UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL, HUMAN, AND MATHEMATICAL SCIENCES

Psychology

A SYSTEMATIC INVESTIGATION OF WRITTEN LANGUAGE PROCESSING IN AUTISM SPECTRUM DISORDER

By

Philippa Lucy Howard

Thesis for the degree of Doctor of Philosophy

April 2017

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF SOCIAL, HUMAN, AND MATHEMATICAL SCIENCES

Psychology

Thesis for the degree of Doctor of Philosophy

A SYSTEMATIC INVESTIGATION OF WRITTEN LANGUAGE PROCESSING IN AUTISM SPECTRUM DISORDER

Philippa Lucy Howard

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterised by language processing differences. These differences are thought to impact upon reading skill and individuals with ASD are often reported to have reduced reading comprehension and inferencing accuracy, in comparison to typically developing (TD) controls. This thesis examined on-line linguistic processing differences that might underpin atypical reading performance in ASD by monitoring the eye movements of TD and ASD adults as they read text that included lexical, syntactic, semantic, and discourse manipulations.

Experiment 1 and Experiment 2 demonstrated that the efficiency of lexical and syntactic processing is similar between TD and ASD readers, as evidenced by comparable word frequency and garden path effects. In contrast, Experiment 3 demonstrated that there is a differential time-course in the processing of situational world knowledge during reading between TD and ASD readers. However, no difference in the efficiency with which TD and ASD readers form co-referential links was found in Experiment 4. In addition, for each experiment, readers with ASD were found to engage in increased re-reading, in comparison to TD readers, which is speculated to reflect a 'cautious' reading strategy.

Collectively, the findings from these experiments demonstrate that in general, the language processing system is very similar between TD and ASD readers. However, individuals with ASD have a specific processing atypicality that is associated with the processing of situational world knowledge. Given that processing of such information is often essential for inferences to be formed and for readers to achieve global text coherence, it is likely that this processing difference contributes to previous reports of comprehension

and inferential atypicalities in ASD. Collectively, these findings provide a novel contribution to our understanding of how linguistic processing during reading occurs on-line in individuals with ASD.

Table of Contents

Table of Contents i

List of Tables v

List of Figures vii

DECLARATION OF AUTHORSHIP ix

Acknowledgements xi

Chapter 1: Literature Review 1

1.1 Reading 1

1.1.1 How do we read? 1

1.1.2 Lexical Processing 1

1.1.3 Syntactic Processing 3

1.1.4 Semantic and Discourse Processing 6

1.1.5 What can Eye Movements tell us about Reading? 8

1.2 Autism Spectrum Disorder 11

1.3 Cognitive Theories of Autism Spectrum Disorder 12

1.3.1 The Mentalizing Theory 13

1.3.2 Executive Dysfunction Theory 14

1.3.3 The Weak Central Coherence Theory 16

1.3.4 The Theory of Complex Information Processing 18

1.4 Reading in Autism Spectrum Disorder 19

1.4.1 Specific Language Impairment 19

1.4.2 Lexical Processing in Autism Spectrum Disorder 20

1.4.3 Syntactic Processing in Autism Spectrum Disorder 23

1.4.4 Semantic and Discourse Processing in Autism Spectrum Disorder 26

1.4.5 Mentalizing Theory: Theory of Mind Processing during Reading in Autism Spectrum Disorder 32

1.4.6 Executive Dysfunction: Monitoring during Reading in Autism Spectrum Disorder 33

1.4.7 Weak Central Coherence: Integration during Reading in Autism Spectrum Disorder 36

1.4.8 Theory of Complex Information Processing: World Knowledge use during Reading in Autism Spectrum Disorder 42

1.5 Methodology 45
1.6 Planned Empirical Research 46
Chapter 2: Lexical, Syntactic and Semantic Processing 48
2.1 Introduction 48
2.2 Experiment 1. Lexical Processing in ASD 54
2.3 Method 56
2.3.1 Participants 56
2.3.2 Materials 56
2.3.3 Procedure 57
2.3.4 Design 58
2.4 Experiment 1: Results 58
2.4.1 Data Preparation and Analyses 58
2.4.2 Global Measures 59
2.4.3 Target Word 60
2.4.4 First Pass Reading 62
2.4.5 Second Pass Reading 62
2.5 Experiment 1: Discussion 67
2.6 Experiment 2: Syntactic and Semantic Processing in ASD 68
2.7 Method 73
2.7.1 Materials 73
2.8 Experiment 2: Results 74
2.8.1 Data Preparation 74
2.8.2 Global Measures 75
2.8.3 Pre-target Region 76
2.8.4 Target Word 77
2.8.5 Post Target Region 78
2.8.6 First Pass Reading 78
2.8.7 Second Pass Reading 79
2.9 Experiment 2: Discussion 85
2.10 Conclusion 87
Chapter 3: Semantic Processing 89
3.1 Introduction 89
3.2 Method 95
3.2.1 Participants 95

3.2.2 Materials 97
3.2.3 Design 98
3.2.4 Apparatus 98
3.2.5 Procedure 98
3.3 Results 99
3.3.1 Data Preparation and Analyses 99
3.3.2 Global Measures 101
3.3.3 Pre-target Region 102
3.3.4 Target Word 103
3.3.5 Post Target Region 106
3.3.6 Total Times 106
3.3.7 Supplementary Analyses 109
3.4 Discussion 112
Chapter 4: Discourse Processing 117
4.1 Introduction 117
4.2 Method 122
4.2.1 Participants 122
4.2.2 Materials 123
4.2.3 Procedure 124
4.2.4 Apparatus 124
4.2.5 Design 124
4.3 Results 125
4.3.1 Data Preparation and Analyses 125
4.3.2 Accuracy 126
4.3.3 Global Measures 126
4.3.4 Target Word 129
4.3.5 Bayes Factor Analysis 131
4.3.6 Post Target Region 131
4.3.7 Supplementary Analyses 133
4.4 Discussion 140
Chapter 5: General Discussion 145
5.1 Chapter 2: Lexical Processing 145
5.2 Chapter 2: Syntactic and Semantic Processing 146
5.3 Chapter 3: Semantic Processing 148

5.4 Chapter 4: Discourse Processing **149**
5.5 Re-reading **151**
5.6 Key Findings and Theoretical Implications **151**
5.6.1 The Mentalizing Theory 153
5.6.2 Executive Dysfunction Theory 154
5.6.3 Weak Central Coherence Theory 154
5.6.4 Theory of Complex Information Processing 156
5.7 Broader Implications **156**
5.8 Strengths and Limitations **158**
5.9 Future Directions **159**
5.9.1 World knowledge 159
5.9.2 Inferential Work 159
5.9.3 Re-reading 160
5.10 Concluding Remarks **160**

Appendices **163**

Appendix A Eye Movement Measures **165**

Appendix B Experiment 1 Stimuli **167**

Appendix C Experiment 2 Stimuli **171**

Appendix D Experiment 3 Model Output **177**

Appendix E Experiment 4 Stimuli **185**

List of References **189**

List of Tables

Table 1. Model parameters and observed means for Experiment 1 global analyses. 60

Table 2. Model parameters for Experiment 1 early measures ROI analyses. 64

Table 3. Model parameters for Experiment 1 later measures ROI and supplementary analyses. 65

Table 4. Observed means (standard deviations) for Experiment 1 ROI and supplementary analyses. 66

Table 5. Model parameters and observed means for Experiment 2 global analyses. 76

Table 6. Model parameters for Experiment 2 start, verb, noun and preposition region analyses. 80

Table 7. Model parameters for Experiment 2 pre-target and target regions. 81

Table 8. Model parameters for Experiment 2 post target and end regions. 82

Table 9. Observed means (standard deviations) for Experiment 2 start, verb, noun, and preposition regions. 83

Table 10. Observed means (standard deviations) for Experiment 2 pre-target, target, post target and end regions. 84

Table 11. Means (standard deviations) for ASD and TD group's age, self reported autistic traits, intelligence, expressive language and reading skill........ 97

Table 12. An example of a plausible, implausible and anomalous sentence with region of interest boundaries marked. 98

Table 13. Global eye movement measure means (standard deviations). 102

Table 14. Observed means (standard deviations) of the eye movement measures (ms) for the pre-target, target and post target regions. 108

Table 15. Observed means (standard deviations) for the three measures analysed as part of the supplementary analyses. 111

Table 16. An example of the experimental stimuli and region of interest boundaries. 124

Table 17. Model parameters and observed means (standard deviations) for global analyses. 128

Table 18. Model parameters and observed means (standard deviations) for target region analyses. 130

Table 19. Model parameters and observed means (standard deviations) for post target region analyses. 132

Table 20. Model parameters for supplementary analyses of the regions within the first sentence. 135

Table 21. Model parameters for supplementary analyses of pre-target and target regions. 136

Table 22. Model parameters for supplementary analyses of post target and end regions. 137

Table 23. Observed means (standard deviations) for all measures calculated for the supplementary analyses. 138

List of Figures

Figure 1. Example of the connectionist model framework at the feature, letter and word level from the interactive-activation model. Arrow heads represent positive activation between levels, circle heads represent inhibition. This image was reproduced from McClelland and Rumerhart (1982). 3

Figure 2. The syntactic tree on the left demonstrates the syntactic structure when the prepositional phrase is attached as a modifier to the second noun phrase the man. The syntactic tree on the right demonstrates the syntactic structure when the prepositional phrase is attached as a modifier to the verb saw. 4

Figure 3. Schematic example of the Sally-Anne false belief task used to assess theory of mind in children. This image was reproduced from Baron-Cohen et al. (1985). 14

Figure 4. The Tower of Hanoi Task requires a participant to reorganise discs that are placed on three rods (e.g., start point A) to form a 'tower' (e.g., end point B) using the fewest number of moves possible. Participants must follow three set rules; I) that only one disc can be moved at a time, II) only discs on top of a stack can be moved, and III) a disc can only be placed upon larger discs. 15

Figure 5. The Wisconsin Card Sorting Task requires a participant to match a single card to another by a single feature (e.g., in the above the target card could be matched to another by colour, number of shapes, or shape type), however participants are not told what feature to match the cards on, but are given feedback as to whether the match they have made is correct or incorrect. The aim of the task is to make as many correct set matches as possible, however the 'rule' as to which set match (e.g., colour, shape) is correct alters throughout the task. This means that participants have to continually utilise feedback to alter the set rule adopted. 16

Figure 6. Example of stimuli used for the Embedded Figures Task. The above image (pram) contains an embedded figure (triangle).. 17

Figure 7. Mean first fixation duration on the target word for plausible, implausible and anomalous sentences. Error bars represent standard error................. 105

DECLARATION OF AUTHORSHIP

I, PHILIPPA LUCY HOWARD declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

A Systematic Investigation Of Text Processing Differences In Adults With Autism Spectrum Disorder

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;

2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated [see below];

   Chapter 3 was piloted and submitted as part of my MSc candidature. For this pilot study, 4 participants were recruited for both the TD and ASD group, and data was analysed using ANOVAs. For the final published version of the experiment reported in this thesis, two of the ASD participants who participated in the original pilot have been excluded, 43 more participants have been recruited, and data has been analysed using linear mixed effects models.

3. Where I have consulted the published work of others, this is always clearly attributed;

4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;

5. I have acknowledged all main sources of help;

6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

7. Parts of this work have been published as: [please list references below]:

Howard, P. L., Liversedge, S. P., & Benson, V. (2017). Benchmark Eye Movement Effects During Natural Reading in Autism Spectrum Disorder. *Journal of Experimental Psychology: Learning, Memory & Cognition*, *43*(1), 109-127. DOI: 10.1037/xlm0000289

Howard, P. L., Liversedge, S. P., & Benson, V. (2017). Investigating the Use of World Knowledge During On-line Comprehension in Adults with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*. DOI: 10.1007/s10803-017-3129-x

Howard, P. L., Liversedge, S. P., & Benson, V. (2017). Processing of Co-Reference in Autism Spectrum Disorder. *Autism Research*. DOI: 10.1002/aur.1845

Signed: ....

Date:...

Acknowledgements

First and fore mostly I would like to thank my supervisors, Val and Simon, for their insightful guidance, advice, and encouragement throughout this entire process. I am indebted to the participants who took part in this research, who made this thesis possible. The postgraduate students and CVC team as a whole have been a fantastic and intellectually stimulating group of people to work. I have thoroughly enjoyed my time at Southampton.

This thesis has been a huge personal challenge for both myself, and my husband, Stacy. Thank you for putting up with me. I am always grateful for the perpetual support of my parents and siblings, and on this occasion am particularly thankful that they frequently allowed me to escape my PhD life, by *not* asking how it was going.

Chapter 1: Literature Review

In the following review, a basic outline of how typically developing adults (TD) read is provided, in relation to both the cognitive processes involved in written language processing, and how the eye movement system operates during reading. Thereafter, autism spectrum disorder (ASD) and how this condition affects cognitive processing is introduced, prior to evaluating and discussing the evidence as to how this condition impacts upon reading performance outcomes.

1.1 Reading

Reading refers to the visual processing and comprehension of written language (text). In modern day society, reading is a vital skill. Initially, children at school are taught to read. However, reading quickly becomes the predominant format through which information and learning takes place (i.e., the transition from learning to read, to reading to learn). As a consequence, reading skill has a significant influence upon an individual's academic success, employment prospects, quality of life and individual prosperity. In addition, given the technological advances that have taken place over the past three decades, reading is becoming increasingly important as a means of everyday communication (e.g., texting, emailing, instant messaging) and gaining information (e.g., on-line applications, on-line bills, council websites). In the following section, the cognitive processes an individual has to engage in, in order to comprehend the meaning of text is described.

1.1.1 How do we read?

It is well established that a reader's interpretation of text is incrementally developed, approximately on a word-by-word basis. This occurs via the completion of three broad stages of linguistic processing; lexical (word), syntactic (structure) and semantic/discourse (meaning). For clarity, each of these are described independently, however, there is evidence that these 'stages' of reading interact (e.g., MacDonald, Pearlmutter & Seidenberg, 1994; Taraban & McClelland, 1988).

1.1.2 Lexical Processing

The very first stage of reading is referred to as lexical processing. This is when a reader visually identifies the meaning and pronunciation of written words. For example, when you recognise that the combination of the letters C A T refer to a domesticated feline

– a cat. Similarly, when this same letter combination is presented in a different order, such as A C T, you recognise that this refers to the practice of pretending to be something or someone else, generally for the amusement of others – to act. This process, word identification, is the basic foundation from which reading can take place.

There are several contemporary models that describe the cognitive processes and mechanisms involved in visual word recognition (e.g., The Multiple Read Out Model, Grainger & Jacobs, 1996; The Interactive-Activation Model, McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; The Dual Route Cascaded Model; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). These models differ in the exact mechanisms they propose to occur during lexical identification. However, each model abides by a number of fundamental assumptions as to how word identification occurs. The first is that the initial stage of word identification requires the orthographic information (string of letters) to be visually encoded. This refers to the bottom up process of the extraction of visual form (i.e., the shape and order of the letters) that is transferred or 'input' into the language processing system (note that there is controversy as to whether letter position encoding is absolute e.g., Davis, 2001, or relative e.g., Whitney, 2001; Schoonbaert & Grainger, 2004). For lexical identification to be achieved, the encoded orthographic information has to be 'matched' against a word representation in the lexicon. The lexicon is a mental store containing information about the words a person knows (akin to a dictionary), such as orthography, phonology, semantic meaning and syntactic category (part of speech e.g., noun, verb etc.). In each of the models of visual word recognition cited above, this information is accessed through a connectionist framework (see the example in Figure 1), whereby features, letters and words in the lexicon are connected and receive activation or inhibition, based upon their consistency with the encoded information. Once activation reaches a 'steady state', lexical access (identification) is reached and the words meaning and associated information such as syntactic class becomes available to the reader (e.g., CAT; Pronunciation = /'kæt/; Syntactic Class = noun; Semantic Meaning = feline mammal, often domesticated and kept as a pet).

Image redacted for copyright reasons

Figure 1. Example of the connectionist model framework at the feature, letter and word level from the Interactive-Activation model. Arrowheads represent positive activation between levels, circle heads represent inhibition. This image was reproduced from McClelland and Rumelhart (1982).

1.1.3 Syntactic Processing

Once a word has been identified, how it structurally relates to the other words in a sentence must be computed, and this process is called syntactic parsing (e.g., how clauses, phrases and sentences are structured). Parsing is a critical process that contributes to the accurate comprehension of a sentence. For example, the following sentence has two possible syntactic structures and semantic interpretations; *John saw the man with the telescope*, who has the telescope? Firstly, it could be interpreted that the man had the telescope. Alternatively it could be that John had the telescope and used this to see the man. The interpretation a reader will make is dependent upon the syntactic structure adopted. The first interpretation is a result of the prepositional phrase *with the telescope* being connected as a modifier to the noun phrase *the man*. The second interpretation is a result of the prepositional phrase *with the telescope* being attached as a modifier (implement) of the verb *saw* (e.g., Figure 2).

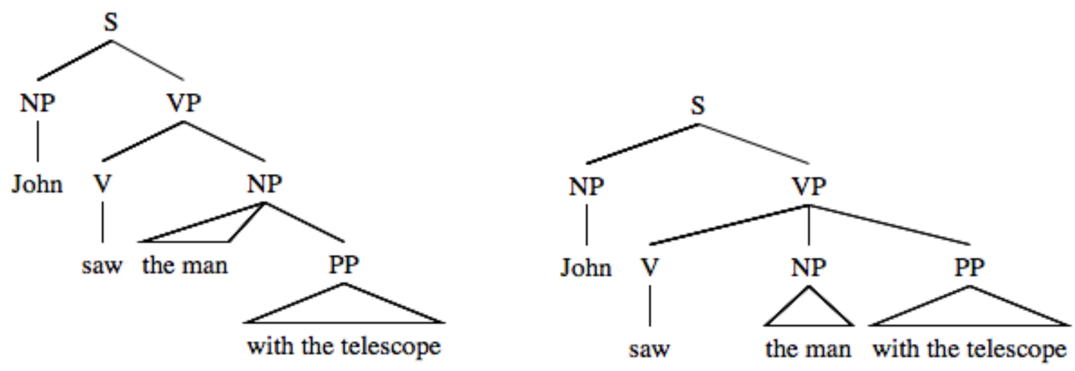

Figure 2. The syntactic tree on the left demonstrates the syntactic structure when the prepositional phrase is attached as a modifier to the second noun phrase *the man*. The syntactic tree on the right demonstrates the syntactic structure when the prepositional phrase is attached as a modifier to the verb *saw*.

There have been numerous positions adopted that attempt to explain how TD readers parse sentences (e.g., Garden Path Theory, Frazier & Rayner, 1982; Constraint Based Models, MacDonald, Pearlmutter & Seidenberg, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998; Tabor, Juliano, & Tanenhaus, 1997; Construal Accounts, Frazier & Clifton, 1996, 1997; Race-Based Parsing accounts, Traxler et al., 1998, van Gompel, Pickering & Traxler, 2000; Good-Enough Processing Accounts, Ferreira, Christianson & Hollingworth, 2001; Ferreira, Bailey & Ferraro, 2002). However, a lack of consensus in relation to exactly how this process occurs remains to date. The Garden Path Theory (Frazier & Rayner, 1982) was an early theory of parsing and postulated that sentences are parsed according to two syntactic principles, minimal attachment and late closure. Minimal attachment is a principle that readers will always build the simplest syntactic structure and the late closure a principle that the parser will always attach the ambiguous phrase to the currently open clause. The Garden Path Theory adopted Fodor's (1983) modularity hypothesis and therefore assumes that information is encapsulated and higher order variables, such as semantic and discourse information, cannot influence the initial parsing of a sentence. As a result, this is often referred to as a two-stage theory, with the initial parsing of a sentence (first stage) being assigned upon the basis of minimal attachment and late closure principles alone. In the second stage, additional information (e.g., thematic roles) is available that may inform whether the initially selected structure requires reanalysis, for example, if the initial structure selected resulted in a semantically implausible sentence.

In contrast, Constraint Based Models (e.g. MacDonald et al., 1994; McRae et al., 1998; Tabor et al., 1997) assume the language processor to be interactive. Therefore, all sources of information (e.g., thematic roles, semantic plausibility, discourse context) contribute to the nature of the initial syntactic structure assigned to a sentence. Parsing occurs via a competition process between potential syntactic structures that are activated in parallel (e.g., the two structures in Figure 2). Each possible structure receives activation, based upon how heavily it is supported by the evidence (e.g., parsing preferences, thematic information, semantic plausibility, discourse context). Increased activation for one structure, in turn inhibits the activation for less supported, alternative structures. Therefore, the structure that satisfies the most constraints will receive the most activation and be assigned to a sentence.

Construal Theory (Frazier & Clifton, 1996, 1997) is similar to the Garden Path Theory in that for primary phrases, only structural information is available during initial parsing, and both minimal attachment and late closure principles are adopted. Therefore, primary phrases (the subject and main predicate of a clause) are initially parsed and receive a determinate analysis using the minimal attachment and late closure principles. Construal Theory differs to Garden Path Theory, as it allows for structural under-specification, referred to as ‘construal’ processing for non-primary phrases. Non-primary phrases are instead assigned under-specified, non-determinate syntactic analyses based upon thematic information. Therefore, for non-primary phrases, non-structural information is used to determine the possible syntactic position.

Race Based Accounts (Traxler et al., 1998; van Gompel, et al., 2000) propose similarly to Constraint Based Accounts, that there is no limit to the sources of information that can inform the initial parsing of a sentence. The more support a potential structure has based upon the linguistic information available (e.g., parsing preferences, thematic information, semantic plausibility), the more quickly a structure is constructed (races) and is assigned to a sentence (wins). For Race Based Accounts, the parser is incremental, it checks whether the structure currently assigned to a sentence is appropriate, as each word is identified, based upon the sources of information available. Therefore, if new information provided by the word is inconsistent with the assigned structure (e.g., plausibility), syntactic reanalysis occurs.

In contrast to each of the above, the Good Enough Account (Ferreira, et al., 2001; Ferreira, et al., 2002) proposes that readers adopt a relatively superficial and shallow interpretation of the structure of a text. Note that this theory is not limited to parsing, but also later stages of comprehension. In this account, readers do not commit to one structural interpretation, but adopt underspecified analyses, which are flexible and can alter with relative ease, dependent upon the continuing text content.

Thus, based upon the theories of parsing described above, it would appear that there are four main aspects by which these theories of sentence parsing diverge (Altman & Stedman, 1988) I) whether the syntactic parser is assumed to be interactive II) whether parsing is incremental or occurs over phrase structures (referred to as fineness of grain by Altman & Stedman, 1988) III) whether structures are activated in parallel IV) whether initial parsing is determinate or flexible.

1.1.4 Semantic and Discourse Processing

To go beyond the basic structural relations of a sentence and comprehend the intended meaning of a text, a reader must engage in semantic and discourse processing. Semantic processing refers to the extraction of meaning from small units of text (e.g., a clause or sentence). Discourse processing refers to the additional cognitive work involved in the extraction of meaning from larger, connected portions of text (e.g., multiple sentences), such as the integration of information between sentences. A further distinction can also be made between semantic and pragmatic processing. Pragmatics refers to the use of prior (i.e., world) knowledge to aid text understanding and semantics refers to the understanding of information explicitly coded or conveyed by the language (i.e., word knowledge). This distinction is predominantly made when referring to spoken interactions and the influence of social context upon language processing, however, there is also evidence that this distinction exists during reading. For example Hagoort, Hald, Bastiaansen, and Petersson's (2004) recorded event related potentials (ERPs) as participants read sentences that contained world knowledge (pragmatic) violations (e.g., *The Dutch trains are white*) and semantic violations (e.g., *The Dutch trains are sour*), in comparison to plausible control sentences (e.g., *The Dutch trains are yellow*). Comparable N400 responses (a negative waveform occurring 400ms after stimuli onset) were detected for both violation types, however, the frequency of oscillatory activation differed. Pragmatic violations resulted in a peak in gamma oscillatory activation (30-70Hz), whereas semantic violations resulted in a peak in theta oscillatory activation (4-8Hz). This suggests that the time-course of pragmatic and semantic processing is similar, but the neural record stored by the brain for each violation type is qualitatively different. Throughout this thesis, the term 'semantics' will be used broadly to refer to all processing concerned with small units of text meaning, however, the distinction between the use of world (pragmatic) and word (semantic) knowledge will be highlighted when necessary.

