative ANOVA tables listing mean square error estimates and degrees of freedoms

**Table A1:** *F*-values, mean square error estimates, and degrees of freedom for the repeated-measures ANOVAs on the ERP amplitude in each analysis window, with two continuous between-subjects factors of *AQ* (level of autistic traits) and *VLFI* (visual language fluency score) and within-subjects factors of *Condition* (Normal, Structural Only, Scrambled), *Site* (frontal, central, parietal), and *Laterality* (left, midline, right). Interactions of *AQ* and *Condition* are highlighted in bold. Asterisks indicate statistically significant results ( $. = p < 0.10$ ;  $* = p < 0.05$ ;  $** = p < 0.01$ ;  $*** = p < 0.001$ ).

Main effects and interactions	df	Time Windows (ms)															
		200-300		300-400		400-500		500-600		600-700		700-800		800-900		900-1000	
		Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value
AQ	1	8.99	0.15	65.70	1.15	91.48	1.9	55.76	0.92	59.53	0.94	45.73	0.94	46.67	1.06	<b>115.59</b>	<b>3.50</b>
VLFI	1	8.97	0.15	0.24	0.00	16.23	0.3	3.10	0.05	10.56	0.17	19.92	0.41	43.16	0.98	71.53	2.17
AQ * VLFI	1	9.96	0.16	49.68	0.87	107.31	2.2	89.83	1.48	65.53	1.03	124.84	2.56	142.11	3.23	130.24	3.94
Condition	2	9.15	4.20*	65.17	14.94***	117.46	19.75***	76.03	13.01***	48.22	9.47***	42.23	7.04**	19.33	3.24	32.67	5.32**
<b>AQ * Condition</b>	2	3.74	1.72	<b>17.29</b>	<b>3.96*</b>	<b>33.92</b>	<b>5.70**</b>	<b>29.88</b>	<b>5.11*</b>	<b>15.88</b>	<b>3.12</b>	<b>22.33</b>	<b>3.72*</b>	<b>30.14</b>	<b>5.05*</b>	<b>31.08</b>	<b>5.07*</b>
VLFI * Condition	2	37.22	17.06***	36.11	8.28**	27.36	4.60*	9.42	1.61	9.92	1.95	1.94	0.32	0.94	0.16	0.25	0.04
<b>AQ * VLFI * Condition</b>	2	<b>18.26</b>	<b>8.37**</b>	<b>20.35</b>	<b>4.67*</b>	9.57	1.6	5.35	0.92	11.89	2.34	11.30	1.88	3.27	0.55	2.88	0.47
Site	2	846.00	105.95***	765.70	81.39***	551.40	90.05***	416.10	50.52***	233.42	23.55***	130.30	14.18***	74.70	8.64***	43.25	5.66**
AQ * Site	2	0.40	0.05	1.50	0.16	2.90	0.5	4.10	0.50	6.56	0.66	12.19	1.33	25.69	2.97	30.46	3.99*
VLFI * Site	2	4.40	0.55	7.90	0.84	13.60	2.2	18.40	2.23	8.86	0.89	4.46	0.49	3.10	0.36	1.45	0.19
AQ * VLFI * Site	2	6.20	0.78	9.00	0.96	9.40	1.5	10.70	1.30	4.29	0.43	3.20	0.35	2.46	0.28	3.05	0.40
Laterality	2	42.79	10.04***	42.42	8.90***	27.25	6.75**	22.95	5.82**	8.39	1.82	6.76	1.66	7.04	1.55	5.15	1.01
AQ * Laterality	2	1.05	0.25	4.08	0.86	3.92	1.0	0.99	0.25	0.20	0.04	0.78	0.19	1.19	0.26	0.92	0.18
VLFI * Laterality	2	0.87	0.20	0.12	0.03	0.02	0.0	0.40	0.10	0.95	0.21	0.67	0.17	0.13	0.03	1.01	0.20
AQ * VLFI * Laterality	2	2.06	0.48	6.03	1.27	3.16	0.8	2.72	0.69	1.74	0.38	1.84	0.45	1.98	0.44	2.64	0.52
Condition * Site	4	1.72	2.71*	5.38	6.00***	4.28	4.75**	4.77	4.08**	4.47	3.77**	3.57	3.73**	2.10	1.63	2.69	1.97
<b>AQ * Condition * Site</b>	4	0.27	0.43	0.48	0.54	0.35	0.4	0.68	0.58	1.30	1.10	1.04	1.09	1.02	0.79	1.58	1.15
VLFI * Condition * Site	4	1.52	2.387	1.40	1.57	0.92	1.0	0.70	0.60	1.03	0.87	0.99	1.03	1.77	1.38	2.89	2.12
<b>AQ * VLFI * Condition * Site</b>	4	0.87	1.36	0.68	0.76	0.60	0.7	0.26	0.23	0.18	0.15	0.86	0.90	0.92	0.72	1.29	0.95
Condition * Laterality	4	1.05	2.078	1.37	2.09	0.75	1.0	0.85	0.83	0.48	0.32	0.23	0.17	0.23	0.16	0.69	0.49
<b>AQ * Condition * Laterality</b>	4	0.32	0.63	0.58	0.89	1.07	1.4	1.19	1.16	1.08	0.72	0.73	0.52	1.42	1.02	1.57	1.12
VLFI * Condition * Laterality	4	0.41	0.82	0.74	1.13	0.73	1.0	0.43	0.42	0.22	0.15	0.23	0.16	0.69	0.5	0.62	0.44
<b>AQ * VLFI * Condition * Laterality</b>	4	0.79	1.56	0.58	0.89	0.63	0.8	0.67	0.66	0.86	0.57	0.61	0.43	0.81	0.58	0.73	0.53
Site * Laterality	4	11.12	10.39***	6.71	5.77***	4.65	4.34**	4.66	4.40**	3.46	3.46*	3.69	4.47**	2.89	3.39*	2.89	3.33*
AQ * Site * Laterality	4	0.48	0.45	0.75	0.64	0.76	0.7	0.42	0.39	0.28	0.28	0.47	0.57	1.17	1.37	2.03	2.35
VLFI * Site * Laterality	4	0.43	0.40	0.13	0.11	0.07	0.1	0.11	0.10	0.24	0.24	0.26	0.32	0.38	0.45	0.20	0.23
AQ * VLFI * Site * Laterality	4	0.30	0.28	0.22	0.19	0.17	0.2	0.33	0.32	0.26	0.26	0.22	0.27	0.30	0.35	0.39	0.45
Condition * Site * Laterality	8	0.15	1.17	0.33	2.69**	0.12	0.8	0.16	0.86	0.28	1.03	0.27	0.96	0.24	0.78	0.31	1.03
<b>AQ * Condition * Site * Laterality</b>	8	0.06	0.51	0.09	0.71	0.11	0.7	0.17	0.90	0.15	0.58	0.25	0.89	0.32	1.06	0.41	1.37
VLFI * Condition * Site * Laterality	8	0.15	1.17	0.17	1.33	0.12	0.8	0.20	1.07	0.26	0.98	0.26	0.94	0.36	1.16	0.39	1.31
<b>AQ * VLFI * Condition * Site * Laterality</b>	8	0.12	0.95	0.09	0.75	0.11	0.8	0.11	0.62	0.13	0.50	0.22	0.79	0.29	0.95	0.27	0.90

Table A2: *F*-values, mean square error estimates, and degrees of freedom for the repeated-measures ANOVAs on the Scrambled – Structural Only difference waves in each analysis window, with a AQ and VLFI as continuous variables and within-subjects factors of Site and Laterality. Main effects of, or interactions with, AQ are highlighted in bold. Asterisks indicate statistically significant results (. =  $p < 0.10$ ; \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.0001$ ).

Main effects and interactions	Time Windows (ms)																
	200-300		300-400		400-500		500-600		600-700		700-800		800-900		900-1000		
	df	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value
AQ	1	3.53	0.73	8.84	1.19	10.17	2.26	<b>20.79</b>	<b>3.44</b>	2.55	0.40	<b>49.14</b>	<b>6.62*</b>	<b>118.22</b>	<b>16.49***</b>	<b>122.05</b>	<b>15.32**</b>
VLFI	1	126.58	26.26***	85.38	11.46**	93.73	20.86***	33.75	5.59*	35.45	5.61*	6.70	0.90	3.53	0.49	0.98	0.12
<b>AQ * VLFI</b>	1	<b>21.39</b>	<b>4.44 .</b>	18.90	2.54	5.04	1.12	11.32	1.87	<b>27.61</b>	<b>4.37 .</b>	1.31	0.18	4.15	0.58	2.82	0.35
Site	2	1.61	1.48	2.99	3.22 .	0.84	0.64	0.03	0.02	0.62	0.24	0.36	0.21	4.04	1.62	1.52	0.45
<b>AQ * Site</b>	2	0.06	0.05	0.40	0.43	0.46	0.35	0.95	0.46	0.70	0.27	1.58	0.91	0.93	0.37	1.40	0.42
VLFI * Site	2	5.84	5.39 **	4.14	4.45 *	2.11	1.59	2.39	1.16	3.49	1.33	3.64	2.09	6.75	2.711 .	9.07	2.70 .
<b>AQ * VLFI * Site</b>	2	<b>3.02</b>	<b>2.79 .</b>	<b>2.48</b>	<b>2.67 .</b>	2.30	1.74	0.95	0.46	0.33	0.13	3.32	1.91	3.09	1.24	1.16	0.34
Laterality	2	2.73	1.94	3.71	2.07	1.63	0.95	1.07	0.60	0.76	0.31	0.51	0.19	0.81	0.25	2.02	0.62
<b>AQ * Laterality</b>	2	0.59	0.42	1.83	1.02	3.22	1.87	1.89	1.07	1.04	0.43	1.06	0.39	2.55	0.77	3.03	0.93
VLFI * Laterality	2	1.20	0.85	1.38	0.77	1.35	0.79	1.14	0.64	0.81	0.34	0.86	0.32	2.61	0.79	2.43	0.75
<b>AQ * VLFI * Laterality</b>	2	1.10	0.78	1.90	1.06	1.60	0.93	2.08	1.17	3.35	1.39	2.37	0.88	3.16	0.96	2.77	0.85
Site * Laterality	4	0.38	1.32	0.58	2.37 .	0.09	0.32	0.18	0.55	0.10	0.23	0.12	0.23	0.23	0.37	0.28	0.44
<b>AQ * Site * Laterality</b>	4	0.11	0.40	0.08	0.31	0.11	0.37	0.22	0.66	0.25	0.59	0.77	1.41	0.96	1.53	1.03	1.62
VLFI * Site * Laterality	4	0.18	0.61	0.15	0.63	0.08	0.26	0.06	0.17	0.05	0.12	0.09	0.17	0.19	0.30	0.38	0.60
<b>AQ * VLFI * Site * Laterality</b>	4	0.21	0.74	0.26	1.05	0.33	1.17	0.31	0.93	0.18	0.43	0.52	0.96	0.86	1.38	0.89	1.40

**Linguistic Modality** – Alternative ANOVA tables listing mean square error estimates and degrees of freedoms

**Table A3:** *F*-values, mean square error estimates, and degrees of freedom for repeated-measures ANOVAs on ERP with continuous between-subjects factors of AQ and WRAT (sentence comprehension score) and within-subjects factors of Condition, Site, and Laterality. Interactions of AQ and Condition are highlighted in bold. Asterisks indicate statistically significant results ( $. = p < 0.10$ ;  $* = p < 0.05$ ;  $** = p < 0.01$ ;  $*** = p < 0.001$ ).

Main effects and interactions	df	Time Windows (ms)									