There are again multiple theories that differ in their approach, each specifying the underlying mechanisms as to the manner in which the meaning of text is extracted (e.g., Construction-Integration Theory, Kintsch, 1988, 1998; Kintsch & van Dijk, 1978; The Structure Building framework; Gernsbacher, 1990, 1991; The Event Indexing Model; Zwaan, Langston, & Graesser, 1995). Despite the different approaches and differences in the precise mechanistic accounts these models specify, there is agreement between the theories that in order to comprehend text appropriately, a reader must engage in thematic and connecting processes, to develop an accurate, detailed and coherent mental representation of the text.

Following parsing, the semantic relationships between words within clauses, phrases and sentences are identified (thematic processing). Thematic processing describes the assignment or establishment of the semantic relationship (thematic roles) between a verb and its arguments/adjuncts (content words) e.g., *Jake drank the orange juice in his kitchen*, (drank = verb/action, Jake = agent, kitchen = location, juice = stimulus). In the Construction-Integration Theory the events these semantic relationships capture and represent, are referred to as propositions (Kintsch, 1988, 1998; Kintsch & van Dijk, 1978).

Following thematic processing, each theory proposes that readers then have to engage in connecting processes, whereby events/propositions are connected to one another. In the Construction-Integration Theory this is refereed to as the ‘integration’ cycle and propositions are connected to one another via overlapping concepts (e.g., a character). In the Event Indexing Model, events/propositions are connected to one another upon the basis of related events. These larger connected units of meaning are then incrementally incorporated into the discourse model, to form a mental representation of the information the text conveys.

In addition, each theory of text comprehension posits that general world knowledge, relevant to text meaning, is incrementally, rapidly and automatically activated in long-term memory as reading takes place. Readers use this world knowledge information to evaluate the information conveyed in the text and maximally elaborate the discourse model, via the computation of inferences. Inferencing is when implicit links or information not explicitly provided within the text is incorporated into the discourse model. For example, when reading *Sally had forgotten her umbrella. She was soaked when* *she arrived at work*, readers would infer that *she* co-refers to *Sally* (co-reference link), but also that it had rained (causal/bridging inference). Therefore the discourse model is not only comprised of information explicitly provided within that text, but also includes representations of information inferred from world knowledge. There is disagreement within the literature as to the kind of inference that can be computed on-line (e.g., Minimalist Hypothesis; McKoon & Ratcliff, 1992; Constructionist Hypothesis; Graesser, Singer & Trabasso, 1994). However, each theory of discourse comprehension (e.g., Construction-Integration Theory, Kintsch, 1988, 1998; Kintsch & van Dijk, 1978; The Structure Building framework; Gernsbacher, 1990, 1991; The Event Indexing Model; Zwaan et al., 1995) assumes both causal inferences and co-reference links (e.g., anaphoric) to be computed on-line, because they are important for basic text comprehension.

Thus, text comprehension occurs via the transfer of information through three levels of representation (note the terminology for these representations here are adopted from Kintsch, 1988); the surface model (verbatim words and syntactic structure), the text base model (consisting of small units of meaning e.g., propositions), and then finally the situation model (detailed, rich representation of the information depicted in the text and inferred from world knowledge; Zwaan & Radvansky, 1998).

1.1.5 What can Eye Movements tell us about Reading?

As a person reads, the eyes move progressively through text in a series of saccades and fixations. A saccade is a fast movement that takes the eye to a new location (e.g. a new word or a new line of text) and a fixation is the time between saccades when the eye remains still to extract and process visual information. On average, the distance of a saccade when reading English is approximately 7-9 letters in length taking around 30-40ms to execute, and a fixation duration during reading is on average 200-250ms (Rayner, 2009).

Recording a readers eye movements is a widely used technique for examining the linguistic processes that underlie reading, because fixation patterns directly reflect on-line cognitive processing (Liversedge & Findlay, 2000). That is, the duration of a fixation (the decision of when to move the eyes) and (to a lesser extent) the direction of a saccade (the decision of where to move the eyes) are contingent upon the ease with which a reader processes text. There are now numerous models that can very accurately predict eye movement patterns, based upon the properties of the text (e.g., E-Z reader; Reichle, Rayner & Pollatsek, 2003, SWIFT; Engbert, Nuthmann, Richter & Kliegl, 2001). Reading is a unique instance where under normal conditions, an individual has control over the amount of linguistic information that they process. This is in contrast to spoken information that is delivered at the rate of the speaker.

The key advantages of eye tracking are that it provides high temporal and spatial resolution information about the natural reading process. By monitoring an individual's eye movements as they read silently (i.e., usually participants read text on a computer monitor), one can very precisely pinpoint the location of any reading disruption within a text, in addition to the time course of these differences within the eye movement record (see Appendix A for a description of the different eye movement measures often calculated and how these reflect different stages of cognitive processing). This method is therefore favourable over more traditional approaches where artificial procedures (e.g., reading one word at a time without information visible in the parafovea) and tasks (e.g., pressing a button when an error is detected) are necessary to establish the location and time-course of linguistic processing, yet interfere with the natural reading process. Obstruction to natural reading when additional tasks demands are imposed is particularly likely when working with special populations who are sensitive to task expectations and instructions (e.g., see White et al. 2013). Consequently, eye tracking is one of the most sophisticated methods used to study reading, as it allows researchers to collect extremely detailed, yet naturalistic data, about the time-course of reading.

The relationship between eye movements and cognitive processing has been elegantly demonstrated by the disappearing text paradigm (Rayner, Liversedge, White & Vergilino-Perez, 2003). In this experiement, the eye movements of participants were recorded as they read sentences that contained words that were either high or low in frequency. The frequency of a word refers to how often a word occurs in the written language, with high frequency words (e.g., *people*) being fixated for shorter periods than low frequency words (e.g., *zombie*), as they have previously been encountered more often and are consequently easier to identify (Inhoff & Rayner, 1986; Rayner & Duffy, 1986). The novel aspect of the disappearing text paradigm was that once a reader had begun to fixate a word, it disappeared after 60ms (recall that the average fixation duration upon a word is between 200-250ms). If the decision of when to move the eyes is governed by low level visual processing of text, such as text encoding, one would expect a reader to execute a saccade and fixate a new word as soon as the currently fixated word disappeared. However surprisingly, participants continued to read normally, fixating upon the blank space where each word had previously been present for an amount of time directly related to the frequency of the word that had disappeared (e.g., approximately 200-300ms). This demonstrates that rather than visual sampling (i.e., the uptake of visual information), it is cognitive processing, and specifically, processing associated with the identification of a word, that drives the eyes through the text and determines when a reader moves their eyes to fixate new information.

Another classic finding that illustrates how eye movement control during reading is predominantly a psychological mechanism comes from McConkie and Rayner's (1975) early perceptual span study. The perceptual span refers to the optimal amount of information presented to the left and right of fixation, for reading to proceed proficiently. McConkie and Rayner (1975) designed the first gaze contingent paradigm whereby they could control the amount information available to a reader using a 'moving window'. The moving window would shift with each new fixation which meant that the amount of letters to the left and right of fixation could be controlled at all times. If the size of the perceptual span were physiologically controlled, one would predict it to reflect the size of the visual field and therefore be of constant size and symmetrical (e.g., equal amounts of letters on each side). However, the optimal size window for an English reader was found to be 3-4 letters to the left and 12-14 letters to the right of fixation (McConkie & Rayner, 1975). The asymmetry of the perceptual span in the direction of which text is read indicates that it is a psychologically (attention) controlled phenomenon. Consistent with this assertion, the perceptual span has been found to alter dependent upon the direction of the language being read. For example, in Hebrew where text is read from the right to left, the perceptual span is found to have a larger number of letters to the left than to the right (Pollatsek, Bolozky, Well, & Rayner, 1981). The perceptual span is also modulated by the density of the language, with the span being much smaller in Chinese, with about 2-3 characters to the left and one character to the right (Inhoff & Liu, 1998). In addition, the reader's individual ability has been found to affect the size and direction of the perceptual span. For example, children whose reading skills are less well developed are found to have smaller perceptual spans, in comparison to skilled adult readers and this reflects their lowered processing capacity for text (Rayner, 1986). These findings strengthen the evidence for cognitive influences on the oculomotor system during reading, and have contributed to the extensive use of eye movement recording techniques to examine linguistic processing over the past four decades.

Manipulating the linguistic properties of text and the amount of information that is available to a reader at any particular time allows psycholinguists to infer how written language is processed and comprehended by readers, and also how linguistic processing differs between groups (e.g., children and adults, Blythe & Joseph, 2011). Reading is an ideal task to study language processing differences, because linguistic variables can be tightly controlled; yet reading still remains relatively naturalistic. Consequently, eye movement recording is a practical and valuable method to adopt when working with both TD and special populations.

1.2 Autism Spectrum Disorder

One condition that impacts upon the language processing system is autism spectrum disorder (ASD). ASD is a life-long neurodevelopmental condition diagnosed in approximately 1% of the population (American Psychiatric Association, 2013). Infantile autism was first included in the Diagnostic and Statistical Manual (DSM) in 1980, when a child could be diagnosed if they presented with a persistent lack of responsiveness to others; bizarre responses to aspects of the environment; gross deficits in language development and (if verbal) peculiar language. These symptoms had to be present before 30 months of age and with absence of delusions. In 1994, the diagnostic criterion for ASD was expanded to be an umbrella term and included the diagnosis of autistic disorder, Asperger's syndrome and pervasive developmental disorder. Asperger's syndrome was diagnosed when an individual had no delay in their language development, and pervasive developmental disorder was diagnosed when an individual met most, but not all of the diagnostic criteria for autistic disorder (American Psychiatric Association, 1994). Very recently however, in an attempt to improve consistency, the three different diagnoses have been collapsed to form a holistic, single diagnosis (American Psychiatric Association, 2013). At present, one must have persistent difficulties with social interaction/ communication (e.g., language atypicalities, lack of awareness or understanding of social norms resulting in 'inappropriate' behaviour; difficulty making eye contact) and restrictive and repetitive patterns of behaviour (e.g., ritualistic behaviour; a severe aversion of change). These symptoms must be present from an early age and result in significant impairment in an individual's everyday functioning. Note that language differences are no longer specified as a core diagnostic criteria in itself, but are one of the characteristics of the condition that contribute to the broad 'social interaction/communication difficulties' criteria. The updated diagnostic criteria means that those who have normal intelligence and may have previously received a diagnosis of Asperger's syndrome now receive the same diagnosis as those who are more severely impaired and would have previously received a diagnosis of autistic disorder. The severity of an individuals symptoms are clinically distinguished using a rating scale from one to three, to guide the level of intervention and support a person requires. In addition, it is now specified whether an individual receives a diagnosis of ASD *with* or *without* additional verbal language impairment (e.g., a delay in verbal language onset and development).

The cause of ASD is still currently undetermined, however a number of genetic abnormalities have been identified that are likely to contribute to atypical development (e.g., Abraham & Geschwind, 2008). Approximately a quarter of the ASD population have normal intelligence and are often labelled 'high functioning', with the remainder of the ASD population commonly having comorbid learning difficulties (estimated at 67%, Mayes & Calhoun, 2006). The current research will focus upon the subgroup of individuals with ASD who do not have additional learning difficulties. These individuals do not differ from the TD population in intelligence, but still require support and often fail to live independently or find permanent employment as a result of the impact that ASD has on everyday functioning (e.g., Buescher, Cidav, Knapp, & Mandell, 2014; Clarke et al, 2009). Therefore, in this thesis I aim to examine *ASD specific* language processing differences. There have been a number of studies (these are discussed in more detail in later sections) that report a positive relationship between the severity of reading difficulties in ASD (e.g., comprehension), and the severity of ASD symptomology (e.g., Huemer & Mann, 2010; Jones et al., 2009; Ricketts et al., 2013). This alludes to the possibility that the nature, but not severity, of any processing differences detected within high functioning groups may be somewhat generalizable to the ASD population more broadly. Four key theories that have attempted to explain cognitive differences specific to ASD are outlined in the following section.

1.3 Cognitive Theories of Autism Spectrum Disorder

The manner in which the differential neurological development associated with ASD impacts upon cognitive processing and how this relates to the behavioural phenotype has been extensively researched (e.g., Frith, 2012). Multiple theories detailing the cognitive differences in ASD have been developed in an attempt to explain behavioural outcomes. However, there is no specific theoretical account as to how language processing occurs in ASD. Therefore, below, I describe the domain general cognitive theories that have been previously adopted to explain the performance atypicalities for reading tasks in ASD. The cognitive theories of ASD that do not directly pertain to language processing have been excluded for conciseness (e.g., Extreme Male Brain, Baron-Cohen, 2002, 2009; Enhanced Perceptual Functioning, Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert &

Burack, 2006; Bayesian Accounts, Pellicano & Burr, 2012). The evidence in support of each theory in relation to reading performance in ASD is outlined and evaluated in the later sections that review ASD and reading research.

1.3.1 The Mentalizing Theory

Theory of Mind (ToM) refers to one's ability to create a meta-representation of another person's mental state in order to understand their goals, emotions, beliefs and behaviour (Frith & Frith, 2005). On average, TD children are able to complete tasks requiring ToM by 4 years of age (Wellman, Cross, & Watson, 2001; Wimmer & Perner, 1983). However, children with ASD are often found to display deficits in the completion of such tasks (Frith, Morton & Leslie, 1991). Baron-Cohen, Leslie and Frith (1985) found that 80% of their sample of ASD children failed to correctly identify a false belief (that was different to their own) of a character in a story (e.g., for an example of this task see Figure 3). Furthermore, children with ASD who pass first order ToM tasks (e.g., 20% in Baron-Cohen et al. 1985 study) tend to fail second-order ToM tasks (Baron-Cohen, 1989), that require the understanding of what somebody thinks another person thinks. Others, however, have failed to find any difference in performance between adolescents and adults with ASD for first (Ozonoff, Pennington & Rogers, 1991) and second-order belief tasks (Bowler, 1992). Therefore, this theory has now been developed to propose that the social difficulties associated with ASD are a result of a delay in the development of ToM skill. Consistent with this hypothesis, difficulties in ToM are found for adults with ASD when more complex tasks are employed, such as the 'Reading the Mind from the Eyes Test', where participants have to identify a persons mental state from an image of their eyes (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997). The Mentalizing Theory has predominantly been used to explain the social difficulties individuals with ASD experience, such as a difficulties identifying subtle cues, social norms and reduced social and emotional awareness.

Image redacted for copyright reasons

Figure 3. Schematic example of the Sally-Anne false belief task used to assess ToM in children. This image was reproduced from Baron-Cohen et al. (1985).

1.3.2 Executive Dysfunction Theory

Executive functions are a group of cognitive processes involved in planning, regulation and control of domain specific processes (e.g. attention, inhibition, task switching, monitoring and problem solving). The Executive Dysfunction Theory arose as an attempt to explain the non-social facets of ASD that the Mentalizing Theory could not account for. It was proposed that the behavioural phenotype of ASD can be explained by deficits in executive functioning that stem from abnormal frontal lobe development (Hughs & Russell, 1993; Hughs, Russell & Robbins, 1994; Pennington & Ozonoff, 1996), with deficits predominantly manifesting in planning and flexibility (Ozonoff & Jensen, 1999). For example, children and adults with ASD have been found to perform with reduced speed and accuracy than TD controls on the Tower of Hanoi task (see Figure 4 for an example and description of this task), and the Wisconsin Card Sorting task (see Figure 5 for an example and description of this task, Hughes, et al., 1994; Ozonoff, et al., 1991; Rumsey & Hamburger, 1988, 1990). To be successful at each of these tasks, a participant has to engage in goal directed processes, such as strategic planning and cognitive rule shifts. Deficits in planning and flexibility form plausible explanations of ASD symptomology associated with restrictive and repetitive patterns of behaviour, such as the necessity for strict routines and a likeness for sameness. However, findings in relation to performance on assessments of executive functioning in ASD are mixed and vary significantly depending upon the sample tested and tasks used (e.g., Hill, 2004a, 2004b; White et al., 2013).

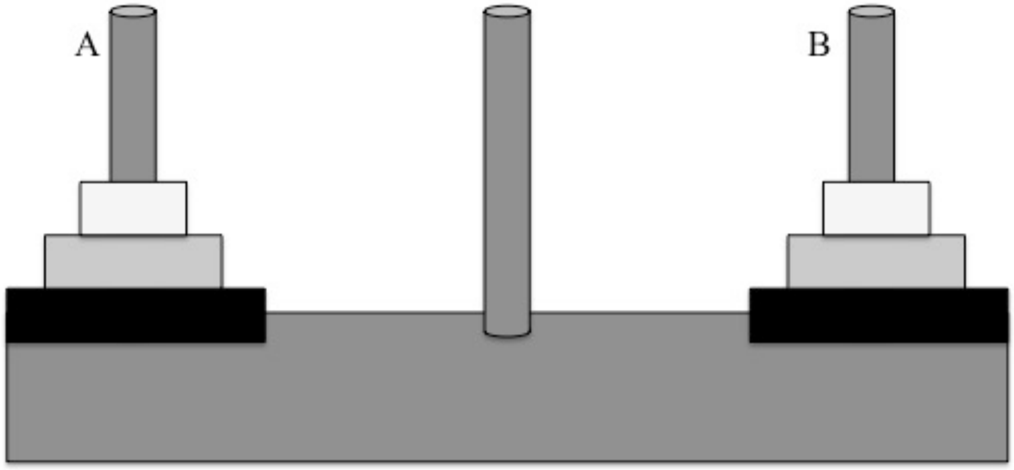

Figure 4. The Tower of Hanoi Task requires a participant to reorganise discs that are placed on three rods (e.g., start point A) to form a 'tower' (e.g., end point B) using the fewest number of moves possible. Participants must follow three set rules; I) that only one disc can be moved at a time, II) only discs on top of a stack can be moved, and III) a disc can only be placed upon larger discs.

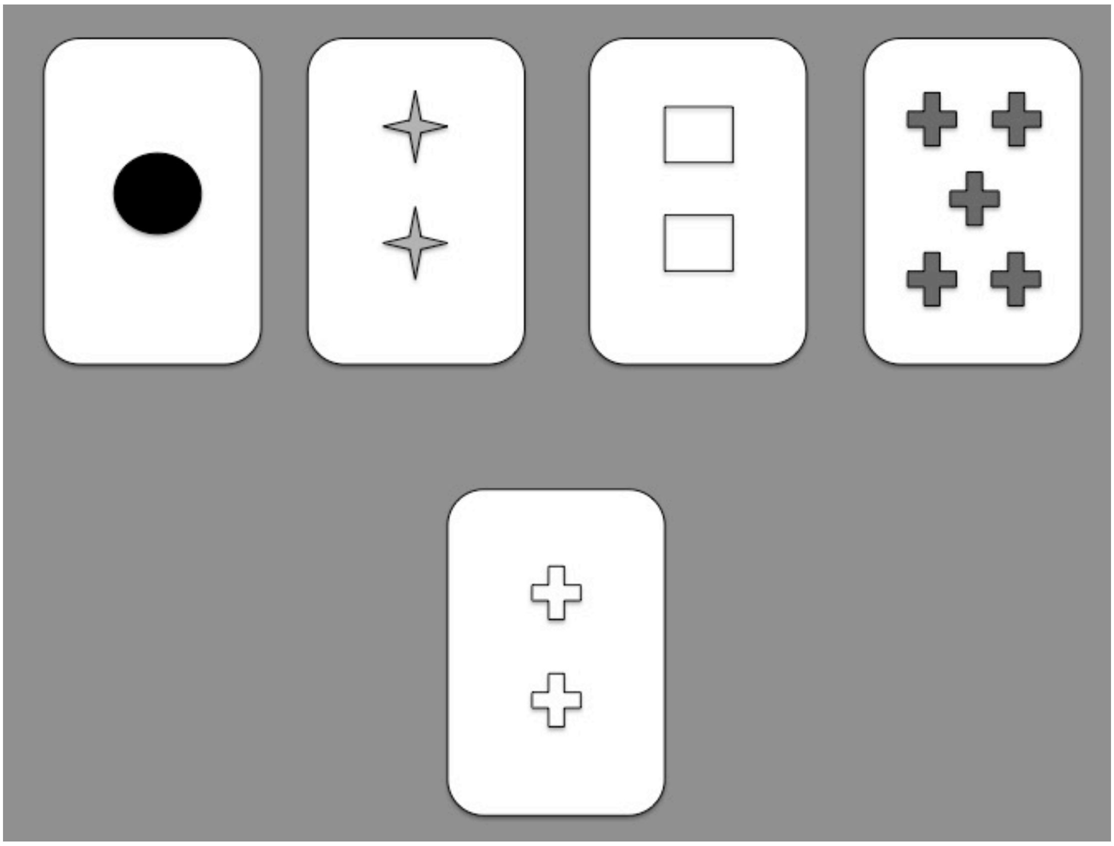

Figure 5. The Wisconsin Card Sorting Task requires a participant to match a single card to another by a single feature (e.g., in the above the target card could be matched to another by colour, number of shapes, or shape type), however participants are not told what feature to match the cards on, but are given feedback as to whether the match they have made is correct or incorrect. The aim of the task is to make as many correct set matches as possible, however the 'rule' as to which set match (e.g., colour, shape) is correct alters throughout the task. This means that participants have to continually utilise feedback to alter the set rule adopted.

1.3.3 The Weak Central Coherence Theory

Central Coherence refers to a bias held in a TD population to process global information (Navon, 1977). The Weak Central Coherence Theory originally proposed that individuals with ASD have a detail focused, local processing bias that consequently results in global processing deficits (Frith, 1989; Frith & Happé, 1994). The Weak Central Coherence Theory was developed in an attempt to explain the non-social symptoms of ASD that the Mentalizing Theory could not explain, in addition to the unusual cognitive abilities and skills that the Executive Dysfunction Theory did not account for (Happé, 1999).

One of the earliest experiments that demonstrated a local bias in individuals with ASD used the Embedded Figures Task. This involved participants searching for an embedded shape within a picture (e.g., see Figure 6). Participants with ASD found the embedded figure significantly faster than TD groups and this has been used as evidence for superior local processing (Shah & Frith, 1983). In addition, groups with ASD have been found to perform as accurately, but significantly faster than TD groups on the block design subset of the Wechsler Test of Intelligence (Shah & Frith, 1993). This test requires a participant to replicate a pattern of blocks using only the component parts. More recent evidence of superior processing of local information include studies where individuals with ASD are found to be less susceptible to visual illusions (Happé, 1996), and complete visual search tasks more quickly, in comparison to TD controls (O’Riordan, Plaisted, Driver & Baron-Cohen, 2001; O’Riordan, 2004). Furthermore, evidence of weak central coherence has been documented in the families of children with ASD, suggesting that this is a cognitive bias that is present in a TD population who are genetically more likely to have autistic tendencies (Briskman, Happé & Frith, 2001; Happé, Briskman & Frith, 2001).

Image redacted for copyright reasons

Figure 6. Example of stimuli used for the Embedded Figures Task. The above image (pram) contains an embedded figure (triangle).

The Weak Central Coherence Theory is capable of explaining a range of the behavioural symptoms associated with ASD, for example fixation on details and difficulties in altering behaviour to fit with context. However, findings of superior local processing are not always replicated (Kaland, Mortensen, & Smith, 2007) and there is an increasing body of evidence to suggest that individuals with ASD automatically process global, contextual information. For example, Mottron, Burack, Iarocci, Belleville and Enns (2003) found individuals with ASD to show equivalent performance to a TD group on a range of configural grouping tasks. To account for such findings, the Weak Central Coherence Theory has been modified to be characterised as a cognitive processing "style" whereby individuals encompass a lack of spontaneous strive for global coherence, rather than a global processing deficit *per se* (Happé, 1999; Happé & Frith, 2006).

1.3.4 The Theory of Complex Information Processing

The Theory of Complex Information Processing attempts to deduce the cognitive underpinnings of ASD symptomology, upon the basis of the Under-Connectivity Hypothesis (Minshew & Goldstein, 1998). The Under-Connectivity Hypothesis proposes that ASD is a neurological disorder stemming from under-connectivity between neocortical brain areas that are necessary for higher level processing, and over-connectivity within regions or domains (Just, Cherkassy, Keller, Kana, & Minshew, 2007; Just, Cherkassy, Keller & Minshew, 2004; Minshew, Williams & McFadden, 2008). Based upon this atypical functional connectivity development, the Complex Information Processing Theory claims that individuals with ASD will have intact processing and performance for "simple" (e.g., low-level) tasks across and within cognitive domains, but will exhibit deficits in the processing and performance for "complex" tasks involving higher order processes and/or the integration of information (Williams, Goldstein, & Minshew, 2006).