		200-300		300-400		400-500		500-600		600-700	
		Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value
AQ	1	1.58	1.05	0.90	0.72	0.17	0.21	0.00	0.00	0.02	0.08
Sentence Comp	1	2.01	1.33	1.04	0.83	1.09	1.29	1.07	1.90	0.40	1.65
AQ * Sentence Comp	1	0.20	0.13	0.01	0.01	0.41	0.48	0.52	0.93	0.01	0.03
Condition	2	0.09	3.66 *	0.16	4.30 *	0.10	2.82 .	0.14	3.98 *	0.07	1.28
<b>AQ * Condition</b>	2	0.00	0.17	0.03	0.67	0.03	0.77	0.02	0.55	0.07	1.31
Sentence Comp * Condition	2	0.08	3.281 *	0.01	0.40	0.01	0.38	0.00	0.11	0.02	0.31
<b>AQ * Sentence Comp * Condition</b>	2	0.10	4.22 *	0.04	1.18	0.07	1.85	0.03	0.91	0.03	0.65
Site	2	44.48	20.93 ***	38.14	17.25 ***	13.23	8.26 **	0.66	0.86	0.21	0.75
AQ * Site	2	0.26	0.12	3.50	1.58	7.38	4.61 *	1.30	1.70	0.14	0.48
Sentence Comp * Site	2	0.98	0.46	0.33	0.15	0.02	0.01	0.06	0.08	0.11	0.39
AQ * Sentence Comp * Site	2	3.93	1.85	2.18	0.99	1.28	0.80	0.07	0.09	0.08	0.27
Laterality	2	0.30	0.22	1.97	1.84	0.82	1.11	0.17	0.34	0.33	1.56
AQ * Laterality	2	0.32	0.24	0.16	0.15	0.33	0.44	0.25	0.49	0.13	0.61
Sentence Comp * Laterality	2	0.93	0.69	0.62	0.57	0.38	0.51	0.14	0.27	0.00	0.01
AQ * Sentence Comp * Laterality	2	1.78	1.31	0.07	0.07	0.26	0.35	0.24	0.47	0.04	0.18
Condition * Site	4	0.03	0.37	0.00	0.04	0.02	0.23	0.05	0.73	0.05	0.78
<b>AQ * Condition * Site</b>	4	0.01	0.14	0.07	0.80	0.04	0.48	0.00	0.03	0.01	0.11
Sentence Comp * Condition * Site	4	0.04	0.54	0.03	0.31	0.02	0.24	0.02	0.37	0.03	0.43
<b>AQ * Sentence Comp * Condition * Site</b>	4	0.05	0.63	0.06	0.69	0.08	1.04	0.03	0.43	0.08	1.32
Condition * Laterality	4	0.13	1.49	0.09	1.21	0.03	0.27	0.03	0.32	0.03	0.41
AQ * Condition * Laterality	4	0.09	1.06	0.04	0.56	0.03	0.25	0.08	0.75	0.06	0.84
Sentence Comp * Condition * Laterality	4	0.04	0.42	0.11	1.54	0.14	1.37	0.04	0.44	0.02	0.34
<b>AQ * Sentence Comp * Condition * Laterality</b>	4	0.06	0.74	0.10	1.43	0.05	0.46	0.01	0.11	0.04	0.54
Site * Laterality	4	0.14	0.76	0.10	0.54	0.07	0.52	0.09	1.02	0.03	0.93
AQ * Site * Laterality	4	0.01	0.06	0.04	0.21	0.02	0.17	0.05	0.51	0.02	0.52
Sentence Comp * Site * Laterality	4	0.14	0.78	0.11	0.58	0.08	0.55	0.05	0.58	0.01	0.27
AQ * Sentence Comp * Site * Laterality	4	0.14	0.81	0.12	0.67	0.11	0.78	0.04	0.43	0.01	0.27
Condition * Site * Laterality	8	0.01	0.97	0.01	1.00	0.01	0.51	0.01	0.76	0.01	0.80
<b>AQ * Condition * Site * Laterality</b>	8	0.02	2.62 *	0.01	0.83	0.01	0.71	0.01	0.71	0.01	0.65
Sentence Comp * Condition * Site * Laterality	8	0.01	0.74	0.01	0.53	0.01	0.60	0.00	0.18	0.01	0.42
<b>AQ * Sentence Comp * Condition * Site * Laterality</b>	8	0.01	1.45	0.02	1.19	0.01	0.93	0.01	0.50	0.01	0.32