The supporting evidence for the Complex Information Processing Theory comes from a battery of cognitive assessments administered to adults with high functioning ASD (IQ >80) that were designed to capture simple and complex cognitive processes in the attention, memory, motor, language, visuospatial, and reasoning domains (Minshew, Goldstein, & Siegel, 1997). Adults with ASD did not differ from the TD participants in their performance on tasks in all domains that could be completed on the basis of bottom-up, perceptual processes. In fact, for low level language tasks (i.e., the basic components of reading such as word identification) the ASD group exhibited superior performance. In tasks identified as complex where higher order/integrative processes were required for successful completion, the ASD group could be discriminated from the TD group due to lower performance in all domains except the visuospatial module, which appeared to be spared from any deficits (Minshew et al., 1997).

An extremely similar pattern of abilities and deficits have been observed in children with ASD (Williams et al., 2006), which would suggest that the Complex Information Processing Theory has the potential to explain the cognitive and behavioural impact of brain abnormalities that develop in ASD across the lifespan. In addition, an eye movement study has found evidence that even when performance outcomes do not differ between TD and ASD groups, that the processing of 'complex', but not 'simple' information is less efficient (Benson, Castelhano, Au-Yeung & Rayner, 2012). This further supports the contention that cognitive differences in ASD are dependent upon task complexity. This theory can account for both social and non-social characteristics of ASD. Note that social processing is inherently complex, as a result of the lack of predictability in social settings, along with implicit rules and dependence upon context. However, as with the majority of cognitive theories of ASD, a shortcoming is that the precise definition of 'complexity' still requires operational formalisation.

1.3.4.1 Summary

In summary, several contemporary cognitive theories have been developed to account for the behavioural manifestations of ASD. Whilst these have supporting evidence, there are also conflicting reports. To date no theory can comprehensively account for the observed behavioural differences in ASD. Furthermore, no specific predictions are made in relation to how the cognitive processing differences may relate to the severity of ASD symptomology. Below, an outline of the research on reading performance in ASD is given, in addition to an explanation as to how each of the theories described above may explain reading differences in ASD, and the supporting evidence for these hypotheses.

1.4 Reading in Autism Spectrum Disorder

Language is one of the most prominent areas where cognitive differences manifest in ASD (e.g., Rapin & Dunn, 2003; Tager-Flusberg, 1981) and consistent with other aspects of the phenotype, reading ability is highly variable (Nation, Clarke, Wright, & Williams, 2006). To take note of this variability, but also in an attempt to draw general conclusions as to aspects of linguistic processing that may be atypical in ASD, the literature that has examined reading in ASD presented below has been divided into three main categories; lexical, syntactic and semantic/discourse processing. Prior to this discussion however, specific language impairment is briefly outlined, as this is highly associated with linguistic skill in ASD and is referred to throughout the remainder of this review.

1.4.1 Specific Language Impairment

Specific language impairment (SLI) is a developmental disorder that is diagnosed when a child displays significant impairment in their oral language development, manifesting as reduced expressive and/or receptive skills that cannot be explained by learning difficulties or other disorders (American Psychiatric Association, 2013). Findings that language difficulties similar to that of SLI are present in approximately 30-50% of children with ASD has led to researchers identifying language subgroups within ASD, namely; ASD with SLI (ALI) and ASD without SLI (ALN, Tager-Flusberg, 2006). However, it is unclear whether the similarities found between SLI and ALI children are a result of shared genetic aetiology (Kjelgaard, & Tager-Flusberg, 2001), undiagnosed comorbidity (note that up until the most recent DSM-5, SLI could not be diagnosed in addition to ASD), or if atypical development in ASD could lead to similar language difficulties as SLI (Boucher, 2012; Lindgren, Folstein, Tomblin, & Tager-Flusberg, 2009; Whitehouse, Barry & Bishop, 2008; Whitehouse, Barry & Bishop, 2007). What is clear is that when these subgroups are identified in children with ASD, differences in the severity of reading and language deficits are apparent, with individuals with ALI performing less accurately at reading tasks, in comparison to both TD and ALN individuals (e.g., Lucas & Norbury, 2015; Norbury & Nation, 2011). For the current review, differences between ALN and ALI groups will be identified, but these will not be discussed in detail, as ASD specific language processing differences are the main point of interest.

1.4.2 Lexical Processing in Autism Spectrum Disorder

Children and adolescents with ASD (variable verbal IQ) have been found to perform at an age appropriate level for standardised word decoding and phonological tasks, such as reading aloud lists of increasingly difficult words and non-words (Huemer & Mann, 2010; Minshew et al., 1995; Nation et al., 2006). In addition, Saldaña, Carreiras, and Frith (2009) found readers with ASD to correctly distinguish between words, non-words (e.g., nilt), pseudo homophones (e.g., rale) and pseudo words (e.g., rabe) in two lexical decision tasks, suggesting that ASD readers used both phonological (matching graphemes to phonemes or ‘sounding out’) and orthographic decoding strategies (e.g., Coltheart et al., 2001). The use of grammar to aid word pronunciation also appears to be intact in ASD. Snowling and Frith (1986) found participants with ASD to use affixes in order to accurately articulate pseudo-words manipulated to be plural or singular. Therefore, upon the basis of the above studies, word identification skill appears to be intact in ASD.

In contrast, there are a number of studies that report some children with ASD to show impairments in phonological aspects of word identification. For example, Nation et al. (2006) found 42% of her sample of children with ASD who had variable ages (between 6-15 years) and abilities to perform with reduced accuracy on non-word pronunciation tasks, in comparison to matched controls. Similarly, White, Frith, Milne, Rosen, Swettenham and Ramus (2006) found a high proportion of their sample (59%) of children (aged between 8-12 years) with ASD who had non-verbal IQ within the normal range to perform more poorly than TD controls, but similarly to a sample of children with dyslexia, on standardised word identification and phonological tasks (e.g., non-word reading and spoonerisms). Both of these studies suggest that there are large subgroups of children with ASD who struggle to match graphemes to phonemes in order to correctly pronounce words. There are two possible explanations as to why these studies may find some children with ASD to have poor word identification and phonological skill.

Firstly, this difference may reflect a delay in language development that is often present in children with ASD (American Psychiatric Association, 2013). A delay in language onset or slowed development is likely to result in children performing more poorly on word identification and phonological tasks, in comparison to age matched controls. Information as to the ratio of children who had language delay was not reported by Nation et al. (2006) or White et al. (2006), and therefore this suggestion is speculative. However, there is some support for the delayed language development hypothesis in the literature. Åsberg and Sandberg (2012) had a group of children and young adolescents (aged 10-15 years) with ASD complete a number of word identification, phonological and language related tests, such as reading words and non-words aloud, spoonerisms and the rapid naming of digits. A subgroup of the participants with ASD (33.33%) performed less accurately on all tasks, in comparison to age matched controls. However when compared to younger participants (approximately a year younger) who scored comparatively on the word reading tasks, group differences disappeared for all tasks. This suggests that the qualitative nature of word identification skill in this group did not differ from controls; rather, there was a quantitative delay in development for the ASD subgroup.

The second explanation as to why poor performance on word identification and phonological tasks is reported for a subgroup of children with ASD may be that these participants have additional oral language difficulties (e.g., SLI). Screening for such difficulties was not conducted in White et al. (2006) or in Åsberg and Sandberg's (2012) study. However, those identified as less-skilled readers in Nation et al.'s (2006) sample, tended to also have numerically reduced scores on measures of oral language skill. This suggestion is also supported by findings of reduced performance for word decoding tasks in children and adolescents with ALI, but not ALN (e.g., Norbury & Nation, 2011). Therefore, it seems reasonable to suggest that the difficulties some children with ASD have with phonological and word identification tasks may be a consequence of oral language difficulties, as opposed to ASD *per se*.

Conversely, there is some evidence ASD may have an impact upon word identification skill in later life. Norbury and Nation (2011) found word identification skill to be at age appropriate levels in children with ALN (approximately 10-11 years of age) but, for these same children, performance fell below age appropriate levels in adolescence (approximately 14-15 years of age). Despite this, no differences were found between ALN and TD readers at either age point in semantic knowledge or non-word decoding. Therefore, Norbury and Nation (2011) concluded that although ASD *per se* does not appear to negatively affect lexical processing, the higher order difficulties readers with ASD often experience with comprehension and inferencing (discussed later in this review) may constrain the development of vocabulary knowledge and word learning in late childhood and early adolescence.

The next question to address is whether readers with ASD access word meaning similarly to controls. Saldaña et al. (2009) found readers with ASD to have appropriate word comprehension, when asked questions requiring the knowledge of homonym meanings (e.g. *bear/bare – which one is an animal?*). Frith and Snowling (1983) found children with ASD to read concrete words (e.g. *house*) more quickly than abstract words that were matched for frequency and length (e.g. *truth*), similarly to TD readers. The difference in the time course of word identification for concrete and abstract words is thought to reflect the ease with which a semantic representation is accessed, with concrete words having an easily accessible, tangible representation, whereas semantic representations for abstract words are intangible and require more cognitive effort to identify. The access to word meaning also appears to be automatic in ASD, with significant word interference consistently being found during the Stroop Task (Adams & Jarrold, 2009; Bryson, 1983; Eskes, Bryson, & McCormick, 1990). The findings of word comprehension in ASD is also supported by findings of age appropriate vocabulary knowledge, when assessed using standardized auditory assessments, such as the Woodcock Reading Mastery Test whereby participants supply synonyms (a word with the same or very similar meaning) or antonyms (a word with an opposite meaning) for target words (Minshew et al., 1995).

Nevertheless, there is one study that reports impairment in the access to word meaning in ASD. Kamio, Robins, Kelley, Swainson and Fein (2007) asked participants to complete a lexical decision task and reported that although both TD and ASD participants identified whether a string of letters was a word or a non-word with similar speed and accuracy, the ASD participants did not show semantic priming. Semantic priming is when the presentation of a semantically related word prior to the presentation of a target word (that participants have to identify as a word or non-word) results in faster response times, in comparison to when an unrelated word is presented. For example if shown *dog-cat*, cat will be identified as a word more quickly than when it is preceded by an unrelated prime (e.g., *dig-cat*). Semantic priming is thought to be a result of an automatic spread of activation amongst related words in the mental lexicon. The lack of semantic priming in ASD was suggested by Kamio et al. (2007) to be indicative of a delay in automatic access to semantic information. The authors note that the prime exposure time they used (250ms) may not have been sufficient for their sample of children and adolescents (aged 9-21 years) with ASD to identify primes. Therefore, it may be that this finding reflects a time-course difference in the access to semantic meaning. Note however that this finding appears to be somewhat of an irregularity within the literature, with semantic priming in ASD being consistently reported to be comparable to that observed in TD readers when alternative paradigms are adopted, such as when participants are required to read words aloud (Hala, Pexman, & Glenwright, 2007; López & Leekam, 2003) or complete a fragmented word (Kamio & Toichi, 2000; Toichi & Kamio, 2001). What this suggests is that although Kamio et al. (2007) found evidence of a delay in automatic access to semantic information in ASD, this is not consistently reported within the literature.

1.4.2.1 Summary

A considerable amount of work has been completed to examine visual word identification in ASD. A high proportion of the studies discussed above suggest that in general, ASD participants can accurately decode and identify the meaning of words, comparably to that of age-matched controls. However, there are findings to suggest that word learning over time may be constrained by comprehension and inferencing skill. In addition, there are groups of children with ASD whose phonological and word identification skill is poorer than TD controls, but this is likely a result of either quantitative (but not qualitative) delays in language development, or additional language impairments that are similar to those found in children with SLI. Critically, these differences do not appear to be specifically related to ASD.

1.4.3 Syntactic Processing in Autism Spectrum Disorder

Syntactic processing during reading in ASD is an area of research that has received little attention. Lucas and Norbury (2014) had TD, ALN and ALI children read syntactically scrambled sentences (e.g., *The my laces I on tied shoe*) and syntactically legal sentences (e.g., *I tied the laces on my shoe*) aloud. There was no difference in the facilitation effect of reading legal sentences for reading times, for ALN and TD participants (time to read a scrambled sentence minus the time to read a legal sentence). In contrast, the ALI group had a smaller facilitation effect. This implies that parsing of sentences occurs at a similar speed for ALN and TD groups, but that syntactic parsing is more effortful overall for children with ALI.

Stockbridge, Happé and White (2014) asked adolescents and children with ASD to identify the indirect object (i.e., *Becky*) of dative sentences either in double object (e.g., *Danny kicked Becky the ball*), prepositional object (e.g., *Danny kicked the ball to Becky*) and passive (e.g., *Becky was kicked the ball by Danny*) sentence constructions. ASD participants were as accurate as TD participants and showed the same pattern of effects, whereby responses to prepositional object constructions were more accurate than double object constructions, as the indirect object is explicitly marked. Both participant groups performed poorly for passive sentence constructions. In general, this finding suggests that individuals with ASD comprehend and are as attentive to changes in sentence structure as TD peers. This is therefore consistent with Lucas and Norbury's (2014) conclusion that syntactic processing is intact in ASD.

Koolen et al. (2012) tested adults with ASD in an error detection task. Participants were presented with sentences using the serial viewing paradigm (one word at a time) and had to press a button if they detected an orthographic error (letter substitutions e.g., *the dog berks/barks*) or a syntactic error (the plurality of a verb subject e.g., *she takes the broom and sweep/s the floor*). Participants either completed this task at the single level, where they had to detect a single type of error (orthographic or syntactic), or at the dual level, where they had to detect both orthographic and syntactic errors. The ASD and TD participants did not differ in their accuracy of detection for either orthographic or syntactic errors during both the single and dual detection tasks. The reaction time data (detection speed) also did not differ between ASD and TD participants during the single task. During the dual task ASD participants were slower to respond to both error types, in comparison to TD readers. Koolen et al. (2012) interpreted the lack of difference in accuracy as evidence that lexical and syntactic error detection is intact in ASD, however that the ASD participants performance was more disrupted than the TD participants, when task demands increased. Therefore, this data is suggestive that at a basic level, error detection for these aspects of linguistic processing are comparable between TD and ASD readers', but when both lexical and syntactic information has to be monitored for errors within the same task, syntactic processing may become less efficient (slower), in ASD.

Koolen, Vissers, Egger and Verhoeven (2014) later replicated this study, but also recorded event related potentials (ERPs) to allow for insight into the nature of on-line processing differences in ASD that could account for reaction time differences in their 2012 experiment. When TD and ASD participants' encountered orthographic errors in single and dual task conditions, both elicited a P600 response. This is a positive waveform occurring approximately 600ms after word onset and this response has previously been associated with error detection. For the syntactic errors, TD readers elicited a reliable P600 response during the dual task, but this was reduced during the single task. In contrast, the ASD participants showed significantly larger P600 amplitudes when detecting syntactic errors in comparison to TD participants, for both task types. What this was interpreted to suggest, was that in order to detect syntactic errors, readers with ASD have to monitor information more intently than TD readers. The authors concluded, upon the basis of both of these experiments, that it is attentional modulation, as opposed to linguistic processing that results in the increased amplitude of P600 responses for syntactic errors in ASD readers. Koolen et al.'s work suggests that as task complexity increases (i.e., the detection of both lexical and syntactic errors), syntactic processing becomes less efficient in ASD. Normal reading requires both lexical and syntactic processing and the monitoring of this information to co-occur. Therefore, this work suggests overall that under normal reading conditions, syntactic processing may be less efficient in ASD.

1.4.3.1 Summary

The studies described above have focused upon the ability of readers with ASD to complete relatively artificial reading tasks and detect syntactic errors or identify words upon the basis of the structural relations within a sentence. Consistent with what was found for lexical tasks, individuals with ALI appear to have more difficulty with syntax, in comparison to individuals with ALN, who do not differ from controls. This finding highlights the importance of accounting for individual language status when considering the effect ASD may have upon syntactic processing. It would also seem that at a basic level, readers with ASD are as accurate as TD readers in the completion of tasks requiring syntactic processing. However, it would also appear that task demands or cognitive load might impede the efficiency of processing speed in relation to syntax, in ASD. What is lacking from the literature and remains to be examined, is whether under normal reading conditions, individuals with ASD parse sentences similarly to TD readers.

1.4.4 Semantic and Discourse Processing in Autism Spectrum Disorder

1.4.4.1 Reading Comprehension

When individuals are required to understand the meaning of text, differences are often found between ASD and TD readers (e.g., Åsberg, Dahlgren & Sandberg, 2008; Brown, Oram-Cardy, & Johnson, 2013; Huemer & Mann, 2010; Jones et al., 2009; Nation et al., 2006; Ricketts, Jones, Happé, & Charman, 2013). Kanner's early report of the condition even highlighted this as an atypical aspect of cognitive processing; "*the children read monotonously, and a story ... is experienced in unrelated portions rather than its coherent totality*''(1943, reprinted in Kanner, 1973, p. 42). In extreme cases, children with ASD are labelled 'Hyperlexic'. Hyperlexia is a rare case when word identification skills are more advanced than would be predicted by an individual's age, coupled with extremely poor reading comprehension (O'Connor & Hermelin, 1994; Silberberg & Silberberg, 1967). Hyperlexia has been found in individuals with a range of intelligence, developmental disorders, and subsides with age (Grigorenko, Klin & Volkmar, 2003; Newman et al. 2007), but is most commonly identified in children with ASD (Burd, Kerbeshian, & Fisher, 1985; Grigorenko, Klin, Pauls, Senft, Hooper & Volkmar, 2002; O'Connor & Hermelin, 1994; Whitehouse & Harris, 1984). What this suggests, is that ASD may be associated with dissociation between basic (e.g., lexical) and higher-level text reading ability (e.g., semantic and discourse).

Poor comprehension is also commonly reported in the ASD population more generally. Nation et al. (2006) examined the reading skill of 41 children with ASD aged between 6-16 years with variable reading and non-verbal abilities, and found a consistent pattern of lower comprehension scores relative to their word reading accuracy. More specifically, 65% of their sample of children with ASD had comprehension scores at least one standard deviation below that of predicted scores based on age. Similarly to what is reported for TD children, weaknesses in oral language skill and word recognition were associated with reduced comprehension.

Similarly, Jones et al. (2009) found reading comprehension to be the most common area of academic attainment whereby adolescents' with ASD had difficulties. In total, 38% of their sample had comprehension scores below what would be predicted based on word reading skill and IQ. Jones et al. (2009) did not measure oral langauge skill, but found the severity of an individuals social and communication difficiulties (as measured by the Autism Disagnostic Observation Scale; ADOS, Lord et al., 2012) to be negatively associated with comprehension skill. Therefore it would seem that in addition to normative factors that impact upon comprehension (e.g., oral language), social and communication skills in ASD are associated with reading comprehension difficulties.

Huemer and Mann (2010) identified the same general pattern of intact word reading, coupled with poorer comprehension than would be predicted by age in a sample of 384 children and adolescents with ASD. In contrast to the studies reported above, Huemer and Mann (2010), divided their sample into three groups according to diagnosis; autism, pervasive developmental disorder, and Asperger's Syndrome. The dissociation between comprehension and decoding was found to be more apparent in the autism and pervasive developmental disorder groups, in comparison to the Asperger's group who performed most comparably (although still more poorly) than TD controls. This finding may be a further indication that the severity of ASD symptomology is associated with the severity of comprehension difficulties. Alternatively, it is possible that this difference could be explained by group differences in oral language skill, given individuals with autism are more likely to have such difficulties compared to those with Asperger's Syndrome (Iwanga et al. 2000; Klin et al. 1995; Ozonoff et al. 1991, 2000), however, oral language skill was not measured as part of this study.

A further large scale study found 60% of the sample of 100 adolescents with ASD, with variable abilities (non-verbal IQ range 53-126), to have significantly lower comprehension in comparison to TD controls, however, 45% of the ASD sample also had decoding difficulties (Ricketts et al., 2013). Word recognition was found to be the strongest predictor of comprehension difficulties (64%), followed by oral language skill and social communication competence, which both accounted for small but significant amounts of variance (< 5%). Social and communication competence was measured using both the ADOS and a ToM task that required participants to understand the mental states of others. Both of these measures, when entered into the regression models separately accounted for similar variance. This is again further evidence for ASD symptomology contributes to reading comprehension difficulties.

Although it is clear from the studies above that ASD is associated with weakened comprehension, reduced comprehension in ASD is not universal. There are a noteworthy proportion of individuals with ASD in the above studies that perform at age appropriate levels. In addition, there are reports where researchers do not find any comprehension differences between TD and ASD readers. Åsberg et al. (2010) examined the comprehension (multiple choice task) and decoding skill of 20 girls aged between 8-17 years with ASD. The ASD readers did not differ from a control group in performance for either literacy measure. Despite the lack of group differences, Åsberg et al. (2010) still found oral language and severity of ASD symptomology to be predictive of reading comprehension accuracy.

Furthermore, when oral language dificulties are severe enough for a child with ASD to be identified as ALI, this has been reported to modulate the presence of comprehension difficulties in ASD. Children with ALI have been repeatedly reported to have significantly reduced comprehension (and often also decoding skills, see the section on lexical processing above), in comparison to TD controls and participants with ALN, who do not differ (Lucas & Norbury, 2014; Norbury & Nation, 2011; Lindgren et al., 2009; Snowling & Frith, 1986).

A meta-analyses that has examined the research investigating reading comprehension in ASD found general support for the conclusion that individuals with ASD often have comprehension skills lower than that of TD peers. Consistent with the pattern that has been reported above, these analyses also indicated that ASD does not necessarily result in comprehension difficulties, but increases the likelihood of such difficulties occurring. Semantic knowledge, decoding and oral language skills were found to be the strongest predictors of comprehension in ASD (Brown et al., 2013).

It would therefore appear that ASD is associated with weak comprehension. This however is not a direct relationship. The presence of comprehension difficulties in ASD appears to largely depend upon an individual's oral language proficiency, which is highly variable in the ASD population (Iwanga et al. 2000). Note that oral language skill is also predictive of comprehension in the TD population, and therefore this is not a finding unique to ASD. However, oral language skill cannot wholly explain the reduced comprehension reported for readers with ASD. ASD symptomology has also been reported to contribute to variation in comprehension and this therefore suggests that the cognitive differences associated with ASD may have an additional impact upon reading comprehension outcomes for these individuals.

1.4.4.2 Inferencing

Inferencing describes when a reader makes assumptions or conclusions about implicit events or links in text. For example, if reading *James checked on the picnic* *supplies. The beer was warm*, one would assume that the beer was part of the picnic supplies, even though this is not explicitly stated within the text. There are numerous reports of children, adolescents and adults with ASD performing less accurately than matched TD controls when asked comprehension questions about a story they have heard, that requires an inference to be made for full comprehension of the story (Bodner, Engelhardt, Minshew & Williams, 2015; Dennis, Lazenby & Lockyer, 2001; Jolliffe & Baron-Cohen, 2000; Minshew et al., 1995).

Norbury and Bishop (2002) highlighted the impact cognitive processing differences associated with ASD have upon inferential skill. Participants answered questions about a story they had been read which required either a text connecting or gap filling inference. Text connecting inferences require links to be made between sentences (e.g., *Michael got the drink out of his bag, the orange juice was very refreshing* – a participant should infer that orange juice co-refers to drink and that this is what Michael got out of his bag). Gap filling inferences require individuals to integrate additional information based upon their world knowledge into the discourse model (e.g., *the girl put on her swimsuit but it was too cold to paddle so she built sandcastles instead* – a participant should infer the girl was at the beach/seaside). Participants with ASD were found to be less accurate at answering questions that required both types of inference to be formed, in comparison to individuals with SLI, pragmatic language impairment and TD controls. In addition, ASD symptomology across the entire sample was associated with poorer inferencing accuracy and ASD accounted for significant and independent variance (approximately 10%) in accuracy scores. This study suggests that difficulties with inferencing in ASD may reflect ASD specific cognitive processing differences.

Similar findings have been reported during tasks whereby inferences are formed during silent reading. Jolliffe and Baron-Cohen (1999) asked three groups of adults, who were either diagnosed with ASD or Asperger's Syndrome, to read two sentences and then choose the missing (inferred) sentence out of three possible options (see example 1 below, correct answer in bold).

1. John left his bath running. John mopped up the mess in the bathroom.

John mopped up the mess in the bathroom because…

A. **The bath had overflowed.**

B. His brother had left it untidy.

C. The workman hadn't cleared up his mess.

Participants with ASD took longer to respond in comparison to the TD and Asperger's group and both the ASD and Asperger's participants were significantly less accurate in their answers, in comparison to the TD group. This is consistent with the findings from aural inferencing tasks and suggests that inferencing difficulties may be associated with the severity of ASD symptomology. Note however, Jolliffe and Baron-Cohen (1999) did not control for oral language skill, which may have also contributed to the group differences.