Table A4: *F*-values, mean square error estimates, and degrees of freedom for the repeated-measures ANOVAs on the Scrambled – Structural Only difference waves in each analysis window, with a AQ and WRAT as continuous variables and within-subjects factors of Site and Laterality. Main effects of, or interactions with, AQ are highlighted in bold. Asterisks indicate statistically significant results (. =  $p < 0.10$ ; \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.0001$ ).

Main effects and interactions	Time Windows (ms)										
	200-300			300-400		400-500		500-600		600-700	
	df	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value	Mean Sq	F value
<b>AQ</b>	1	0.00	0.00	0.06	1.74	0.06	0.97	0.05	0.92	0.25	3.54 .
Sentence Comp	1	0.13	6.85 *	0.03	0.89	0.06	0.93	0.00	0.00	0.00	0.01
<b>AQ * Sentence Comp</b>	1	0.28	14.99 **	0.10	2.92	0.00	0.03	0.01	0.17	0.02	0.31
Site	2	0.08	0.78	0.00	0.03	0.01	0.14	0.03	0.22	0.09	0.72
<b>AQ * Site</b>	2	0.00	0.01	0.15	1.58	0.02	0.27	0.01	0.05	0.02	0.13
Sentence Comp * Site	2	0.02	0.19	0.07	0.71	0.03	0.39	0.04	0.33	0.04	0.28
<b>AQ * Sentence Comp * Site</b>	2	0.15	1.52	0.06	0.60	0.10	1.14	0.10	0.79	0.14	1.07
Laterality	2	0.20	1.24	0.11	0.83	0.04	0.25	0.05	0.32	0.01	0.06
<b>AQ * Laterality</b>	2	0.12	0.73	0.03	0.23	0.05	0.28	0.00	0.02	0.02	0.19
Sentence Comp * Laterality	2	0.10	0.62	0.05	0.33	0.02	0.09	0.11	0.63	0.08	0.64
<b>AQ * Sentence Comp * Laterality</b>	2	0.02	0.10	0.02	0.17	0.07	0.41	0.01	0.06	0.15	1.18
Site * Laterality	4	0.01	0.43	0.00	0.19	0.01	0.40	0.02	0.62	0.01	0.31
<b>AQ * Site * Laterality</b>	4	0.01	0.55	0.01	0.46	0.01	0.47	0.01	0.18	0.02	0.48
Sentence Comp * Site * Laterality	4	0.01	0.82	0.00	0.21	0.02	0.83	0.01	0.33	0.02	0.59
<b>AQ * Sentence Comp * Site * Laterality</b>	4	0.03	1.75	0.04	1.68	0.03	1.14	0.03	0.81	0.01	0.26