Norbury and Nation (2011) addressed this issue by identifying language subgroups within their sample of participants with ASD. The task involved participants reading a story, followed by comprehension questions that could be answered upon the basis of literal information provided within the text, or questions that required a reader to engage in inferential work to combine world knowledge with text information. There were no differences between the accuracy of answers provided by ALI, ALN or TD readers for literal questions. In contrast, the ALI group were significantly less accurate in their answers to inferential questions in comparison the ALN and TD participants, and in turn the ALN group were also less accurate than the TD group. Moreover, ASD status uniquely accounted for 11% of the variance associated with inferencing accuracy, following for the control of word reading and oral language (which accounted for 7 and 31% of the variance, respectively).

Similarly, Lucas and Norbury (2015) also found children with ALI to show reduced accuracy for comprehension questions that require inferential processing. However, ALN children did not differ significantly from TD controls, but there was a strong numerical trend to suggest that, similar to the ALI group (50%), a higher proportion of the ALN group (33.3%) had difficulty making inferences in comparison to TD controls (12.5%). Therefore, these studies suggest that the cognitive differences associated with ASD may impact upon the processes required to compute an inference, and the magnitude of this effect is mediated by oral language skill. However, in both Norbury and Nation (2011), and Lucas and Norbury's (2015) experiments participants were asked to respond to comprehension questions verbally. It is therefore possible that the ability to accurately produce a verbal response contributed to reductions in performance accuracy for both LI and ALI groups, as opposed to group differences being a specific consequence of variations of inferential skill.

Tirado and Saldaña (2016) had participants with ASD who were comprehensively matched to TD controls on a number of oral language measures, read passages that implied an emotion, followed by a statement explicitly stating an emotion that was either consistent or inconsistent with the implied emotion. This study aimed to examine whether readers with ASD compute inferences about a characters emotion during reading. Both TD and ASD participants had longer reading times for the statement when the emotion was inconsistent with the emotion that was implied by the text, in comparison to when this was consistent. This finding suggests that the ASD participants had inferred the character emotion based upon the passage context. However, when the distance between the sentence whereby the inference was formed, and the explicit statement, were separated by a filler sentence, only TD readers showed increased reading times for inconsistent statements. Therefore, this suggests that although initially computed, the inferred information may not be retained in the discourse model in ASD. In addition, Tirado and Saldaña (2015) found that although ASD readers appeared to compute inferences on-line, as indexed by reading times, when explicitly asked a comprehension question in relation to the inferred emotion, they fail to correctly identify the emotion. Moreover, when participants had to select the valence category of the emotion instead (positive or negative), ASD readers still performed less accurately. This finding again suggests that inferred information may not be stored or integrated into the discourse model as efficiently in ASD, in comparison to TD readers.

1.4.4.3 Summary

What is clear from the discussion of the literature so far, is that semantic and discourse processing is often atypical in ASD. Individuals with ASD are vulnerable to both comprehension and inferencing difficulties during reading. These differences in performance accuracy are partly a consequence of reduced oral language skill, a finding that is also observed for TD readers. In addition however, ASD specific factors appear to contribute to these processing differences, particularly in relation to inferencing. However, based on the experiments described above that have examined basic comprehension and inferencing skill, the nature of the ASD specific cognitive differences that impede comprehension and inferencing remain unclear. The following four subsections attempt to address this issue by reviewing the studies that have examined whether the Mentalizing Theory, Executive Dysfunction Theory, Weak Central Coherence Theory, or Theory of Complex Information Processing are able to explain why comprehension and inferencing accuracy are often found to be reduced for readers with ASD, relative to TD readers.

1.4.5 Mentalizing Theory: Theory of Mind Processing during Reading in Autism Spectrum Disorder

The Mentalizing Theory cannot holistically explain language processing differences in ASD, because mentalizing processes are not considered to be essential for general text comprehension (e.g., Kintsch, 1988, Gernsbacher, 1991; Zwaan, Langston, & Graesser, 1995). However, ToM can make predictions about specific aspects of reading, such as the comprehension of non-literal or non-explicit language whereby the understanding an author's or character's intentions are often necessary (e.g., metaphor, sarcasm, jokes and making inferences about a characters mental state). The Mentalizing Theory would predict that readers with ASD adopt the literal interpretation of non-literal text, as a result of difficulties processing a mental state that is in contrast to their own. Therefore, the cognitive processes that the Mentalizing Theory predicts to be compromised in ASD have the potential to impede reading comprehension, when such processes are required. The studies that have directly examined this hypothesis using reading tasks are outlined below.

Happé (1995) examined the effect of mentalizing on the comprehension of metaphorical expressions by asking participants with and without ASD to choose a phrase to complete sentences from a choice of four possible options. The correct answer was a simile (a comparison used to increase descriptive content e.g., it was like…), metaphor (a symbolic non-literal description) or appropriate control synonym (e.g., see example 3 below where the options are underlined and the correct answer is in bold).

3. The heating had been left on overnight and the room was very warm.

It was like…

A. **an oven**

B. a blanket

C. a grill

D. a spice.

Participants with ASD made more errors when selecting the correct phrase in comparison to TD controls, and Happé (1995) concluded that this was a result of the ASD participants having a reduced ability to engage in mentalizing cognitive skills necessary for understanding the authors' communicative intentions.

Norbury (2005a) replicated this experiment, but separated her sample of children with ASD into ALI and ALN groups. Norbury (2005a) found language status to modulate performance accuracy in ASD, with no differences in performance found between TD and ALN groups, but ALI participants made significantly more errors, in comparison to TD controls (similarly to what Happé, 1995 reported for her entire ASD sample). When regression analyses were carried out, ToM skill was not found to be predictive of accuracy scores. Similarly, in a task where children were asked to explain the non-literal meaning of idioms, Norbury (2004) found those with ASD to have lower accuracy than age matched controls, but that this difference was modulated by oral language skill. Oral language skill was also found to be the strongest predictor of idiom understanding, and ToM skill did not account for a significant amount of variance in idiom comprehension accuracy. Together, what these two studies suggest is that although there are individuals with ASD who have difficulty understanding figurative language, this is not necessarily a result of difficulties engaging in mentalizing processes.

1.4.5.1 Summary

Based upon the studies outlined above, it would appear that the evidence for mentalizing processing being reduced or impaired during reading in ASD is weak. It would seem that difficulties comprehending text that require such processes (e.g., figurative language) is a consequence of reduced oral language skill, as apposed to cognitive processing difficulties specifically associated with ASD. This conclusion is consistent with a recent meta-analysis of figurative language comprehension (aural and reading comprehension, Kalandadze, Norbury, Naerland, Naess, 2016). Moreover, given that mentalizing processing is not a fundamental requirement or aspect of reading, but is necessary only for very specific types of text, the Mentalizing Theory cannot provide a sufficient explanation as to the cognitive processes associated with ASD that may contribute to performance differences for comprehension and inferencing of texts that do not require mentalizing processing.

1.4.6 Executive Dysfunction: Monitoring during Reading in Autism Spectrum Disorder

An executive function that is considered necessary during reading, is the monitoring of text comprehension (e.g., Perfetti, Landi, & Oakhill, 2005). Text monitoring refers to the use of information held in memory to incrementally track performance, coherence and comprehension. Therefore, the Executive Dysfunction Theory would predict monitoring to be less efficient or absent in ASD readers, which, if shown to be the case, could impact upon the ability to identify gaps in coherence and general text comprehension. What this hypothesis suggests is that difficulties that may arise during reading are a consequence of poor comprehension monitoring and do not result from linguistic processing impairments in ASD.

Norbury and Nation (2011) examined this hypothesis by asking a sample of adolescents with ALI and ALN to read a passage of text that contained orthographic, grammatical and contextual errors. Participants were asked to circle any errors in the text that they detected. Participants with ALI performed more poorly (missed more errors) than both the ALN and TD groups who did not differ from each other. This finding suggests that ASD does not specifically result in reduced monitoring of text coherence, orthographic or grammatical information, but, that individuals with reduced oral language proficiency may have increased difficulty in monitoring text information.

Recall from the syntactic processing section above that Koolen et al. (2012; 2014) found evidence of poor monitoring of syntactic information in ASD when lexical information had to be monitored simultaneously. Koolen, Vissers, Egger and Verhoeven (2013) adopted a similar paradigm to examine the monitoring of lexical and semantic information during reading in ASD. Participants read sentences that included either orthographic errors in the form of spelling mistakes, or semantic errors as a result of thematic relations that conflicted with world knowledge (e.g., the photographer who posed for the model worked for the magazine). As with Koolen et al.'s (2012, 2014) previous experiments discussed in the section on syntactic processing, EEG recordings were taken and therefore the sentences were presented one word at a time. Participants were either told to read normally, without any specific instructions (free reading condition), or were instructed to focus on and detect orthographic or semantic errors (instructed condition). A normal P600 component was detected for both TD and ASD readers when detecting orthographic errors for both instruction conditions, and when detecting semantic errors in the instructed condition. For the semantic error free reading condition, a normal P600 effect was also detected for TD participants; however, no such effect was detected for ASD participants. Therefore this study suggests that there are differences in the efficiency with which ASD readers process and detect semantic implausibilities. However, this difference in itself is not evidence of an inherent monitoring atypicality in ASD, as this effect disappears when participants are instructed to detect errors. Therefore this finding was interpreted to suggest that ASD participants do not spontaneously monitor semantic coherence.

More recently, Caruana and Brock (2014) examined the on-line monitoring of comprehension using a more naturalistic paradigm whereby students silently read text, as their eye movements were monitored. Students did not have formal diagnoses of ASD but had various levels of self-reported ASD traits, as measured using the Autism Quotient questionnaire (AQ, Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001). Caruana and Brock (2014) aimed to examine whether there is an association between ASD symptomology and monitoring during reading using a TD sample. Participants read sentences that contained an ambiguous word (e.g., *crane* in example 4a below).

4a. The crane was slowly flying over the lake.

4b. The bird was slowly flying over the lake.

Each ambiguous word was preceded by a determiner and was not contextually constrained. Therefore, participants were expected to lexically identify the dominant version of the ambiguous word (e.g., *crane – machine*). However, this word was disambiguated to be the subordinate meaning (e.g., *crane – bird*) later in the sentence, by the verb *flying*. This disambiguation was predicted to result in increased fixation times upon the verb for the sentence contained an ambiguous word (e.g., 4a), in comparison to when this was replaced with a control synonym (e.g., *bird* in example 4b above). This was predicted to reflect participants detecting the inconsistency between what they had initially identified the word to mean, in comparison to what the word was intended to mean, based upon text context. Therefore, any increase in fixation time was thought to be is indicative of text monitoring. If readers with high levels of ASD traits have a reduction in monitoring behaviour, the effect of inconsistency (detection) on fixation times for the verb were predicted to be reduced. However, no effect of ambiguity was found. Moreover, when the effect of ambiguity was examined separately for heterophonic and homophonic words, an effect of AQ score was apparent for homophonic words only, however this effect was in the opposite direction to what was predicted, with readers with higher levels of ASD traits showing larger effects of ambiguity. This finding therefore suggests that counter to the monitoring hypothesis, ASD traits may actually result in more sensitive comprehension monitoring.

The last study to be presented in this section aimed to examine whether using prompts to aid monitoring of different kinds of information would improve the reading comprehension of adolescents diagnosed with ASD (O'Connor & Klein, 2004). Participants took part in one of four different kinds of passage comprehension task; one referred to as the 'cloze' task where words were replaced with blank spaces and participants had to identify from the prior text, what word should be included. In the second 'anaphoric cueing' version of the task each pronoun was underlined and participants had to chose from an option of three referents, which one they thought was correct. The third version of the task involved 'pre-reading' whereby participants were asked five questions prior to passage reading and this was aimed to activate relevant knowledge, in relation to the text. Finally, a control version of the task simply involved participants reading the passage without any alterations, and answering comprehension questions. The only manipulation that was found to improve participant's comprehension of the text, in comparison to the control condition, was the anaphoric cueing task. The authors concluded that the cueing task induced self-monitoring behaviour. However, it would seem that prompting monitoring in general was not facilitative (e.g., the cloze task), but that spontaneous or automatic monitoring specifically in relation to the integration of information across sentences in order to compute anaphoric links, was facilitative.

1.4.6.1 Summary

The evidence in relation to the Executive Dysfunction Theories prediction that the monitoring of text information is atypical in ASD is varied. Some studies find no evidence for differences in monitoring behaviour in ASD and those studies that do report differences in monitoring, do not find this for all types of linguistic information. It would therefore seem reasonable to conclude that a universal difficulty in the monitoring of text information during reading is not an appropriate explanation for the comprehension and inferential difficulties that have been found in ASD. However, there may be subtle differences in the efficiency or automaticity of text monitoring in ASD for particular types of information and during particular types of tasks e.g., error detection tasks.

1.4.7 Weak Central Coherence: Integration during Reading in Autism Spectrum Disorder

In relation to linguistic processing, the Weak Central Coherence Theory predicts that the integration required to reach global coherence of a text does not spontaneously occur in ASD. Happé (1999) has stated that for ASD readers the Weak Central Coherence Theory would predict text to be read on a word-by-word basis, with little attempt to integrate information within and between sentences. Upon the basis of this prediction, it can be inferred that single words are the local unit prioritised for processing during reading in ASD. In other words, the Weak Central Coherence Theory would predict the integration of information required to reach global coherence of a text does not automatically occur in ASD. This would have an impact upon an individual's ability to comprehend the meaning of connected text and is the most commonly used explanation within the literature, as to why readers with ASD are often found to have reduced comprehension accuracy. Recall that the integration of information (connecting processes) is identified as a fundamental aspect of language processing, necessary for proficient reading comprehension in TD individuals (Kintsch, 1988, 1998; Kintsch & van Dijk, 1978; Gernsbacher, 1990, 1991; Zwaan, et al., 1995).

Participants with ASD have been found to perform less accurately than TD readers at abstract reading tasks that have been designed to assess contextual and integrative processing. For example, ASD participants have been found to perform less accurately when putting sentences in order to create a coherent story based on context, when temporal cues are omitted (Jolliffe & Baron-Cohen, 2000). In addition, Minshew et al. (1995) found adolsecents with ASD to perform less accurately than IQ matched TD controls at identifing a missing word from a passage, during silent reading. However, the most well known paradigm that is thought to demonstrate reduced integration of information during reading in ASD is the Homograph Task.

Homographs are ambiguous words with one spelling but two pronunciations and meanings (e.g., lead-guide/lead-metal), which are disambiguated by sentence context. Readers with ASD have repeatedly been found to be poor at modulating their identification and pronunciation of homographs, on the basis of sentence context. Frith and Snowling (1983) were the first to report this effect. In their original experiment, participants read sentences aloud. Each sentence was designed to contextually cue either a homographs dominant (see example 5a below, tear = cry), or subordinate meaning (see example 5b below, tear = rip).

5a. Sarah's eye had a big tear in it

5b. Sarah's dress had a big tear in it.

TD participants pronounced the homographs correctly in each condition (dominant vs. subordinate), whereas the participants with ASD made a higher proportion of errors, often pronouncing the dominant meaning of the homographs, regardless of sentence context.

This was interpreted to suggest that the participants with ASD were not processing sentence context sufficiently to disambiguate the homograph.

Snowling and Frith (1986) later repeated this experiment, but also manipulated homograph position within the sentence. This resulted in 4 types of sentence; dominant context prior (to homograph) (6a), dominant context after (6b), subordinate context prior (6c) and subordinate context after (6d).

6a. Molly was very happy, but in Lilian's eye there was a big tear**.**

6b. There was a big tear in her eye.

6c. The girls were climbing over the hedge. Mary's dress remained spotless, but in Lucy's dress there was a big tear.

6d. There was a big tear in her dress.

Snowling and Frith (1986) found that the ability to use context in order to disambiguate the homograph was modulated by verbal IQ, with only ASD participants who had a low verbal skill performing less accurately than controls. The ASD participants with age appropriate verbal skill performed equally to controls. This suggests that the lack of ability to use context in order to modulate homograph pronunciation was not necessarily a result of ASD *per se*. However, these findings were based upon a very small sample (n = 8). This experiment has been replicated multiple times, and in each of these replications, readers with ASD have been reported to have difficulty disambiguating homographs on the basis of sentential context, even when TD and ASD groups are matched for verbal IQ (Happé, 1997; Jolliffe & Baron-Cohen, 1999; López & Leekam, 2003). These findings have been used as evidence to support the suggestion that individuals with ASD read on a word-by-word basis, making no attempt to integrate information within and between sentences (Happé, 1999).

More recently, the theoretical implications drawn from the homograph studies have been questioned on the basis of methodological flaws (Brock & Caruana, 2014). These include a lack of appropriate counterbalancing, omission of filler sentences and only initial pronunciations being recorded. To examine the impact of these factors upon performance, Brock and Bzishvili (2013) had TD participants complete the homograph task as their eye movements were monitored. Performance (pronunciation) accuracy for these TD participants was highly predicted by previous trial interference (particularly when the subordinate version had previously been read) and the ability to adapt reading strategy by lengthening the eye to voice span in order to reduce errors. Individuals with ASD often have difficulties with task switching (e.g., the Wisconsin Card Sorting Task e.g., Rumsey & Hamburger, 1988) and it could therefore be that the ASD participants who have taken part in the homograph task, have experienced increased disruption as a result of previous trial interference when switching from one pronunciation of a homograph to the alternative. It is also possible that the ASD readers were less efficient at adapting their reading strategy to reduce the chance of making an error. Therefore, Brock and Bzishvili's (2013) experiment challenges the assumption that poor performance on the homograph task is a result of poor contextual processing and integration.

Furthermore, contradictory findings of intact contextual processing in ASD have been reported when alternative paradigms are used. For example, in a priming paradigm, participants had to read primes and target words aloud that were semantically related, unrelated, or homographs that were preceded by a prime of either the dominant or subordinate meaning (Hala et al., 2007). ASD participants were found to display stronger semantic priming overall and not to differ to the TD group in their ability to disambiguate dominant/subordinate homograph meaning upon first presentation. Upon second presentation of a homograph, the ASD group made significantly more errors, often having difficulties switching from their original pronunciation. This suggests that the ASD readers had difficulty inhibiting the previously identified version of the word, and is consistent with what may be predicted by Executive Dysfunction Theory. In addition, this is further evidence that the methods used in a number of the homograph tasks, whereby participants identified the same homograph multiple times (embedded in different sentence frames), within one testing session, is inappropriate when working with participants with ASD (Brock & Bzishvili, 2013; Brock & Caruana, 2014). Moreover, similar findings of context sensitivity in ASD have also been reported for picture naming/aural priming tasks (e.g., Hahn, Snedeker & Rabagliati, 2016; Henderson, Clarke & Williams, 2011).

A more recent study has attempted to examine on-line contextual processing during reading in ASD. Caruana and Brock (2014) examined the effect of word predictability on the eye movements of individuals with subclinical levels of self-reported autistic traits. Sentence context can facilitate word identification speed, with words that are highly predicted by the previous sentence context are identified more quickly and consequently fixated for shorter periods of time, than unpredictable words (e.g., Ehrlich & Rayner, 1981). Caruana and Brock (2014) found individuals with high levels of self reported ASD traits to have longer fixation durations on average, however, there was no difference in the word predictability and in turn processing of sentential context, in participants with high levels of self reported autistic traits in comparison to those with low levels.

Furthermore, the presence of oral language difficulties have been found to mediate the sensitivity to contextual information in ASD groups when visual/aural language tasks are adopted, such as picture/sentence matching (Norbury, 2005b) and visual world paradigms (Brock, Norbury, Einav & Nation, 2008). ALN participants perform comparably to TD participants, whereas ALI groups show reduced performance accuracy and reaction times In addition, preliminary findings suggest that Hebrew speakers with ASD are as accurate and efficient in the use of context to disambiguate homographs during sentence reading, in comparison to TD controls (Sukenik, Friedmann, & Brock, 2014). However, high variability on an individual basis was found for accuracy and this was accounted for by oral language skill (Sukenik et al., 2014). What these studies indicate is that participants with ASD do not read on a word-by-word basis, as predicted by the Weak Central Coherence Theory, but process sentential context on-line. Therefore, this is additional support to suggest that oral language skill determines the efficiency with which sentence context is utilised, as apposed to ASD *per se*.

Similarly, oral language skill has been found to modulate whether reduced performance is found in ASD for reading tasks that require integrative processing beyond the single sentence. In one of the earliest studies to examine reading in ASD (Snowling & Frith, 1986), participants read a story and had to select a word out of a choice of three to fill in a gap. The three options were either story appropriate, sentence appropriate or inappropriate (at both the story and sentence level). For example *The mother/friends/room led the beaver to the pond* (based on story context, mother was the correct answer). This manipulation aimed to examine whether ASD readers processed text at a sentence and/or story level. Individuals with ASD with age appropriate verbal ability did not differ from TD participants, who chose story appropriate answers. Individuals with ASD with low verbal ability however were less accurate at selecting story appropriate answers in comparison to controls. In addition, Snowling and Frith (1986) asked these participants to read a story about a hedgehog and circle any words that were anomalous, as they read. For example *The hedgehog could smell the scent of the electric (replacing spring) flowers.* Children with low verbal ability performed below chance and had a high false alarm rate, often circling words that were plausible. In contrast children with ASD and age appropriate verbal ability did not differ from TD controls. Therefore, these findings suggest that children with ASD and age appropriate verbal skill process the global context of text, which is suggestive of intact integration.

Norbury and Nation (2011) partially replicated this task, but separated their ASD participants into an ALI and ALN groups. Participants had to select a word to fill in a gap that was globally (passage) coherent, locally coherent (sentence) or implausible. Similarly to what Snowling and Frith (1986) reported, ALI children selected globally (story) coherent words less often than TD and ALN adolescents, who did not differ from one another. This finding again supports the suggestion that verbal language proficiency, as apposed to ASD, often results in wider text integration difficulties. Lucas and Norbury (2014) examined the effect of structural language skill in ASD further by having ALI and ALN children read sentences that contained a semantically anomalous final word (e.g., *I tied the laces on my wolf*). Reading times for this final word were found to be significantly longer for all participant groups when the word was anomalous, in comparison to plausible. Therefore in contrast to Snowling and Frith (1986) and Norbury and Nation's (2011) finding, children with ALI were similarly sensitive to sentence context, in comparison to TD and ALN groups.

Further supporting evidence that the on-line processing of context during reading is intact in ASD comes from Au-Yeung, Kaakinen, Liversedge and Benson's (2015) experiment, where TD and ASD adults read short (three sentence) passages that either contained an ironic, or a literal statement. Irony describes when a person makes a statement that is the opposite of what they mean, sometimes used for humorous effect or sometimes used to sarcastically mock another. TD readers have been shown to require increased processing time when reading ironic text, in comparison to literal text, as a result of having to access both the literal and non-literal meaning (e.g., Filik & Moxey, 2010). Therefore by monitoring the eye movements of adults with ASD as they read such texts, Au-Yeung et al. (2015) were able to examine whether ASD readers processed the text context in order to correctly access either the literal or non-literal, ironic interpretation of the text (note that this experiment could also be argued to examine mentalizing processes during reading). No differences were detected between the groups, with both ASD and TD readers requiring increased processing time when reading ironic statements, in comparison to the literal text. Therefore, this provides further evidence that individuals with ASD process text context on-line, similarly to TD readers.

1.4.7.1 Summary

A considerable amount of research has been conducted to examine the Weak Central Coherence Theories hypothesis that text integration difficulties may underpin reading comprehension and inferencing difficulties in ASD. This hypothesis is appealing given the fundamental importance of information integration during reading comprehension. However, based on the behavioural evidence above, there does not appear to be a general impairment in ASD related to contextual and integrative processing that could adequately explain the reading difficulties reported for individuals with ASD. It would seem that reduced performance for tasks that require integrative and contextual processing in ASD are related to oral language proficiency, as apposed to an ASD specific processing differences.

1.4.8 Theory of Complex Information Processing: World Knowledge use during Reading in Autism Spectrum Disorder

The Theory of Complex Information Processing predicts that the complexity of information determines processing efficiency and performance outcomes in ASD. When related to reading, the Theory of Complex Information Processing would predict performance outcomes for 'simple' language tasks that can be completed upon the basis of explicit, bottom up information (e.g., word identification, initial syntactic parsing) to be intact in ASD. In contrast, performance outcomes and processing efficiency is predicted to be reduced when the integration of information (as discussed above) and/or the use of higher order, world knowledge are required. Recall that both the integration of information (connecting processes) and the processing and incorporation of world knowledge information into the discourse model are both fundamental and core processes required for proficient reading comprehension (Kintsch, 1988, 1998; Kintsch & van Dijk, 1978; Gernsbacher, 1990, 1991; Zwaan, et al., 1995). Results from a battery of assessments that exclusively focused upon language abilities showed this pattern, with individuals with ASD having intact performance for low level language tasks such as letter and word identification, but poorer performance than TD participants for tasks requiring world knowledge and/or integrative processes e.g., comprehension questions requiring a participant to make an inference (Minshew et al., 1995). Note that both the Weak Central Coherence Theory and the Theory of Complex Information Processing predict integrative processing to be atypical during reading in ASD and the evidence in support of this was presented and discussed in the above section. Therefore in this section, the unique prediction that world knowledge processing is atypical in ASD during reading is examined.

Two experiments have directly examined the use of world knowledge during reading in ASD. Saldaña and Frith (2007) asked participants with and without ASD to read two sentence vignettes intended to produce an inference (e.g., in the examples below *the rocks hurt the cowboys*) that was followed by a general knowledge question either primed (e.g., 7a) or not primed (e.g., 7b) by the inference.

7a. The Indians pushed the rocks off the cliff onto the cowboys.

The cowboys were badly injured.

Can rocks be large?

7b. The Indians pushed the cowboys off the cliff onto the rocks.

The cowboys were badly injured.

Can rocks be large?

Comprehension questions primed by an inference tend to be read more quickly by TD groups, than questions that do not refer to an inference. Saldaña and Frith (2007) recorded the reaction time of participant's question reading time in an attempt to get an on-line measure of whether participants with ASD were making an appropriate inference. No group differences were detected, with both groups reading the question more quickly when it was primed by the inference, in comparison to when it was not. Saldaña and Frith (2007) concluded that this was evidence of intact on-line use of world knowledge in their ASD sample.

Wahlberg and Magliano (2004) asked participants with ASD to read ambiguous texts that either had or did not have an informative title, and were preceded with or without a primer paragraph. The titles and primer paragraphs cued relevant world knowledge that disambiguated the texts. Both TD and ASD participants showed a recall facilitation effect when either a title or primer preceded the passage. This suggested that the ASD readers activated and had access to world knowledge. However, when asked comprehension questions that required participants to draw upon this world knowledge, ASD readers were not as facilitated by the title or primer paragraph, as TD readers. Therefore, although world knowledge appeared to be processed by ASD readers, they did not appear to use or integrate this with the explicit text information, to aid interpretation of the text. This is in contrast to Saldaña and Frith's findings (2007).

One study that had the potential to tease apart any integrative vs. world knowledge processing during reading in ASD was conducted by Sansosti, Rawson and Remaklus (2013), who replicated Saldaña and Frith's (2007) experiment, but also recorded participants eye movements as they read the vignettes. Overall, readers with ASD were found to have longer reading times, longer fixations and to make more fixations whilst reading the vignettes. Unfortunately, Sansosti and colleagues (2013) only recorded and reported global eye movement measures (calculated across an entire trial), so it is difficult to determine the on-line processing difficulties that these differences in eye movements reflect. Sansosti et al. (2013) concluded that the differences for these global measures were consistent with the Weak Central Coherence Theory and likely a result of the ASD group having more difficulty than the TD group in the integration of world knowledge information into a mental representation of what the text conveys. However, longer reading times could also reflect world knowledge processing differences in ASD.

In comparison to the other theoretical explanations for reduced comprehension and inferencing in ASD, the prediction that the use of, or processing of, world knowledge is atypical in ASD has been less well researched. The Theory of Complex Information Processing predicts this to be less efficient in ASD, because of the requirement for higher-order, top-down work to be carried out. Based on the few studies that are discussed above, it is unclear whether there are differences with which world knowledge is used during reading in ASD. World knowledge processing is often necessary for both text comprehension and inferential processing. Therefore it would seem that any impairment in accessing or processing world knowledge during reading might be a possible contributor to the difficulties reported for off-line performance in these tasks.

1.4.8.1 Summary

The four cognitive theories of ASD discussed as part of this thesis have been developed to apply to all cognitive domains (e.g., memory, perception, attention etc.). As a consequence, the predictions each theory make in relation to reading are broad. There is no specific theoretical account as to how reading occurs in ASD, and currently, none of the theories presented can provide a sufficient explanation as to why comprehension and inferencing is atypical in ASD. The predictions these theories make in relation to reading in ASD are under specified when examining fine-grained mechanisms of linguistic processing, as is the intention in the current thesis. This lack of specification makes it difficult to draw precise predictions about how the domain general cognitive accounts of ASD may impact upon the on-line processing of written language. These theories will be considered and referred to throughout this thesis in relation to reading when appropriate. However, the main focus of this thesis is to develop more precise, mechanistic explanations of how linguistic processing may differ in ASD, based upon our understanding of how such processes occur during reading in a TD population. The four empirical chapters of this thesis will focus upon aspects of linguistic processing that are necessary for proficient reading comprehension (as per theories of reading comprehension e.g., Kintsch, 1988, 1998; Kintsch & van Dijk, 1978; Gernsbacher, 1990, 1991; Zwaan, et al., 1995), and are predicted to be atypical in an ASD population. Consequently, the empirical chapters will focus upon the Weak Central Coherence theory and the theory of Complex Information Processing. These theories predict integrative and/or world knowledge processing to be atypical in ASD, which are both specified as critical processes within general theories of discourse processing. The Mentalizing and Executive Dysfunction theories will not be explicitly examined, given these theories make predictions about cognitive processes that are not specified by these models of reading comprehension (e.g., perspective taking, monitoring). It would seem inappropriate to suggest that differences associated with such aspects of processing may underpin reading difficulties for individuals with ASD, given they are not considered necessary for proficient reading comprehension in a TD population.

1.5 Methodology

The studies outlined above have predominantly reported performance outcome measures, such as accuracy and reaction time. Whilst these studies are informative in relation to which tasks these groups may have difficulties with, research into reading in ASD is now at a point whereby off-line behavioural measures have limited usefulness in informing theory as to the specific aspects of linguistic processing that differ in ASD. In order to gain insight into why performance is often poor for higher order linguistic tasks in ASD, we must be able to examine the nature of moment-to-moment linguistic processing. An appropriate method that has yet to be exploited in the field of linguistic processing in ASD is eye tracking. As described in the first section of this review, eye movements are tightly associated with on-going cognitive processing. Furthermore, by measuring participant's eye movements as they read, it is possible to obtain detailed insight into linguistic functioning in individuals with ASD. This method provides more naturalistic data regarding the linguistic processes engaged in when comprehending text on-line, as it excludes the requirement for any additional processes (e.g., decision making) that are unnecessary during natural reading, but are required for a high proportion of the tasks adopted in the studies outlined above (e.g., inserting words into gaps in a sentence).

Each of the experiments I will conduct will adopt a standard eye movement and reading paradigm. This will involve participants reading text silently as their eye movements are monitored. Therefore, this paradigm is a laboratory imitation of how reading would occur naturally. There are three studies, outlined above, that have utilised eye tracking to examine reading in ASD (Au-Yeung et al., 2015; Caruana & Brock, 2014; Sansosti et al., 2013). Each of these studies have contributed to the literature regarding the nature of linguistic processing in ASD, but there are methodological issues with two of these experiments. Caruana and Brock (2014) used a student population with 'sub-clinical' levels of self-reported autistic traits. Although ASD is often referred to as a continuum throughout the general population, it is difficult to know how much we can generalise these findings to those diagnosed with ASD. Sansosti et al. (2013) did not analyse critical regions of the text participants read, but reported findings based on global measures that were calculated across the entire vignette. The use of global, but not local, measures leads to limited and coarse-grained conclusions as to the differences in linguistic processing in ASD. In the present research, numerous spatially and temporally defined eye movement measures will be analysed for both critical localised, and global, regions of text.

Adults (18+ years) with a formal diagnosis of ASD will be recruited to participate to avoid confounds and complications associated with individual differences in developmental trajectories found for children with ASD. Moreover, language differences between ALI and ALN groups are generally found to disappear through adolescence (e.g., Boucher, 2012) and therefore by recruiting adults, this should reduce the variation in oral language skill that may impact upon reading skill, in our sample. These adults will have both verbal and non-verbal IQ within the normal range and not differ to a control sample of TD adults in age or oral language ability. Thus any differences observed between the ASD and TD groups in the experiments in the thesis should reflect differences in cognitive processing specific to ASD.

1.6 Planned Empirical Research

ASD is a disorder that presents with cognitive processing differences that impact upon reading proficiency. ASD readers have generally been shown to have intact performance in tasks requiring lexical and syntactic processing, although the evidence for the latter is minimal to date. Differences are observed for tasks that require participants to engage in semantic and discourse processing, which result in impaired performance accuracy for comprehension and inferencing tasks. Reading is an important skill for an individual to master in order to succeed academically, to have good employment prospects and to be able to live independently. The aim of this thesis is to gain insight into ASD specific cognitive processing differences that impact upon reading. A series of four experiments that systematically investigate lexical, syntactic, semantic and discourse processes in ASD will be conducted, and eye movements will be recorded and analysed in order to address the following broad research questions;

(1) What is the time course of on-line lexical processing in ASD?

(2) What is the time course of on-line syntactic parsing in ASD?

(3) What is the time course and nature of on-line world knowledge processing in ASD?

(4) What is the time course and nature of on-line inferential processing in ASD?

To examine each of these questions, participants will read text that include (1) a word frequency manipulation, (2) an ambiguous prepositional phrase manipulation, (3) a plausibility manipulation, and (4) an antecedent typicality manipulation. These text manipulations were selected according to two criteria; (a) each manipulation must have been replicated in a TD population multiple times, and (b) the cognitive processes thought to underlie changes in eye movement behaviour caused by these manipulations must be uncontroversial within the literature. The application of this criteria was to assure specific predictions could be made about how lexical, syntactic, world knowledge, and inferential processing would occur on-line for TD participants, and in turn permit the development and testing of precise predictions about how such processing may differ for ASD participants.

Chapter 2: Lexical, Syntactic and Semantic Processing

Published: Howard, P. L., Liversedge, S. P., & Benson, V. (2017). Benchmark Eye Movement Effects During Natural Reading in Autism Spectrum Disorder. *Journal of Experimental Psychology: Learning, Memory & Cognition*, *43*(1), 109-127. DOI: 10.1037/xlm0000289

2.1 Introduction

Autism spectrum disorder (ASD) is characterised by restrictive and repetitive patterns of behaviour and significant impairments in social interaction/communication (American Psychiatric Association, 2013). The cognitive differences that underpin this behavioural phenotype are often found to affect reading ability (e.g. Nation, Clarke, Wright, & Williams, 2006). Individuals with ASD who do not have an associated learning difficulty or those who have Asperger syndrome, in general, are found to have intact performance accuracy for 'low level', basic reading tasks (e.g. word identification; Frith & Snowling, 1983; Huemer & Mann, 2010; Mayes & Calhoun, 2006; Minshew, Goldstein, & Siegel, 1995; Saldaña, Carreiras, & Frith, 2009), but frequently display impairments in performance for 'higher order' reading tasks (e.g. text comprehension and inferencing; Huemer & Mann, 2010; Jolliffe & Baron-Cohen, 1999, 2000; Jones et al. 2009; Minshew et al. 1995; but see also Åsberg, Kopp, Berg-Kelly, & Gillberg, 2010).

As yet, there has been no specific theoretical explanation put forward to explain how linguistic processing occurs in ASD. Previous hypotheses as to why performance on higher order linguistic tasks is impaired have been derived from domain general cognitive accounts of ASD. The Weak Central Coherence Theory (WCC) claims ASD to result in a local processing bias coupled with a lack of spontaneous strive for global coherence (Frith, 1989; Frith & Happé, 1994; Happé & Frith, 2006). In the context of reading this would suggest that individuals with ASD might not integrate information within and between sentences. Evidence for this lack of contextual/global processing during reading has most notably been demonstrated using the homograph task. The homograph task involves participants reading sentences aloud that contain a heterophonic homograph (i.e., a word with one spelling, but two meanings and pronunciations) and readers with ASD have been reported to identify and pronounce the dominant meaning of the homograph, regardless of sentence context (Frith & Snowling, 1983; Happé, 1997; Jolliffe & Baron-Cohen, 1999; López & Leekam, 2003 c.f., Snowling & Frith, 1986). However, the validity of these studies has been criticised (e.g., Brock & Bzishvili, 2013; Brock & Caruana, 2014) and when other paradigms are adopted the findings of impaired integration during reading tasks are inconsistent, with some researchers finding poorer performance for individuals with ASD (e.g., Jolliffe & Baron-Cohen, 1999; 2000), whereas others do not (e.g., Au-Yeung, Kaakinen, Liversedge & Benson, 2015; Hala, Pexman & Glenwright, 2007). The Theory of Complex Information Processing (CIP; Minshew & Goldstein, 1998; Minshew, Goldstein & Siegel, 1997; Minshew, Williams & McFadden, 2008) proposes low level 'simple' processes to be intact in ASD, but 'complex' processes that require the integration of information or the use of top down knowledge, to be impaired. The evidence in support of this theory in relation to reading stems from studies showing that adults and children with ASD perform comparably to matched controls on batteries of standardised reading assessments that are defined as 'simple' (i.e., tasks that are rule based and can be completed upon the basis of information explicitly stated in the text e.g., word identification and grammar). In contrast performance is poorer compared to controls at reading tasks that are defined as 'complex' (i.e., tasks that require processing beyond explicit text information e.g., inferencing and comprehension, Minshew et al., 1995; Minshew & Goldstein, 1998; Williams, Goldstein & Minshew, 2006).

The majority of research examining reading in ASD has focused on accuracy and reaction time measures of performance. Although these studies are informative in relation to offline reading performance, they provide little insight into specific aspects of on-line cognitive processing associated with reading impairments in ASD. In the present work, we recorded participants' eye movements as they read naturally, to gain an insight into the on-line linguistic processing of written language in ASD. A literature search indicated that only three peer-reviewed articles have adopted this approach when examining natural reading in ASD (Au-Yeung et al., 2015; Caruana & Brock, 2014; Sansosti, Was, Rawson, & Remaklus, 2013). This is the case, even though eye movement recording is one of the most widespread methods used to examine reading in a typical population (e.g. Rayner, 1998; 2009).

The first study that used eye movements to examine reading in ASD was conducted by Sansosti et al., (2013) who partially replicated an experiment originally conducted by Saldaña and Frith (2007), whereby a group of children and adolescents with ASD read vignettes consisting of two sentences, designed to evoke a bridging inference. Each vignette either evoked an inference that required social or spatial knowledge and was followed by a general knowledge question that was either related (e.g. 1a) or unrelated (e.g. 1b) to the evoked inference (e.g. for the examples below *the rocks hurt the cowboys*).

1a.

The Indians pushed the rocks off the cliff onto the cowboys.

The cowboys were badly injured

Can rocks be large?

1b.

The Indians pushed the cowboys off the cliff onto the rocks.

The cowboys were badly injured

Can rocks be large?

Sansosti et al. (2013) replicated Saldaña and Frith's (2007) main finding that both typically developed (TD) and ASD readers responded to questions related to an inference more quickly than questions that were unrelated to the inference. In addition, Sansosti et al. (2013) reported that whilst reading the vignettes, the ASD participants had longer average reading times, longer average fixation durations and made more fixations and regressions overall, in comparison to the TD group. This finding highlights the discrepancy between offline and on-line measures of reading. The lack of difference between the groups in response times to the general knowledge questions indicates that the ASD group made bridging inferences on-line. However, the eye movement data indicate that the on-line processing of the vignettes was significantly more effortful for ASD participants. Sansosti et al. (2013) interpreted their findings to be consistent with the WCC Theory and suggested that ASD readers access world knowledge on-line, but have difficulty in the integration of this knowledge into the discourse model. Although possible, this interpretation should be considered tentative, as it is based upon global eye movement measures that are averaged across the reading of the entire vignette. In order to make precise deductions about the exact processes that may differ during reading, both global and localised eye movement measures on critical, experimentally manipulated words and regions of a text are required. Therefore, although this experiment gives evidence for the processing of text to be less efficient in ASD readers, the time course of such differences were not fully explored. Consequently, the aspects of cognitive processing that underpin eye movement differences are unclear.

The second study that used eye tracking to gain an insight into linguistic processing in ASD examined two opposing hypotheses as to why ASD readers have previously been found to perform poorly at the homograph task (Caruana & Brock, 2014). The homograph task involves participants reading sentences aloud that contain a heterophonic homograph (i.e., a word with one spelling, but two meanings and pronunciations). Readers with ASD are often reported to identify and pronounce the dominant meaning of heterophonic homographs, regardless of sentence context (Happé, 1997; Jolliffe & Baron-Cohen, 1999; López & Leekam, 2003; Snowling & Frith, 1983). Firstly, Caruana and Brock (2014) examined the predominant conclusion drawn from these studies on the basis of the WCC Theory, that an impairment in contextual processing is present in ASD. To test this hypothesis, fixation times of students with various levels of self-reported ASD traits were measured (using the Autism Quotient [AQ]; Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001), on words that were highly predictable by sentence context (e.g. 2a, target word italicised) and words that were unpredictable (e.g. 2b).

2a. Crocodiles live in muddy *swamps* most of the time.

2b. The girl knows about the *swamps* in the bush.

For TD readers, a highly constrained context is found to facilitate lexical access, with predictable words being identified more quickly and fixated for less time, than unpredictable words (e.g. Ehrlich & Rayner, 1981). Caruana and Brock (2014) found students with both high and low AQ scores to show equivalent contextual facilitation, with shorter first fixation durations on the target words when the sentence context was highly constrained (e.g. 2a), in comparison to when it was not (e.g. 2b). This suggests that readers with high AQ scores or ‘subclinical levels of ASD’ process contextual information at the sentence level, similarly to those with low AQ scores. This contributes to the developing literature that suggests the contextual processing of language to be intact in ASD (e.g. Brock, Norbury, Einav, & Nation, 2008; Hahn, Snedeker & Rabagliati, 2015; Hala, et al., 2007; Henderson, Clarke, & Snowling, 2011; Norbury, 2005) and indicates that the previous reports of poor performance for ASD readers at the homograph task may not be a result of atypical contextual processing (see Brock & Caruana, 2014; Brock & Bzishvili, 2013 for a discussion about methodological issues that may have contributed to previous findings of poor performance in the homograph task).

Caruana and Brock (2014) also examined an alternative hypothesis, consistent with the Executive Dysfunction Theory, that poor performance on the homograph task may be a result of less efficient comprehension monitoring. In other words, that individual's with ASD do not track comprehension as efficiently as TD readers and therefore may not detect when their interpretation of a sentence is no longer coherent. To examine this hypothesis, participants read sentences that contained a homograph (e.g. *crane* in 3a below) that was preceded by a determiner and therefore not contextually constrained.

3a. The crane was slowly *flying* over the lake.

3b. The bird was slowly *flying* over the lake.

An offline cloze task indicated that for such sentences, participants identified the dominant meaning of the word (e.g. crane – machine), as apposed to the subordinate meaning (e.g. crane – bird). Following the homograph, the sentences contained a disambiguating verb that indicated the dominant meaning of the homograph was incorrect and in fact that the subordinate meaning of the homograph was intended. Typical readers were expected to fixate the disambiguating verb for longer periods when it was preceded by a homograph in comparison to a control synonym (e.g. 3b), as a result of the detection of an initial misidentification of the ambiguous word. This manipulation however did not result in any differences in fixation measures on the disambiguating verb, regardless of AQ score. An interaction was found however, between heterophonic homographs (two pronunciations) and AQ score, but not homophonic homographs (one pronunciation), with participants who had high AQ scores having longer gaze durations (the sum of fixations from when a word is first fixated until the reader leaves that word to either the left or right) on the target, in comparison to those with low AQ scores. This may suggest that participants with high levels of self-reported autistic traits detected the discrepancy for heterophonic homographs, but that those with low levels did not. This is in contrast to what was predicted, as it indicates that readers with higher AQ scores were more sensitive to alternations of sentence meaning and therefore were monitoring their comprehension more carefully. Note though, this finding only occurred for a small number of heterophonic homograph stimuli and should therefore be treated with caution. Therefore, Caruana and Brock (2014) did not find support for either hypothesis; contextual processing appeared to be comparable across participants and the findings in relation to comprehension monitoring were unclear. An additional more general observation noted by Caruana and Brock (2014) was that a high AQ score was associated with longer fixations for all sentence and condition types (although only reliable in the predictability experiment). Note that this is similar to what Sansosti et al. (2013) reported for their sample of clinically diagnosed participants. If it is accepted that findings from a typical population with high levels of self reported autistic traits can be generalised to individuals with a clinical diagnosis, these findings suggest that contextual processing and comprehension monitoring at the single sentence level are intact in ASD.

The third study was conducted by Au-Yeung et al. (2015), who had adult participants with and without ASD read passages of text that contained either a sincere or ironic statement. Previous work that has examined the processing of written irony in a typical population has found ironic statements to require longer processing time and in turn longer fixation times, in comparison to non-ironic statements (Filik & Moxey, 2010). It was predicted that if readers with ASD are less sensitive to contextual information, as is predicted by the WCC Theory, that the processing of ironic versus sincere utterances would not differ. Alternatively, it was also predicted upon the basis of the CIP Theory, that the comprehension of figurative language is more complex than the comprehension of literal language and therefore readers with ASD should show increased processing disruption when encountering ironic statements, as apposed to sincere statements. Surprisingly however, no differences in first pass reading times (the time from when a region of text was initially fixated until that region was left to the left or right) for ironic statements were found between TD and ASD groups, with both displaying longer times for ironic than sincere statements, replicating what has previously been found for a typical population. This suggests that the comprehension of irony was as effortful for TD and ASD readers and is in contrast to both the WCC and CIP Theory. The only group difference detected was that the ASD readers had longer total times (the total amount of time spent fixating a region) for the critical regions in comparison to the TD group. Note that no difference in first pass times were detected and that the increased time that was observed was found for both ironic and sincere texts. The increased total times appeared to be a result of the ASD participants re-reading the passages following initial processing. The authors concluded that this difference was either a result of the ASD readers requiring longer to develop a discourse representation of the text, or that they required longer to conclude that their interpretation of the text was reasonable.

What should be evident from the above studies is that although very few have examined on-line reading processes in ASD, those that have, focus upon aspects of semantic and discourse processing that are predicted to be impaired by cognitive theories of ASD (e.g. Frith & Happé, 1994; Minshew & Goldstein, 1998). However, only two of these studies assessed a clinically diagnosed sample (Au-Yeung et al., 2015; Sansosti et al., 2009) and only one of these demonstrated a difference in the initial extraction of information from the text (Sansosti et al., 2009). Unfortunately this was evident in global reading time measures, which makes the precise cause or timing of this effect difficult to determine. Therefore, the question remains as to how the presence of this developmental disorder impacts upon the on-line processing of written language.

The aim of the present work was to extend the emerging literature examining on-line linguistic processing in ASD and to identify whether differences in fundamental lexical, syntactic and semantic components of sentence processing are present in individuals with ASD during natural reading. In order to achieve this we adopted robust, benchmark linguistic manipulations from the eye movement and reading literature (Rayner, 1998; 2009).

2.2 Experiment 1. Lexical Processing in ASD

Lexical identification refers to the processes a reader engages in to identify a word. There are multiple computational models that specify the exact mechanisms involved in visual word recognition in a typical population and each differ regarding particular aspects of lexical processing (e.g. Coltheart, Rastle, Perry, Langdon & Ziegler, 2001; Grainger & Jacobs, 1996; Rumelhart & McClelland, 1982). For example, the Dual Route Cascaded Model (Coltheart et al., 2001) includes separate lexicons for phonological and orthographic information and the Multiple Read Out Model includes variable response criteria that can be altered dependent upon task requirements (Grainger & Jacobs, 1996). However, these models are similar at a more basic level, in that they propose words to be identified by a matching process between encoded orthographic information relative to a stored word representation in the mental lexicon (cf. Siedenberg & McClelland, 1986). Regardless of the precise mechanistic account underpinning lexical identification, in the current experiment, we were interested in whether the time course of such lexical processing is similar in ASD readers.

Performance accuracy for word identification tasks varies between individuals with ASD (e.g. Nation et al., 2006), however, for individuals without language impairment or learning difficulties, performance on word identification tasks is generally found to be intact. For example, children and adolescents with ASD have been found to use both phonological and orthographic decoding strategies when identifying words, be as accurate as TD peers in the reading of words aloud and have intact word comprehension (e.g. Huemer & Mann, 2010; Minshew et al., 1995; Saldaña, et al., 2009).

There are also reports however, of atypical lexical processing in ASD that may be suggestive of a difference in the timecourse of lexical identification. For example, Kamio, Robins, Kelley, Swainson and Fein (2007) found children, adolescents and young adults with ASD to respond as quickly and accurately as TD participants during a lexical decision task, but to lack facilitaion from closley related semantic primes. Note that this is in contrast to findings of normal semantic priming in ASD participants when other paradigms are adopted (e.g. Hala et al., 2007; López & Leekam, 2003; Kamio & Toichi, 2000; Toichi & Kamio, 2001), but this finding may be indicative of a slow in the access to word meaning. Further support for less efficient lexical processing comes from Sansosti et al. (2009) and Caruana and Brock's (2014) experiments that were previously discussed above and have reported participants with ASD to have longer average fixation durations in comparison to TD readers.

In this experiment, we aimed to directly examine the time course of on-line lexical identification in adults with ASD in order to identify whether the efficiency of such processing is comparable between ASD and TD readers. This is an important question to address, because if on-line lexical processing is less efficient, this may cascade forward impacting on later aspects of linguistic processing. Thus, prior to examining on-line higher order linguistic processing, it is necessary to have knowledge of the proficiency of on-line visual word identification.

We recorded the eye movements of TD and ASD participants as they read sentences that included words manipulated to be either high or low in frequency. Word frequency is one of the most reliable lexical characteristics that affect the speed of lexical identification. Word frequency is a measure of how often a word occurs in the written language. High frequency words (e.g. *people*) are identified more quickly than low frequency words (e.g. *zombie*) because they have been previously encountered more often. This difference in identification speed is reflected in fixation durations, with low frequency words being fixated for significantly longer than high frequency words (e.g. Inhoff & Rayner, 1986; Rayner & Duffy, 1986). Connectionist models posit that each time a word is identified, the baseline level of activity for that word increases and consequently, the more quickly a word reaches the activity threshold necessary for identification (e.g. Rumelhart & McClelland, 1982). Therefore, the frequency effect is thought to reflect a real difference in the time it takes to identify a stored word representation on the basis of visually encoded orthographic information. If lexical processing were less efficient in ASD, we would expect these readers to have longer fixations on target words and possibly even show an increased magnitude of the frequency effect, in comparison to the TD participants.

2.3 Method

2.3.1 Participants

A group of 19 adults with a formal diagnosis of ASD took part in the experiment, 18 of which had a diagnosis of Asperger's disorder and 1 with high functioning ASD (3 females, aged 18-52 years). Each ASD participant was administered module 4 of ADOS-2 (Lord et al., 2012) and all but four met the autism spectrum cut off criteria. When these participants were excluded the pattern of effects did not change and therefore all participants are included in all analyses reported below. The control group consisted of 18 TD adults (4 females, aged 20-52). Participants had normal or corrected to normal vision, were native English speakers and did not differ in age t (35) = 0.94, p = .354 (TD M = 28.33 years SD = 9.18, ASD M = 31.37 years SD = 10.45). The ASD group had a significantly higher number of self-reported autistic traits in comparison to the TD group, as measured by the AQ (Baron-Cohen, et al., 2001) t (32) = 9.24, p < .001 (TD M = 15.61 SD = 8.03, ASD M = 37.37 SD = 6.10), but did not differ in verbal IQ t (35) = 0.58, p = .621 (TD M = 116.50 SD = 11.07, ASD M = 118.32 SD = 11.06), performance IQ t (34) = 0.99, p =. 331 (TD M = 111.94 SD = 11.45, ASD M = 116.21 SD = 14.75) or full scale IQ t (35) = 0.87, p = .389 (TD M = 116.17 SD = 10.79, ASD M = 119.42 SD = 11.89), as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). In addition, the two groups did not differ in expressive language ability t (35) = 0.53, p = .599 (TD M = 88.00 SD = 5.87, ASD M = 86.95 SD = 6.22), as measured by raw scores on the sentence repetition subscale of the Clinical Evaluation of Language Fundamentals II (Semel, Wiig & Secord, 2003). General reading ability was assessed using raw scores from the York Assessment of Reading Comprehension (Snowling et al., 2010) and performance between groups did not differ for a single word reading task; t (33) = 0.51, p = .614 (TD M = 67.74 SD = 2.96, ASD M = 68.17 SD = 2.12) nor for a passage comprehension task; t (34) = 0.35, p = .727 (TD M = 9.19 SD = 1.77, ASD M = 8.97 SD = 2.03). Participants were paid for their time and either visited the University of Southampton to be tested, or were visited at their homes and completed the experiment in the psychology departments mobile research unit.

2.3.2 Materials

Thirty-four sentence pairs were developed to include a target word located at approximately the centre of each sentence that was either high (HF e.g. 4a below) or low frequency (LF e.g. 4b). In the examples below the slashes denote region of interest boundaries.

4a. |John walked to the large| office| yesterday morning.|

4b. |John walked to the large| cavern| yesterday morning.|

All target words were six letter nouns and significantly differed in frequency t (33) = 12.95, $p < .001$ (HF M = 151.43 SD = 3.04, LF M = 3.04 SD = 10.04), but not in the number of orthographic neighbours; t (33) = 0.45, p = .659 (HF M = 1.71 SD = 2.38, LF M = 1.44 SD = 2.67), mean bigram frequency; t (33) = 1.34, p = .190 (HF M = 3896.04 SD = 7614.47, LF M = 3419.44 SD = 1353.73), number of syllables; t (33) = 0.37, p = .768 (HF M = 1.85 SD = 0.56, LF M = 1.88 SD = 0.48) or number of morphemes; t (33) = 0.81, p = .422 (HF M = 1.21 SD = 0.41, LF M = 1.26 SD = 0.45), as obtained from the SUBTLEX database (Brysbaert & New, 2009). Target words were equally unpredictable t (33) = 1.66, p = .107 (HF M = .01 SD = .03, LF M = .00 SD = .00), as rated by 12 undergraduate students on a cloze task. In addition, sentences in each condition did not differ in plausibility t (33) = 1.65, p = .109 (HF M = 4.35 SD = 0.49, LF M = 4.15 SD = 0.56) as rated by 13 undergraduate students (who had not taken part in the cloze task) on a five point likert scale as to how likely it was that the events they describe would occur (1 = very unlikely, 3 = quite likely, 5 = very likely). The full set of the materials can be seen in Appendix B.

2.3.3 Procedure

Participants read sentences presented on a 19-inch LCD computer monitor (75 Hz) as their head position was stabilised using a forehead and chin rest. The right eye was monitored (viewing was binocular) using an Eyelink 1000 (SR Research) operating at a sampling rate of 1000 Hz. Before the experiment began, a calibration procedure was completed whereby participants fixated three dots on the screen that appeared sequentially on a horizontal line where the sentences were set to appear. Following calibration, a validation procedure was completed to assure fixations were within 0.5° of each point.

At the start of each trial, participants fixated a dot on the far left of the screen, where the first letter of each sentence was set to appear. If fixation was off-centre, participants were re-calibrated. If calibration was accurate, the experimenter triggered a sentence to appear. Sentences were presented one at a time and participants were instructed to read normally and to press a button on a controller once they had finished reading each sentence. Sentences were presented in random order. Following 50% of the sentences, participants were asked a simple comprehension question about what they had just read. Participants responded with a *Yes/No* answer using a button controller. Instructions as to which button corresponded to each answer were included beneath each question. In total, the eye-tracking task took approximately 25 minutes.

2.3.4 Design

A 2 X 2 design was employed, with sentence type as a within participants variable (Experiment 1: High vs. Low frequency; Experiment 2: High vs. Low attachment) and group (TD vs. ASD) as a between participants variable. The experimental sentences from Experiment 1 and Experiment 2 (44 sentence pairs manipulated to include an ambiguous prepositional phrase) were presented to participants within the same testing session. All experimental sentences were divided into four separate lists that each contained only one version of each sentence pair. In total each list consisted of 88 sentences; 34 that included a frequency manipulation (17 HF, 17 LF), 44 manipulated to include an ambiguous prepositional phrase (22 high attached, 22 low attached) and 10 practice sentences that were presented prior to experimental sentences. Each participant read one of the four sentence lists.

2.4 Experiment 1: Results

2.4.1 Data Preparation and Analyses

Fixations below 80ms and above 800ms were removed from analysis, resulting in a loss of less than 1% of the original fixation data. Trials when a participant blinked whilst fixating the target word and when the trial was disrupted in some way were also removed, resulting in a loss of 7.95% of data. In addition, data points that were more than 2.5 standard deviations away from the mean (computed individually for each participant per condition) were further excluded. This led to a loss of less than 3% of data from each fixation measure calculated. Comprehension accuracy was high for both groups (TD M = 0.94, SD = .07; ASD M = 0.97, SD = 0.04), which indicates that offline comprehension was not impaired.

For fixation measures, data was log transformed and confirmatory linear mixed effects models (Baayen, Davidson & Bates, 2008) were computed using the lme4 package (Bates, Maechler, Bolker & Walker, 2014) for R (R Core Team, 2015), with group (TD vs. ASD) and frequency (HF vs. LF) defined as fixed categorical factors. Contrasts to obtain main effects and the associated interaction were coded using the contr.sdif function from the MASS library (Venables & Ripley, 2002). The full random structure was included (Barr, Levy, Scheepers & Tily, 2013); with crossed random effects specified for both participants and items. At the participant level, random slopes were included for frequency. At the item level, random slopes were included for frequency, group and the associated interaction between these factors. This resulted in the following syntax; lme(depvar ~ group*frequency + (1 + frequency|participants) + (1 + group*frequency|items), data = data). Effects were identified as significant if $t > 2$.

For binary variables (skipping and regressions), logistic linear effects models were computed. For logistic models, when the full random structure was included (as specified for continuous measures), models would not converge. Models were systematically trimmed of parameters, beginning with the interaction in the random structure, until model convergence was achieved. This resulted in a random structure whereby random slopes were only included for frequency at the participant level, as depicted in the following syntax; glmer(depvar ~ group*frequency + (1 + frequency|participants) + (1 |items), data = data, family = binomial). Binary variables were identified as significant when $z > 2$.

2.4.2 Global Measures

To examine whether there were any basic sampling differences between the two groups, the mean fixation duration, mean fixation count and total sentence reading time was calculated across each trial. Model parameters and observed means for each of these measures are presented in Table 1.

No difference between groups was found for mean fixation duration, but an effect of frequency was found, with sentences that included a low frequency word receiving longer average fixation durations than those that included a high frequency word. No interaction between group and frequency was detected. For mean fixation count, a reliable difference between groups was found, with ASD readers making more fixations over the course of each trial, in comparison to TD readers. However, the number of fixations participants made over the course of each trial was not affected by the frequency of the target word, and there was no interaction. Total sentence reading times were also found to be significantly longer for the ASD group, in comparison to the TD group, but there was no effect of frequency and no group by frequency interaction.

These global measures indicate that the ASD group extracted information during fixations at a similar speed to TD readers, but made more fixations during the course of each trial and also had longer sentence reading times, in comparison to TD participants.

Table 1.
Model parameters and observed means for Experiment 1 global analyses.

		Model				TD		ASD	
		b	SE	*t*	Sig	High	Low	High	Low
MFD	Intercept	5.40	0.02	279.08	*	217 (30)	220 (30)	229 (40)	233 (41)
	Group	-0.05	0.04	-1.24					
	Frequency	0.02	0.01	2.54	*				
	Group X Frequency	< 0.01	0.02	-0.29					
MFC	Intercept	2.40	0.05	44.83	*	10 (4)	11 (4)	13 (6)	14 (6)
	Group	-0.24	0.10	-2.45	*				
	Frequency	0.02	0.02	1.33					
	Group X Frequency	0.03	0.03	0.86					
SRT	Intercept	7.81	0.06	126.81	*	2243 (905)	2359 (971)	3174 (1864)	3223 (1723)
	Group	-0.28	0.12	-2.41	*				
	Frequency	0.03	0.02	1.81					
	Group X Frequency	0.03	0.03	0.93					
SSRT	Intercept	6.37	0.11	57.46	*	774 (727)	679 (624)	1483 (1615)	1555 (1574)
	Group	-0.47	0.22	-2.11	*				
	Frequency	0.01	0.07	0.09					
	Group X Frequency	-0.26	0.13	-1.91					

Nb. MFD = mean fixation duration, MFC = mean fixation count, SRT = total sentence reading time, SSRT = second pass sentence reading time.

2.4.3 Target Word

A region of interest was created around the target noun. For the target word, the following eye movement measures were calculated; skipping, first fixation duration (the duration of the first fixation on the target), single fixation duration (the duration of a fixation on the target, when this was the only fixation made on this word during first pass reading), gaze duration and total time.

All model parameters are presented in Table 2 and reading measure means and standard deviations are included in Table 3. Word frequency did not have an affect on the probability of the target word being skipped. However, frequency was found to affect the duration of first fixations, single fixations, gaze durations and total times on the target word, with each of these measures being greater for low frequency words in comparison to high frequency words. No interactions were found for any measure and the only group difference detected was that the readers with ASD had longer total times for the target region, in comparison to TD readers.

Based on this analysis, there is no evidence for the hypotheses that lexical processing is less efficient in ASD. However, in order to infer the extent to which our data reflect a null effect of group, as apposed to a Type II error, we computed Bayes factor (Kass & Raftery, 1995; Rouder, Morey, Speckman & Province, 2012) for the first fixation LME model on the target word reported above (with a frequency by group interaction), when compared to a denominator model that had the same random structure, but only included frequency as a fixed effect. Bayes factor is a form of Bayesian analysis whereby one can quantify the relative evidence (probability) for apposing hypotheses, based on the change of prior odds to posterior odds, as a result of the observed data. One of the benefits of this approach is that one can assess evidence in favour of a null hypothesis, which is not possible through more traditional null hypothesis significance tests. A detailed description of this analysis is beyond the scope of this chapter, however interested readers are referred to (Kass & Raftery, 1995; Rouder et al., 2012; Wagenmakers, 2007). Thus, to be clear, we directly compared our original model to one that did not specify group as a predictor. We chose to focus this analysis on the first fixation duration data because this measure is highly influenced by the lexical properties of a word and this measure for this region was the first point that frequency had an effect on fixations for the TD group. A Bayes factor of less than 1 would favour the denominator model and a value above 1 would favour the original model (that included a group by frequency interaction). We computed the Bayes factor in R (R Core Team, 2015) using the BayesFactor package (Morey & Rouder, 2013) with 100,000 Monte Carlo iterations and with g-priors scaled to $r = 0.5$ for fixed effects. The Bayes factor for the original model, when compared to the denominator model was 0.045. Based on Jeffrey's (1961) evidence categories for Bayes factor, this provides strong evidence in favour of the denominator model that did not include group as a predictor. Moreover, the denominator model is 22 times more likely, based on our data, than the original model. This supports the conclusion that the ASD and TD groups did not appear to differ in the efficiency with which they lexically processed the target words.

Note that the lack of group differences in the early stages of target word processing indicates that the increased number of fixations and increased time spent reading the sentences in the global analyses, is not a result of differences in the early stages of lexical processing. In order to determine the possible cause of these global differences, the spatial and temporal characteristics of the extra fixations ASD participants made are examined in the analysis below.

2.4.4 First Pass Reading

In the following analyses, the start and end regions of the sentences were examined, in addition to the target word. The start region included all words prior to the target. The end region included all the words following the target. It is possible that the increased sentence reading times and number of fixations made by the ASD group are a result of longer and more effortful first pass reading. To examine whether such a difference exists, gaze durations for the start and end region, and the proportion of regressions made out of the target and end region during first pass was examined.

Recall that no group differences were present for gaze durations in the target region. Similarly, for both the start and the end region, no effect of group, condition or an interaction was detected. Furthermore, for both the target and end region, there were no differences between groups or frequency in the proportion of regressions made out of these regions during first pass of the sentences. What this suggests is that the initial processing of each region of the sentence did not differ between groups.

2.4.5 Second Pass Reading

Given the lack of difference detected between groups during the initial processing of the sentences, it is possible that the increased reading and fixations made by ASD participants occurred during second pass reading, that is, after the participants had read each sentence once in its entirety.

Total second pass reading times were first calculated across the entire sentence (summed total times – summed gaze durations, see Table 1). Readers with ASD were found to have larger second pass reading times for the entire sentence, in comparison to TD readers, but there was no effect of condition or any interaction. To determine whether there was a particular area of sentences that the ASD group were re-reading, second pass reading times were computed for each region individually (total time- gaze duration) and the ASD group were found to have longer second pass reading times for the start and end region of the sentence. However, no effect of frequency or any interactions were detected.

To examine whether the ASD group were making more regressions into either the start or target region, in order to engage in second pass reading, the proportion of trials a regression was made into these regions was examined. No effect of group or word frequency was found for either region. This suggests that there was no reliable difference in the proportion of trials with which the two groups regressed into the start and target regions, but that when the ASD group did make such a regression, they spent longer re-reading each region of the sentences, compared to the TD group.

Table 2.
Model parameters for Experiment 1 early measures ROI analyses.

		Start				Target				End			
		b	SE	*t*	Sig	*b*	SE	*t*	Sig	*b*	SE	*t*	Sig
Skipping†	Intercept					-2.57	0.23	-11.33	*				
	Group					0.67	0.41	1.63					
	Frequency					-0.59	0.32	-1.83					
	Group X Frequency					0.23	0.48	0.48					
First Fixation Duration	Intercept					5.44	0.03	203.20	*				
	Group					-0.03	0.05	-0.56					
	Frequency					0.08	0.02	4.02	*				
	Group X Frequency					0.04	0.04	1.03					
Single Fixation Duration	Intercept					5.48	0.03	180.78	*				
	Group					-0.05	0.05	-0.86					
	Frequency					0.11	0.03	4.45	*				
	Group X Frequency					0.01	0.05	0.26					
Gaze Duration	Intercept	6.86	0.08	82.42	*	5.62	0.04	151.52	*	6.20	0.08	75.67	*
	Group	-0.11	0.11	-1.03		-0.04	0.07	-0.64		-0.07	0.11	-0.60	
	Frequency	0.00	0.02	-0.12		0.17	0.03	6.03	*	0.03	0.04	0.71	
	Group X Frequency	0.03	0.04	0.75		0.03	0.05	0.57		0.10	0.07	1.35	

† *Values in the t column for this variable correspond to z values.*

Table 3.
Model parameters for Experiment 1 later measures ROI and supplementary analyses.

		Start				Target				End			
		b	SE	*t*	Sig	*b*	SE	*t*	Sig	*b*	SE	*t*	Sig
Total Time	Intercept					5.86	0.05	119.92	*				
	Group					-0.18	0.09	-2.02	*				
	Frequency					0.23	0.05	4.86	*				
	Group X Frequency					-0.09	0.08	-1.08					
Second Pass Reading Time	Intercept	6.00	0.09	63.49	*	5.55	0.06	94.29	*	6.07	0.09	67.75	*
	Group	-0.38	0.18	-2.10	*	-0.16	0.12	-1.36		-0.50	0.16	-3.20	*
	Frequency	0.02	0.07	0.23		0.15	0.08	1.85		-0.13	0.09	-1.57	
	Group X Frequency	-0.26	0.14	-1.91		0.04	0.15	0.26		-0.09	0.16	-0.56	
Regressions In†	Intercept	0.38	0.28	1.38		-1.52	0.12	-12.63	*				
	Group	-0.85	0.53	-1.62		-0.22	0.21	-1.03					
	Frequency	-0.21	0.20	0.28		0.39	0.21	1.88					
	Group X Frequency	0.23	0.29	0.80		-13.00	0.39	-0.33					
Regressions Out†	Intercept					-1.79	0.23	-7.67	*	0.58	0.27	2.15	*
	Group					-0.30	0.33	-0.92		-0.88	0.53	-1.67	
	Frequency					-0.11	0.18	-0.59		-0.02	0.17	-0.15	
	Group X Frequency					-0.42	0.35	-1.22		0.55	0.34	1.65	

† *Values in the t column for this variable correspond to z values.*

Table 4.
Observed means (standard deviations) for Experiment 1 ROI and supplementary analyses.

		Skipping	First Fixation Duration	Single Fixation Duration	Gaze Duration	Total Time	Second Pass Reading Time	Regressions In	Regressions Out
					Start				
TD	High				1025 (525)		504 (417)	.49 (.50)	
	Low				1028 (497)		481 (427)	.47 (.50)	
ASD	High				1172 (613)		869 (837)	.63 (.48)	
	Low				1188 (707)		960 (874)	.59 (.49)	
					Target				
TD	High	.14 (.35)	225 (67)	230 (75)	268 (129)	334 (184)	264 (180)	.16 (.37)	.19 (.40)
	Low	.12 (.32)	253 (81)	260 (83)	325 (147)	400 (212)	321 (256)	.20 (.40)	.15 (.36)
ASD	High	.09 (.29)	239 (84)	245 (88)	281 (114)	385 (231)	386 (469)	.18 (.38)	.21 (.40)
	Low	.07 (.26)	257 (94)	274 (97)	335 (154)	522 (338)	422 (353)	.24 (.43)	.23 (.42)
					End				
TD	High				569 (372)		492 (342)		.49 (.50)
	Low				611 (393)		441 (444)		.55 (.50)
ASD	High				679 (485)		948 (815)		.65 (.48)
	Low				648 (440)		845 (657)		.63 (.48)

2.5 Experiment 1: Discussion

We examined on-line lexical processing in ASD by measuring participant's eye movements as they read sentences that contained a target word manipulated to be of high or low frequency. The target analyses revealed that both TD and ASD readers showed normal word frequency effects for all target fixation measures. Fixations were significantly longer on low frequency words, in comparison to high frequency words. This finding of a normal frequency effect extends our current knowledge in relation to lexical processing in ASD, as it demonstrates that in addition to intact performance accuracy for isolated word identification tasks (e.g. Frith & Snowling, 1983; Mayes & Calhoun, 2006; Minshew et al., 1995; Saldaña et al., 2009), that the processes engaged in to identify a word during normal reading appear to be comparable between ASD and TD readers. This is in line with cognitive theories of ASD that suggest low-level 'bottom up' processing to be intact (e.g. Minshew & Goldstein, 1998).

Our findings are inconsistent however with Sansosti et al.'s (2013) study that reported ASD readers to have longer average fixation durations. We found no evidence of such a difference in our data. This inconsistency may be attributable to the differences between the stimuli employed by our own and Sansosti et al.'s (2013) experiment. The vignettes in Sansosti et al.'s (2013) study were designed to evoke a bridging inference, whereas our sentences required no inferences to be made in order to comprehend sentence meaning. Our finding therefore gives indirect support for Sansosti et al.'s (2013) interpretation that the larger average fixation durations observed for ASD participants, reflected more effortful processing in relation to the computation of an inference, as apposed to differences in lexical processing.

In the global analyses, we found participants with ASD to spend longer reading sentences and make more fixations overall, during the course of a trial. This is consistent with what Sansosti et al. (2013) reported, however the time course of the increased reading time found for their experiment was not reported, making the cause of these global effects unclear. In our analysis we examined the time course of the increased reading times for the ASD participants, in order to determine whether these differences were related to our experimental manipulation, and the nature of such increased reading. This analyses revealed no difference between the groups for first pass reading times or first pass regressions, which suggests that the speed and manner in which an initial sentence interpretation was constructed to be alike for both TD and ASD participants. Crucially, although our experiments were not designed to examine integrative processes, this finding is inconsistent with theories that suggest such processes to be atypical in ASD (e.g. Frith & Happé, 1994, Minshew & Goldstein, 1998). If integration were more effortful for ASD readers, we would have found longer gaze durations in each region and a larger proportion of first pass regressions being made. This was not the case.

The analyses also suggested that the increased sentence reading times for ASD participants appeared to be wholly a result of the these participants re-reading the sentences for significantly longer periods of time than the TD group. Note that this increased re-reading appeared to be unrelated to our target word manipulation, with re-reading occurring equally often for sentences that contained low and high frequency words and is consistent with what Au-Yeung et al. (2015) report for ironic and sincere texts. In addition, no group differences in the proportion of regressions made between groups were found. This is inconsistent with Sansosti et al.'s (2013) finding of increased regressions being made by ASD participants and indicates that our ASD group were as likely as the TD group to make a regression out of a region and also that the target of this regression did not differ. What did differ, was that once having made a regression, the ASD readers spent longer re-reading the sentences.

The cause of this re-reading behaviour is unclear, but it seems unlikely to be a result of a linguistic processing deficit *per se*, as any difficulty associated with the extraction of sentence or word meaning would have been evident during first pass reading. We speculate that this difference may reflect a 'checking' strategy adopted by the ASD group. Recall that there were comprehension questions after 50% of sentences and this may have contributed to ASD participants being more cautious of their sentence interpretation and consequently spending longer than TD participants re-reading sentences to ensure that they could answer the questions accurately. What is important is that the increased second pass reading was not a result of difficulties in the initial extraction of sentence meaning.

2.6 Experiment 2: Syntactic and Semantic Processing in ASD

It is common to encounter structural ambiguities within natural language; however, these often go unnoticed due to the parsing preferences readers hold. For example, in the sentence below (5) the prepositional phrase is syntactically ambiguous.

5. Jane hit the man with the handlebar moustache.

A reader can either attach the prepositional phrase high as a modifier to the verb *hit*, or low as a modifier to the noun phrase *the man*. The two possible syntactic structures result in a different sentence interpretation, with the first suggesting that Jane hit the man using a handlebar moustache and the latter suggesting that Jane hit the man who had a handlebar moustache. For sentence 5, if a high attached structure is adopted, the sentence meaning is implausible and reading is disrupted (e.g. Rayner, Carlson & Frazier, 1983; Taraban & McClelland, 1988). This is because the reader has to re-evaluate their initial parse of the sentence, to adopt the alternative, low attached structure. This disruption is evident in the eye movement record as increased fixation durations on the disambiguating noun and increased regressions out of this region, to re-read previous parts of the sentence (e.g. Joseph & Liversedge, 2013; Rayner et al., 1983).

There are several theoretical positions adopted as to why certain structures are preferred and initially adopted by readers. The Garden Path Theory (Frazier & Rayner, 1982) posits that sentences are parsed according to two principles; Minimal Attachment and Late Closure. Minimal Attachment is a rule according to which a reader will always initially build the simplest syntactic structure, and the Late Closure rule stipulates that the parser will always attach a phrase to the currently open phrase structure. An alternative theoretical position is that of Constraint-Based models where the language processor is assumed to be interactive and higher order information such as contextual information can influence initial decisions (e.g. MacDonald, Pearlmutter & Seidenberg, 1994). There are other theoretical accounts of parsing too (e.g. Construal, Frazier & Clifton, 1996; Race Based Parsing, Van Gompel, Pickering & Traxler, 2000; Good Enough Parsing, Ferreira, Bailey & Ferraro, 2002). For present purposes, we will again sidestep the issue of which theoretical account provides the most adequate account of processing, and instead simply accept that processing biases exist for sentences with particular linguistic characteristics. On this basis, in Experiment 2, analogous to Experiment 1, we will investigate how comparable on-line syntactic processing is in TD and ASD readers.

The research that has examined syntactic processing in ASD during spoken language processing has reported mixed results (for a review see Eigsti, Marchena, Schuh & Kelley, 2011), and little work has been conducted to examine the syntactic processing of written sentences. In a study assessing the impact of ASD and language phenotype on reading comprehension, Lucas and Norbury (2014) had children with ASD and typical language skills (ALN); children with ASD and language impairments (ALI) and TD participants read sentences that were syntactically 'scrambled'. All groups showed equivalent disruption to reading times when reading scrambled sentences, however there was a trend to suggest that the ALI participants took longer to read syntactically legal sentences, in comparison to the TD and ALN participants, who did not differ. This suggests that syntactic processing in ASD may be intact, but that the presence of language impairment has an impact upon the efficiency of syntactic processing during reading (Lucas & Norbury, 2014). Stockbridge, Happé and White (2014) found that children with ASD were as accurate as TD children in the identification of the indirect object of a verb in sentences that varied in structural form. In addition, both TD children and children with ASD showed higher accuracy for sentences containing a preposition phrase construction (e.g. *Toby read the book to Jenny*) in comparison to a double object construction (e.g. *Toby read Jenny the book*), indicating that both TD and ASD children benefited from the indirect object being more explicit. These results are consistent with Lucas and Norbury's (2014) finding and suggest that syntactic processing of written sentences is intact in ASD. The important finding from these experiments in relation to the current work is that the individuals with ASD appeared to exhibit comparable syntactic processing to that observed in TD children.

There is evidence, however, of a delay in the detection of syntactic errors in ASD. Koolen, Vissers, Hendriks, Egger and Verhoeven (2012) had adults with ASD take part in a 'single' or 'dual' level reading task where sentences were presented in a serial viewing paradigm. For the dual task participants had to detect orthographic errors (letter substitutions e.g. *the dog berks/barks*) and syntactic errors (verb agreement errors e.g. *she takes the broom and sweep/s the floor*), and in the single task participants had to detect only one error type (lexical or syntactic). Koolen et al. (2012) found that ASD and TD participants did not differ in their performance accuracy for either task and that for the single task reaction times did not differ. However, during the dual task, ASD participants were slower to detect both orthographic and syntactic errors, in comparison to the TD group who only showed a slowed response for orthographic errors. The lack of difference between groups for the single task was taken as evidence of intact lexical and syntactic processing in ASD. The slow in the detection of both types of errors under dual task conditions however suggested that when both lexical and syntactic information had to be monitored simultaneously that processing became less efficient. Furthermore, Koolen, Vissers, Egger and Verhoeven (2014) replicated this study but also recorded event related potentials (ERP) and found that when an orthographic error was encountered, both TD and ASD participants emitted comparable P600 (a positive waveform that has previously been associated with error detection) responses under both task conditions. However, larger P600 amplitudes were found for ASD readers upon the detection of syntactic errors under both dual and single task conditions. The authors concluded that it is reduced attentional modulation, as apposed to atypical linguistic processing that results in poor performance for reading tasks in ASD and that the increased P600 amplitudes for syntactic errors reflect a difficulty in the processing of language during complex tasks. It is therefore possible that more basic differences in the on-line processing of information are present in ASD during normal reading conditions, which requires the simultaneous processing of lexical and syntactic information.

From the work mentioned above, it would seem that individuals with ASD are able to accurately complete tasks requiring syntactic processing, however it is unclear whether the efficiency of such processing is similar between ASD and TD groups. A recent study (Riches, Loucas, Baird, Charman & Simonoff, 2015) had adolescents with ASD complete an aural comprehension task for sentences that contained an ambiguous prepositional phrase (e.g. *the girl approached the butterfly on the log*). Response times were longer for each group when the picture displayed reflected the least plausible interpretation, suggesting that both groups had to reanalyse their initial plausible interpretation of the sentence, prior to making a response. In addition, participants with ASD had longer response times overall, indicating that they required longer to complete the task in all conditions. However, as noted by the authors, it is unclear whether this increase in response time reflects differences in the efficiency of language processing, or a more task oriented effect, such as increased scanning of the pictures. In addition, there was a trend to suggest that ASD participants may hold a stronger high attachment bias, in comparison to a TD group. However, again, the exact cause of this effect is difficult to pinpoint given the analysis of reaction times. What this experiment does elucidate however is that when presented with visual displays of an image, individuals with ASD were able to reanalyse their initial interpretation of a sentence and select an alternative.

In the present study we aimed to further examine the processing of such sentences in ASD, however we were specifically concerned with such processing and its time course during natural reading (as apposed to during listening, and in the absence of visual cues). We had participants with and without ASD read sentences that contained an ambiguous prepositional phrase and were designed to evoke a high attachment preference. We were more specifically interested in whether the syntactic preferences held by ASD participants for ambiguous sentences are similar to those of TD readers and also whether the time course of disruption to reading by an initial syntactic misanalysis was comparable between groups. We predicted that if readers with ASD did not hold a high attachment preference for sentence stimuli, they would not show disruption to reading upon encountering the disambiguating noun in low attached sentences. Alternatively, if readers with ASD do hold a high attachment preference, but are less efficient in the recovery from an initial syntactic misanalysis, we would expect to find increased disruption to reading for low attached sentences, in comparison to the TD group.

The second aim of this experiment was to assess whether ASD readers use world knowledge on-line during reading. The detection of an incorrect interpretation for low attached sentences is dependent upon a reader's ability to evaluate their sentential interpretation against their knowledge of the world. Therefore, in Experiment 2 we were able to directly assess the efficiency of on-line world knowledge use during reading.

Impairments in performance accuracy are often found for reading comprehension and inferencing tasks in ASD (Huemer & Mann, 2010; Minshew et al., 1995; Jolliffe and Baron-Cohen, 1999) and for each of these tasks, the processing of world knowledge and then the integration of this information into the discourse model is critical (Graesser, Singer, & Trabasso, 1994; McKoon & Ratcliff, 1992). Furthermore, it has been suggested that top down processing may be atypical in ASD (e.g. Minshew & Goldstein, 1998) and in the context of reading, this may result in the efficiency with which world knowledge is known to be used on-line being compromised.

Few studies have directly examined the use of world knowledge during reading in ASD and those that have report mixed results. Saldaña and Frith (2007) had participants read two sentence vignettes intended to produce an inference. Participants were then asked a comprehension question that was or was not related to the inference the vignette was intended to evoke. Reaction times to the questions did not differ between TD and ASD readers and both groups showed faster responses when the question was related to the evoked inference. This was interpreted to suggest that the use of world knowledge is intact in ASD, as ASD participants must have incorporated such information into the discourse model in order to demonstrate an inference priming effect on question reading times. Recall that Sansosti et al. (2013) reported their sample of ASD readers to make longer average fixation durations, more fixations and more regressions on average than their TD group when reading the vignettes originally used in Saldaña and Frith's (2007) experiment. It is therefore possible that subtle differences in the on-line use of such knowledge are present in ASD and may impact upon the comprehension of larger portions of text, but are undetectable via relatively coarse measures, such as reaction times. Consistent with this hypothesis, Wahlberg and Magliano (2004) found subtle differences between TD and ASD participants in the use of world knowledge to aid recall of ambiguous texts. Participants read passages that were either preceded by a title (informative or non-informative) and with, or without, a primer paragraph that explicitly described the events the stories referred to. Overall, when a cue was present (title or primer paragraph), TD readers recalled more clauses in total and recalled more clauses that demonstrated world knowledge had been integrated into the discourse model, in comparison to the ASD group. Note however that the number of clauses recalled that were inferred on the basis of world knowledge did not differ between groups. This suggests that readers with ASD accessed world knowledge on-line during reading, however they did not use this information as efficiently as TD readers to assist in the disambiguation and recall of the ambiguous texts. This is similar to the conclusions of Sansosti et al. (2013).

In Experiment 2, we aimed to directly examine the time course and efficiency of world knowledge use during reading of syntactically ambiguous sentences in ASD. We predict that if participants with ASD are less efficient in the use of world knowledge during reading, then there will be a delay in their detection of an initial misanalysis of low attached sentences, in comparison to TD readers.

2.7 Method

Participants, procedure and experimental design were identical to Experiment 1.

2.7.1 Materials

Forty-four sentence frames were devised that included a prepositional phrase that could either be attached high (HA) to a verb (e.g. 6a) or low (LA) to the noun phrase that immediately preceded the preposition (e.g. 6b). Both sentence types were identical aside from the disambiguating target noun.

6a. |Charlie| demolished| the dilapidated house| with| a huge| crane| last| year.|

6b. |Charlie| demolished| the dilapidated house| with| a huge| fence| last| year.|

To confirm that the chosen verbs elicited a high attachment preference in a typical population, 13 undergraduate students completed a cloze task and the experimenter went through each sentence completion with each student, to clarify any possible ambiguities. The students completed the sentences using a noun that resulted in a high-attached structure, 98% of the time. On average, the target words did not differ in length t (43) = 0.17, p = .868 (HA M = 5.59 SD = 1.69, LA M = 5.57 SD = 1.59), frequency t (43) = 0.64, *p* = .524 (HA *M* = 22.61 *SD* = 39.20, LA *M* = 27.83 *SD* = 61.08), number of orthographic neighbours *t* (43) = 1.25, *p* = .225 (HA *M* = 4.66 *SD* = 5.55, LA *M* = 5.89 *SD* = 6.53), mean bigram frequency *t* (43) = 1.34, *p* = .186 (HA *M* = 3587.87 *SD* = 1395.70, LA *M* = 4232.46 *SD* = 2079.95), number of morphemes *t* (43) = 0.38, *p* = .767 (HA *M* = 1.25 *SD* = 0.53, LA *M* = 1.23 *SD* = 0.48) or number of syllables *t* (43) = 0.83, *p* = .412 (HA *M* = 1.59 *SD* = 0.76, LA *M* = 1.52 *SD* = 0.73), as retrieved from the SUBTLEX database (Brysbaert & New, 2009). To assure the high and low attached sentences did not differ in plausibility, 15 undergraduates (who had not completed the cloze task) rated how likely it was that the events described in the sentences would occur on a 5-point likert scale (1 = extremely unlikely, 3 = quite likely, 5 = extremely likely). To avoid the low attachment of the prepositional phrase acting as a confounding variable that may cause participants to rate these sentences as less likely, the sentences rated were an unambiguous description of the events depicted in the sentences (e.g. see 7a and 7b).

How likely is it…

7a. that a crane would be used to demolish a huge, dilapidated house.

7b. that a huge, dilapidated house that has a fence, would be demolished.

The order of items was pseudo-randomised so that the same sentence versions (e.g. 7a & b) were at least 20 items apart. Participant ratings indicated that the events described in the sentences did not differ in plausibility *t* (43) = 1.30, *p* = .200 (HA *M* = 3.39 *SD* = 0.78, LA *M* = 3.27 *SD* = 0.79). The full set of materials can be seen in Appendix C.

2.8 Experiment 2: Results

2.8.1 Data Preparation

Sentences were divided into eight regions, three of which were of primary interest; the pre-target region which consisted of a determiner and adjective that immediately followed the preposition; the target, which consisted of the disambiguating noun and the post target region which included the one or two words that followed the target (e.g. 6a & b).

Data exclusion procedures where the same as Experiment 1, which resulted a loss of 4.74% of the original data, and a loss of less than 3% of data from each fixation measure analysed. Sentence comprehension was high for both participant groups and therefore, similarly to what we found for Experiment 1, any differences detected in the eye movement data did not appear to impact upon offline comprehension outcomes (TD *M* = .96 *SD* = .04; ASD *M* = .97 *SD* = .05). Analyses procedures were also identical to Experiment 1, but with each model containing attachment condition (HA vs. LA) in place of frequency.

2.8.2 Global Measures

Global measures were calculated across trials to identify whether there were any basic sampling differences between TD and ASD readers during the reading of the syntactically ambiguous sentences. Means, standard deviations and model parameters for the global analysis are displayed in Table 5. No differences between groups or sentence types were detected for mean fixation duration and there was no interaction. For mean fixation count, there was a significant effect of attachment, with both groups making more fixations when sentences were low attached, in comparison to high attached. In addition, there was a significant effect of group, with ASD readers making more fixations overall in comparison to TD readers, but there was no interaction. A similar pattern was also found for total sentence reading time, with both groups having longer reading times for low attached sentences, in comparison to high attached sentences, and ASD readers having longer reading times overall, but again there was no interaction. These findings replicate what was found for Experiment 1 and are explored in more detail later.

Table 5.
Model parameters and observed means for Experiment 2 global analyses.

		Model				TD		ASD	
		b	SE	*t*	Sig	High	Low	High	Low
MFD	Intercept	5.39	0.02	274.52	*	218 (31)	219 (30)	226 (36)	226 (38)
	Group	-0.03	0.04	-0.80					
	Attachment	<0.01	0.01	0.31					
	Group X Attachment	0.01	0.01	0.48					
MFC	Intercept	2.67	0.06	47.69	*	12 (4)	14 (5)	18 (9)	20 (11)
	Group	-0.33	0.11	-2.98	*				
	Attachment	0.09	0.02	5.33	*				
	Group X Attachment	-0.01	0.04	-0.37					
SRT	Intercept	8.07	0.07	123.41	*	2739 (1069)	3015 (1277)	4171 (2486)	4687 (2898)
	Group	-0.36	0.13	-2.78	*				
	Attachment	0.09	0.02	4.39	*				
	Group X Attachment	-0.01	0.04	-0.29					
SSRT	Intercept	6.61	0.13	50.85	*	774 (715)	1064 (959)	2064 (2330)	2571 (2679)
	Group	-0.66	0.26	-2.56	*				
	Attachment	0.27	0.06	4.73	*				
	Group X Attachment	0.08	0.11	0.68					

Nb. MFD = mean fixation duration, MFC = mean fixation count, SRT = total sentence reading time, SSRT = second pass sentence reading time.

2.8.3 Pre-target Region

Means, standard deviations and model parameters for all region analyses are displayed in Tables 6-10. Note that the pre-target region was identical across both high and low attached sentences and as a result, no effect of attachment was found for skipping, first fixation durations, single fixation durations, gaze durations, go past times (the time from when a word is first fixated until the eyes leave this region to the right, including all time spent re-reading previous regions of the sentence) or the proportion of regressions made out of this region. In addition, group membership did not have an effect on any of these measures, and there were no interactions. An effect of both attachment and group was found, however, for total times, with the ASD group fixating this region for longer than the TD group overall and both groups spending longer fixating this region when the sentence was low attached. In addition, an effect of attachment for the proportion of regressions made into the pre-target region was found, with both groups regressing back into the pre-target region on a higher proportion of trials when the prepositional phrase was low attached, in comparison to when it was high attached. No group difference or interaction was detected. See Table 7 for model parameters and Table 10 for descriptives.

2.8.4 Target Word

The target word disambiguated the prepositional phrase attachment and was therefore the point at which participants were expected to first show disruption to reading for low attached sentences. One unexpected finding was that ASD readers were less likely to skip the target region in comparison to TD readers, but this did not differ between attachment conditions and there was no interaction. No effect of group or attachment was found for first fixations durations, indicating that during the very early stages of target processing, neither TD nor ASD readers had detected an incorrect interpretation. An effect of attachment was first present in single fixation durations, with both groups spending longer fixating target words in low attached sentences, in comparison to high attached sentences. No group differences or interactions were detected, indicating that the onset and severity of initial processing disruption was equivalent for TD and ASD readers. Similarly, gaze durations and go past times were found to be longer for target words within low attached sentences. Again, no group differences or interactions were found for these measures. Expectedly, an effect of attachment was also present in total times, with longer time being spent fixating target words for low attached sentences in comparison to high attached sentences, but no group difference or interaction was present. In addition, both groups made a higher proportion of regressive fixations into the target region when the sentence was low attached, in comparison to high attached, but the proportion of first pass regressions made out of the target region did not differ between groups or attachment conditions. See Table 7 for model parameters and Table 10 for descriptives.

The results above provide no evidence for the hypothesis that readers with ASD may display increased disruption for low attached sentences, or a delay in the onset of disruption, in comparison to TD readers. In order to examine the supportive evidence for this null effect, we again compared the single fixation duration LME reported above to a denominator model that only included prepositional phrase attachment as a fixed effect using Bayes factor. We were, therefore, once again able to directly compare the relative evidence for the original model to a model that excludes group as a predictor. We analysed the single fixation duration data because this was the first point in time an effect of prepositional phrase attachment was detected for the TD group, and this is a critical measure in relation to our hypotheses, where differences in the magnitude or onset of the effect might be expected to occur. A Bayes factor of 0.037 was computed using the same methods as detailed in Experiment 1. This indicates that there is strong evidence that the denominator model is more probable and is 27 times more likely based on the observed data, than the original model that included a group by prepositional phrase attachment interaction. Our analysis provides evidence in favour of a null effect of group in our data during the initial processing of the target word.

2.8.5 Post Target Region

The post target region was examined to assess the extent to which low attached sentences continued to disrupt reading, following processing of the target noun. No spill over effects were found, with no effect of group, attachment or any interactions for skipping, first fixations, single fixations or gaze durations. Attachment did however influence go past times, with both groups taking longer to progress to the right, past the post target region, when the sentences were low attached, in comparison to high attached sentences. In addition, there was a difference between groups, with ASD participants having longer go past times overall for this region, but this did not interact with condition. For total times, there was a main effect of attachment and group, with all participants spending longer fixating this region for low attached sentences and the ASD group spending longer in this region overall. Participants made significantly more regressions out of the post target region when the sentences were low attached and this did not differ or interact with group. There were no differences between groups or sentence types in the proportion of regressions made into this region. See Table 8 for model parameters and Table 10 for descriptives.

2.8.6 First Pass Reading

To examine whether the increased sentence reading time and number of fixations made by ASD participants in Experiment 2 was a consequence of increased first pass or second pass reading times, additional first and second pass measures were examined (see Tables 6-10). Recall from the main analyses, there were no group differences or interactions in gaze durations for the pre-target, target or post-target region. This was also true for the start, verb, noun, preposition and end regions. Furthermore, there was no effect of attachment and no interactions. The probability of readers making a regression out of each region during first pass reading was also examined. If ASD readers made more regressions during first pass this may have contributed to the increased sentence reading times. Recall that in the main analysis, no group differences or interactions were detected in the pre-target, target or post target regions. Similarly, there were no reliable differences between the proportions of first pass regressions made between groups for any other region and there was also no effect of attachment. These analyses suggest that there were no differences in the way the two groups sampled information during first pass reading.

2.8.7 Second Pass Reading

Analysis of second pass reading time for the entire sentence (see Table 5) indicated that the ASD group had longer second pass reading times overall, in comparison to the TD group and that both groups engaged in more re-reading for low attached sentences in comparison to high-attached sentences. To determine whether this increase in second pass reading of the sentences was a result of the ASD group re-reading a particular area of the sentence, second pass times were calculated for each region. The ASD group had longer second pass times in comparison to the TD group for the start, noun, pre-target, target and end. No differences between second pass reading of the preposition, post target or verb regions were detected, but there is a numerical trend in the data, consistent with the above findings. In addition, a reliable effect of attachment was detected for the noun and pre-target region, indicating that when sentences were low attached, both groups re-read these areas of the sentence more so, to assist in structural reanalysis. No interactions or effects of attachment were detected for any other region. Recall from the main analysis that both groups made a higher proportion of regressions into the target and pre-target regions, when the sentences were low attached. This was also true for the noun and preposition, indicating that this information was crucial for both groups, when reanalysing an initial structural interpretation. These findings replicate the findings from Experiment 1, with ASD readers spending significantly longer re-reading each region of the sentence, regardless of sentence condition. Once again this demonstrates that this increased re-reading is independent of our sentence manipulation.

Table 6.
Model parameters for Experiment 2 start, verb, noun and preposition region analyses.

		Start				Verb				Noun				Preposition			
		b	SE	*t*	Sig	*b*	SE	*t*	Sig	*b*	SE	*t*	Sig	*b*	SE	*t*	Sig
GD	Intercept	5.72	0.05	107.85	*	5.53	0.04	125.71	*	6.08	0.06	103.02	*	5.31	0.04	146.75	*
	Group	-0.15	0.09	-1.63		-0.08	0.08	-1.02		-0.13	0.10	-1.38		-0.03	0.07	-0.48	
	Attachment	0.03	0.02	1.33		< 0.01	0.02	0.24		-0.03	0.03	-0.83		0.03	0.03	0.95	
	Group X Attachment	0.03	0.04	0.68		< 0.01	0.04	0.12		0.05	0.06	0.82		< 0.01	0.05	0.19	
SPT	Intercept	5.61	0.07	78.10	*	5.72	0.06	92.71	*	5.92	0.09	68.83	*	5.60	0.07	75.76	*
	Group	-0.33	0.14	-2.47	*	-0.23	-0.12	-1.97		-0.41	0.16	-2.57	*	-0.16	0.15	-1.03	
	Attachment	-0.06	0.07	-0.89		0.06	0.06	1.08		0.18	0.07	2.40	*	0.14	0.10	1.39	
	Group X Attachment	-0.07	0.13	-0.55		0.08	0.11	0.72		0.07	0.16	0.44		0.08	0.21	0.38	
RI†	Intercept	-1.40	0.27	-5.23	*	-0.81	0.26	-.3.12	*	-0.94	0.24	-3.90	*	-0.69	0.21	-3.27	*
	Group	-0.86	0.50	-1.71		-0.63	0.51	-1.22		-0.77	0.47	-1.64		-0.31	0.40	-0.78	
	Attachment	0.17	0.15	1.13		0.09	0.14	0.65		0.34	0.16	2.08	*	0.55	0.16	3.47	*
	Group X Attachment	-0.47	0.26	-1.78		0.32	0.27	1.21		0.26	0.32	0.82		0.07	0.31	0.22	
RO†	Intercept					-2.56	0.20	-12.57	*	-2.07	0.18	-11.26	*	-2.45	0.21	-11.58	*
	Group					0.27	0.39	0.68		0.02	0.34	0.07		-0.21	0.35	-0.61	
	Attachment					-0.03	0.18	-0.17		0.07	0.18	0.39		0.03	0.32	0.10	
	Group X Attachment					-0.44	0.37	-1.19		0.16	0.30	0.53		-0.23	0.51	-0.45	

† Note that the values in the *t* column for this variable correspond to z values.
Nb. GD = gaze duration, SPT = second pass reading time, RI = regressions in, RO = first pass regressions out.

Table 7.
Model parameters for Experiment 2 pre-target and target regions.

		Pre-target				Target			
		b	SE	*t*	Sig	*b*	SE	*t*	Sig
Skipping[†]	Intercept	-3.25	0.29	-10.96	*	-2.27	0.25	-9.21	*
	Group	0.33	0.46	0.72		0.82	0.39	2.13	*
	Attachment	0.58	0.35	1.65		-0.25	0.19	-1.28	
	Group X Attachment	-0.02	0.52	-0.05		0.13	0.33	0.38	
First Fixation Duration	Intercept	5.29	0.19	273.44	*	5.42	0.03	215.70	*
	Group	0.06	0.04	1.50		0.02	0.05	0.42	
	Attachment	-0.02	0.01	-1.25		0.02	0.02	1.24	
	Group X Attachment	0.01	0.03	0.43		-0.01	0.03	-0.40	
Single Fixation Duration	Intercept	5.33	0.02	233.44	*	5.46	0.03	186.04	*
	Group	0.02	0.04	0.45		0.02	0.06	0.29	
	Attachment	-0.01	0.02	-0.73		0.06	0.02	2.49	*
	Group X Attachment	0.02	0.03	0.53		0.02	0.04	0.41	
Gaze Duration	Intercept	5.53	0.03	166.66	*	5.58	0.03	172.10	*
	Group	-0.09	0.06	-1.52		-0.01	0.06	-0.17	
	Attachment	0.01	0.02	0.60		0.09	0.03	3.00	*
	Group X Attachment	-0.03	0.05	-0.70		<0.01	0.04	0.02	
Go Past Time	Intercept	5.68	0.05	108.09	*	5.75	0.04	130.58	*
	Group	-0.18	0.10	-1.79		-0.07	0.08	-0.79	
	Attachment	-0.02	0.03	-0.82		0.10	0.03	3.07	*
	Group X Attachment	-0.01	0.04	-0.19		0.01	0.05	0.21	
Total Time	Intercept	5.96	0.07	90.57	*	5.82	0.05	107.04	
	Group	-0.33	0.13	-2.62	*	-0.18	0.10	-1.73	
	Attachment	0.11	0.04	2.52	*	0.18	0.04	4.41	*
	Group X Attachment	-0.01	0.07	-0.10		-0.04	0.05	-0.85	
Second Pass Reading Time	Intercept	5.75	0.06	90.30	*	5.62	0.06	94.93	*
	Group	-0.35	0.13	-2.76	*	-0.33	0.11	-2.95	*
	Attachment	0.15	0.07	2.32	*	0.13	0.06	1.95	
	Group X Attachment	0.14	0.13	1.15		0.11	0.13	0.84	
Regressions In[†]	Intercept	0.07	0.18	-4.07	*	-1.40	0.17	-8.90	*
	Group	-0.49	0.35	-1.39		-0.12	0.28	-0.42	
	Attachment	0.43	0.12	3.57	*	0.31	0.14	2.15	*
	Group X Attachment	0.11	0.23	0.46		-0.08	0.27	-0.28	
Regressions Out[†]	Intercept	-2.30	0.22	-10.30	*	-1.72	0.16	-10.57	*
	Group	-0.61	0.41	-1.46		-0.15	0.32	-0.46	
	Attachment	-0.15	0.19	-0.79		0.12	0.17	0.69	
	Group X Attachment	0.08	0.32	0.26		-0.10	0.30	-0.33	

Table 8.
Model parameters for Experiment 2 post target and end regions.

		Post Target				End			
		b	SE	*t*	Sig	*b*	SE	*t*	Sig
Skipping†	Intercept	-1.67	0.36	-4.64	*				
	Group	0.09	0.41	0.23					
	Attachment	-0.29	0.20	-1.44					
	Group X Attachment	0.21	0.27	0.78					
First Fixation Duration	Intercept	5.40	0.03	200.86	*				
	Group	-0.02	0.05	-0.29					
	Attachment	0.02	0.02	0.94					
	Group X Attachment	-0.03	0.04	-0.79					
Single Fixation Duration	Intercept	5.44	0.03	176.97	*				
	Group	-0.04	0.06	-0.66					
	Attachment	< 0.01	0.03	0.03					
	Group X Attachment	-0.03	0.06	-0.53					
Gaze Duration	Intercept	5.62	0.05	124.41	*	5.62	0.05	110.62	*
	Group	-0.10	0.08	-1.18		-0.01	0.08	-0.13	
	Attachment	0.01	0.03	0.42		-0.03	0.03	-0.95	
	Group X Attachment	0.05	0.06	0.77		-0.06	0.06	-1.07	
Go Past Time	Intercept	60.40	0.07	85.15	*				
	Group	-0.29	0.13	-2.13	*				
	Attachment	0.15	0.05	2.86	*				
	Group X Attachment	0.05	0.10	0.50					
Total Time	Intercept	5.90	0.06	94.07	*				
	Group	-0.30	0.12	-2.63	*				
	Attachment	0.08	0.03	2.32	*				
	Group X Attachment	0.03	0.07	0.37					
Second Pass Reading Time	Intercept	5.69	0.07	83.54	*	5.86	0.07	83.08	*
	Group	-0.25	0.14	-1.83		-0.55	0.14	-3.90	*
	Attachment	0.06	0.08	0.74		0.08	0.09	0.94	
	Group X Attachment	-0.11	0.16	-0.71		0.04	0.17	0.24	
Regressions In†	Intercept	-1.19	0.17	-7.16	*				
	Group	-0.43	0.25	-1.72					
	Attachment	0.04	0.14	0.32					
	Group X Attachment	0.28	0.26	1.07					
Regressions Out†	Intercept	-0.95	0.18	-5.34	*	0.81	0.25	3.22	*
	Group	-0.02	0.28	-0.06		-0.77	0.49	-1.56	
	Attachment	0.40	0.13	3.07	*	0.23	0.16	1.43	
	Group X Attachment	-0.03	0.25	-0.13		0.21	0.30	0.68	

Table 9.
Observed means (standard deviations) for Experiment 2 start, verb, noun, and preposition regions.

		Gaze Duration	Second Pass Time	Regressions In	Regressions Out
			Start		
TD	High	304 (137)	294 (178)	.21 (.41)	
	Low	325 (196)	266 (159)	.20 (.40)	
ASD	High	357 (167)	490 (403)	.31 (.47)	
	Low	364 (176)	542 (623)	.38 (.49)	
			Verb		
TD	High	268 (122)	321 (204)	.26 (.44)	.11 (.32)
	Low	272 (129)	368 (218)	.32 (.47)	.10 (.30)
ASD	High	297 (126)	466 (333)	.42 (.49)	.07 (.26)
	Low	301 (139)	527 (513)	.41 (.50)	.09 (.29)
			Noun		
TD	High	469 (261)	405 (315)	.23 (.42)	.14 (.34)
	Low	472 (259)	495 (389)	.31 (.46)	.15 (.36)
ASD	High	564 (302)	773 (714)	.37 (.48)	.15 (.36)
	Low	553 (332)	864 (751)	.41 (.49)	.14 (.35)
			Preposition		
TD	High	223 (105)	259 (144)	.29 (.45)	.38 (.49)
	Low	229 (91)	328 (202)	.40 (.49)	.47 (.50)
ASD	High	236 (106)	364 (253)	.09 (.28)	.09 (.29)
	Low	241 (118)	447 (327)	.09 (.28)	.11 (.32)

Table 10.
Observed means (standard deviations) for Experiment 2 pre-target, target, post target and end regions.

		SKIP	FFD	SFD	GD	GP	TT	SPT	RI	RO
					Pre-target					
TD	High	.07 (.26)	212 (50)	216 (51)	261 (115)	307 (164)	356 (197)	291 (179)	.27 (.44)	.11 (.32)
	Low	.09 (.28)	209 (48)	214 (48)	262 (117)	299 (167)	408 (236)	373 (233)	.36 (.48)	.10 (.30)
ASD	High	.07 (.26)	203 (57)	212 (63)	288 (138)	381 (269)	564 (485)	546 (439)	.37 (.48)	.20 (.40)
	Low	.08 (.27)	198 (52)	210 (73)	299 (144)	373 (234)	616 (447)	582 (518)	.44 (.50)	.17 (.37)
					Target					
TD	High	.22 (.41)	239 (84)	242 (88)	276 (116)	328 (178)	322 (160)	253 (144)	.22 (.41)	.16 (.37)
	Low	.19 (.39)	243 (82)	259 (98)	300 (119)	364 (198)	386 (203)	315 (193)	.26 (.44)	.18 (.38)
ASD	High	.13 (.34)	234 (82)	242 (87)	278 (112)	375 (390)	401 (277)	445 (389)	.20 (.40)	.18 (.38)
	Low	.10 (.30)	243 (90)	254 (93)	305 (127)	407 (306)	503 (355)	474 (383)	.25 (.43)	.21 (.41)
					Post Target					
TD	High	.27 (.44)	236 (97)	244 (105)	298 (154)	421 (356)	361 (210)	311 (235)	.22 (.42)	.27 (.45)
	Low	.25 (.43)	237 (95)	244 (105)	312 (175)	541 (472)	391 (221)	321 (281)	.25 (.43)	.35 (.48)
ASD	High	.25 (.43)	236 (90)	250 (104)	339 (180)	684 (816)	533 (381)	482 (378)	.32 (.47)	.28 (.45)
	Low	.21 (.41)	248 (107)	253 (107)	340 (201)	890 (1256)	570 (415)	565 (522)	.31 (.46)	.35 (.48)
					End					
TD	High				349 (205)			345 (314)	674 (505)	.54 (.50)
	Low				324 (199)			338 (204)	644 (452)	.60 (.49)
ASD	High				342 (227)					.67 (.47)
	Low				349 (236)					.72 (.45)

Nb. SKIP = skipping, FFD = first fixation duration, SFD = single fixation duration, GD = gaze duration, TT = total time, SPT = second pass time, RI = regressions in, RO = first pass regressions out.

2.9 Experiment 2: Discussion

We examined aspects of syntactic and semantic processing by having participants read sentences that contained an ambiguous prepositional phrase. Our first research question was related to whether readers with ASD hold similar syntactic preferences to TD readers. Both TD and ASD readers displayed disruption to reading for low attached sentences upon fixation of the target word, which indicates that similarly to TD readers, adult readers with ASD hold a high attachment preference. Furthermore, the severity of this disruption did not differ between groups, which suggests that readers with ASD are also as efficient as TD readers, in the recovery from an initial structural misanalysis. These findings suggest that the syntactic parsing of written sentences is intact in ASD.

Our results are consistent with Lucas and Norbury's (2014) study that demonstrated children with ASD to show similar disruption to TD children when reading syntactically scrambled sentences. In addition, similarly to Riches et al.'s (2015) study we found adult readers with ASD to be successful in the reanalysis of an initial interpretation of a sentence containing an ambiguous prepositional phrase. Note however there was no evidence that adults with ASD show a stronger high attachment preference, as a trend in Riches et al.'s (2015) data suggested. Our findings are inconsistent with Koolen et al.'s (2012; 2014) work that suggested syntactic processing to be less efficient in ASD. This inconsistency may be attributable to the difference in task types adopted in our own and Koolen et al.'s (2012; 2014) experiments. The current study simply required participants to read sentences for comprehension, whereas Koolen et al.'s (2012; 2014) studies required readers to detect and respond to lexical and syntactic errors during a serial viewing paradigm. This requires additional memory load and decisional processes that are not necessary during natural reading.

Our second research question was related to the use of world knowledge on-line during reading. We predicted that if such processing was less efficient that there would be a delay in the onset of reading disruption for the target word for low attached sentences. However, no such delay was detected, with both groups first showing disruption in single fixation durations. What this suggests, is that counter to our hypothesis and to theories that predict top down, higher order processing to be atypical (e.g. Minshew & Goldstein, 1998), ASD readers had access to and made use of world knowledge on-line and did so as efficiently as TD readers. This finding is consistent with Saldaña and Frith's (2007) study that reported participants with ASD to use world knowledge in order to make an inference, and in turn respond more quickly to comprehension questions that were related to such an inference. However, our finding is inconsistent with Wahlberg and Magliano's (2004) report of ASD readers being less efficient in the use of world knowledge. Note that Wahlberg and Magliano's (2004) study examined the use of such knowledge to aid in the recall of ambiguous texts and it is therefore possible that the difference reported by Wahlberg and Magliano (2004) is specifically related to memory functions following text comprehension, as apposed to linguistic processing *per se*.

There were two subtle differences found between the participant groups in the early processing of the sentences examined for Experiment 2. Firstly, the ASD readers were less likely to skip the target word of both high and low attached sentences, in comparison to TD readers. The lack of difference in skipping found in Experiment 1 and all other critical regions of the sentences in Experiment 2, suggests that the lower rate of skipping was not a result of an inherent difference in skipping probabilities in ASD, but is localised to this region. Decreased skipping of the target word in the ASD group may reflect the adoption of a more cautious reading strategy. It is possible that this is a result of the ASD readers being sensitive to the manipulation of attachment and consequently the importance of the disambiguating target noun. Therefore, decreased skipping may have been a strategy adopted in order to avoid overlooking a potential misanalysis.

The second group difference was that ASD readers were found to have longer go past times for the post-target region. Since this was present across both high and low attachment conditions. If this was evidence of increased disruption for low attached sentences for readers with ASD, we would have found an interaction whereby go past times were larger for ASD readers for low attached sentences only. However, this is not the case and thus it is likely a consequence of the increased re-reading that ASD participants engaged in for all sentences (note that the post target region was often the penultimate word in the sentence).

Differences in the later stages of sentence processing were also detected. Replicating what was found for Experiment 1, no group differences or interactions for first pass reading were found. What this suggests is that the ASD readers did not differ from the TD group in the speed with which they constructed an initial interpretation of the sentence. The ASD group did differ however in the amount of second pass reading they engaged in, following intact initial processing. Again this increased re-reading was found across both sentence types and was unrelated to the sentence manipulation. As for Experiment 1, we speculate that this may be a strategy adopted by the participants with ASD to 'check' their understanding of the sentence, prior to (possibly) answering a comprehension question. Different reading strategies have been previously identified in a TD population (Hyönä, Lorch & Kaakinen, 2002) and it is therefore possible that the increased re-reading and reduced skipping for the target region may be part of a more general, cautious reading strategy, adopted by ASD participants.

Finally, in relation to what would be expected in terms of typical cognitive processing from general theories of reading, the overall findings from the two experiments for TD readers replicate previous findings. In ASD readers however, this was not the case. Here, the findings replicate those that would be predicted for normal cognitive processing in first pass measures, but for second pass reading there was evidence for atypical cognitive processing which is not in line with any general theory of reading.

2.10 Conclusion

We aimed to gain a more accurate understanding as to how lexical, syntactic and semantic processing occurs in adults with ASD during natural reading, by measuring eye movements as participants read single sentences. Overall, there were striking similarities in first pass reading of sentences between TD and ASD readers. Experiment 1 indicated that lexical processing is intact in ASD, with both groups showing a comparable frequency effect. Experiment 2 indicated that there is no difference in syntactic preferences between the groups of readers, and in their ability to detect and recover from an initial syntactic misanalysis through the use of world knowledge. This was demonstrated by the immediacy with which an initial syntactic misanalysis was detected and the magnitude of disruption to reading being comparable between TD and ASD readers. More critically, what these findings imply, is that an impairment in lexical identification, syntactic parsing or the use of to world knowledge during the processing of single sentences is unlikely to contribute to the offline performance differences for reading comprehension and inferencing tasks that have been reported in the literature. The only group differences that were present in the current study appear to be independent of the linguistic manipulations in our experimental sentences and, instead, reflect a more cautious reading strategy that the ASD readers show a preference to adopt.

Chapter 3: Semantic Processing

Published: Howard, P. L., Liversedge, S. P., & Benson, V. (2017). Investigating the Use of World Knowledge During On-line Comprehension in Adults with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*. DOI: 10.1007/s10803-017-3129-x

3.1 Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterised by communication/social interaction difficulties and restricted and repetitive behaviour (American Psychiatric Association, 2013). There is a large body of literature to suggest that this unique behavioural phenotype is underpinned by cognitive processing differences (Frith, 2012).

Language is one area where cognitive differences manifest in ASD (Tager-Flusberg, 1981) and consistent with this, reading ability is often found to be atypical. The population of individuals diagnosed with ASD is heterogeneous and as a consequence, reading ability is highly variable (Nation, Clarke, Wright, & Williams, 2006). However, there is a general finding that individuals with ASD and no known learning difficulties or evidence of additional language impairment perform comparably to typically developing (TD) participants on low-level linguistic tasks, such as word identification (Howard, Liversedge & Benson, 2017a; Huemer & Mann, 2010; Mayes & Calhoun, 2006; Minshew, Goldstein, & Siegel, 1995; Saldaña, Carreiras, & Frith, 2009; Frith & Snowling, 1983, but see also Åsberg & Sandberg, 2012; Nation et al., 2006; White et al., 2006, who found subgroups of children with ASD to have less accurate word reading). Conversely, performance accuracy for tasks that require higher order linguistic processing, such as text comprehension and inferencing, is generally reported to be less accurate in comparison to TD controls (Brown, Oram-Cardy, & Johnson, 2013; Huemer & Mann, 2010; Jolliffe & Baron-Cohen, 1999; Nation et al., 2006; Newman et al., 2007; Minshew et al., 1995; Jones et al., 2009, but see also Åsberg, Kopp, Berg-Kelly, & Gillberg, 2010; Saldaña & Frith, 2007 who found no differences, and Lucas & Norbury, 2014, 2015; Norbury & Nation, 2011 who found performance differences in ASD to be associated with additional language impairment). It is these group differences in performance for higher order linguistic tasks that are of interest in the present work, because they often cannot be attributed to poor basic reading skill. Hence, it is possible that performance difficulties are associated with ASD specific cognitive processing differences.

The Weak Central Coherence Theory (WCC) proposes that individuals with ASD have a domain general local processing bias (Frith,1989; Frith & Happé, 1994; Happé & Frith, 2006). Some researchers have suggested that the associated lack of a global processing bias and consequential integration difficulties, may underpin reading difficulties in ASD. For example, readers with ASD are found to be less accurate at modulating their pronunciation of a homograph (word with two spellings, one meaning e.g., *tear* meaning cry or rip) based upon the (global) sentence context (Happé, 1997; Jolliffe & Baron-Cohen, 1999; López & Leekam, 2003; Frith & Snowling, 1983, but see also Snowling & Frith, 1986, where performance was modulated by verbal ability). However, concerns have been raised as to the methodology employed, and the assumptions and conclusions that have been made about the cognitive processes a participant has to engage in to be successful at this task (Brock & Bzishvili, 2013; Brock & Caruana, 2014). Furthermore, participants with ASD who do not have language impairment, are successful at modulating their pronunciation of a homograph and are sensitive to contextual linguistic information when other paradigms are adopted, such as semantic priming (Hala, Pexman, & Glenwright, 2007; Henderson, Clarke, & Snowling, 2011; Norbury, 2005), eye movements in a visual world (Brock, Norbury, Einav, & Nation, 2008; Hahn, Snedeker, & Rabagliati, 2015) and eye movements and reading (Au-Yeung, Kaakinen, Liversegde, & Benson, 2015, also see Caruana & Brock, 2014 for evidence of on-line contextual processing during reading in a group of adults with high levels of self reported autistic traits). Therefore, it would seem that difficulties in the construction of a mental representation of text (integration), as is predicted by WCC theory, is not a driving force behind difficulties with higher order linguistic tasks in ASD.

An alternative theory that has attempted to explain the cognitive differences in ASD is the Theory of Complex Information Processing (CIP; Minshew & Goldstein, 1998; Minshew, Goldstein & Siegel, 1997; Williams, Goldstein & Minshew, 2006). The CIP theory is a description of the behavioural and cognitive outcomes that you would expect from the Under-Connectivity Hypothesis, which proposes that ASD is a result of under-connectivity between neocortical brain areas (Just, Cherkassky, Keller, Kana, & Minshew, 2007; Just, Cherkassky, Keller, & Minshew, 2004; Minshew, Williams, & McFadden, 2008). The CIP theory posits that individuals with ASD have intact performance for 'simple' tasks, defined in the context of linguistic processing as those tasks that can be completed upon the basis of explicit rules (e.g., syntax) or information deducible from the stimuli (e.g., word meaning), whereas performance differences will be present for 'complex' tasks, defined as tasks that require processing beyond what is explicitly stated within a text (e.g., Minshew & Goldstein, 1998; Minshew et al. 1997; Williams et al. 2006). Consistent with the CIP's predictions, research using 'simple' linguistic tasks tends to show similar performance for TD and ASD readers, whereas research using 'complex' tasks show differences (e.g., tasks relying on word identification vs. tasks requiring text comprehension and inferencing in Minshew et al., 1995).

Therefore, the CIP theory posits that processing will differ between TD and ASD groups when a reader is required to use knowledge that is not explicitly provided in the text. But, for comprehension to succeed, it is often the case that a reader must infer such information on the basis of schematic knowledge of the world that is gained and developed through life experience, and stored in long-term memory (e.g., episodic, procedural, semantic, Gernsbacher, 1991; Kintsch, 1988; Zwaan, Langston & Graesser, 1995).

1. John got distracted whilst running his bath. He sighed as he mopped up the sodden bathroom floor. Why did John have to mop the bathroom floor?

In example 1 above, most readers would confidently answer the comprehension question with a response such as "the bath overflowed". However, this information is not explicitly provided in the preceding sentence; the reader must infer that the bath overflowed and flooded the bathroom floor, based upon their knowledge of baths, taps, water and distraction (world knowledge). Note that the relative ease in answering this question reflects the automaticity of activation of this information during natural reading.

As demonstrated above, the incremental evaluation of world knowledge is fundamental for inferential processing and the comprehension of text in order for local and global coherence to be gained. If readers with ASD do have deficits in these processes, this would significantly impact upon their understanding of text and may contribute to the commonly reported performance differences in tasks that require a reader to engage in such processes.

There is evidence of performance difficulties in ASD during reading tasks that require the use of world knowledge. For example, there have been numerous reports of participants with ASD performing less accurately than controls when they are asked to answer comprehension questions about a story they have read or heard that requires inferential work (Bodner, Engelhardt, Minshew & Williams, 2015; Jolliffe & Baron-

Cohen, 1999, 2000; Dennis, Lazenby & Lockyer, 2001; Minshew et al., 1995; Norbury & Bishop, 2002; Norbury & Nation; 2011, see also Lucas & Norbury, 2014 who found performance in children to be associated with verbal working memory and vocabulary). In addition, Norbury and Bishop (2002) identified that children with ASD were more likely than children with specific or pragmatic language impairment to have difficulties making inferences and ASD symptomology has been found to account for unique variance associated with inferential skill (Bodner et al., 2015; Norbury & Bishop, 2002; Norbury & Nation, 2011). Inferencing requires the activation and evaluation of relevant world knowledge that is then incorporated into the reader's mental representation of a described event (Graesser, Singer, & Trabasso, 1994; McKoon & Ratcliff, 1992). It has been concluded in the majority of the studies cited above that a deficit in construction of a discourse representation (integration difficulties), is likely to contribute to poor performance accuracy, as predicted by the WCC theory. However, it is also possible that the use and evaluation of world knowledge in ASD may be the underlying cause of such difficulties.

In an attempt to evaluate whether readers use world knowledge during reading, Saldaña and Frith (2007) tasked participants with and without ASD to read two sentence vignettes that required a bridging inference in order for successful comprehension to be attained, followed by a comprehension question that was or was not related to the inference. Both groups read questions that were related to the inference faster than they read questions that were not. Saldaña and Frith (2007) concluded that the lack of difference between the TD and ASD groups was evidence of intact on-line use of world knowledge. However, question-reading time that follows the computation of an inference does not necessarily reflect the moment-to-moment cognitive processes that occur during normal reading, and therefore it is possible that this approach was not sufficiently sensitive to allow detection of on-line processing differences between ASD and TD groups.

A study conducted by Sansosti, Was, Rawson, and Remaklus (2013) has attempted to address this issue by replicating Saldaña and Frith's (2007) experiment. However, in this study, eye movements were recorded as participants processed sentences, because there is a strong relationship between when and where readers make fixations and on-line cognitive processes readers engage in to comprehend text (Liversedge & Findlay, 2000). Sansosti et al. (2013) reported global measures of reading behaviour in their study. Note however, that global eye movement measures are calculated based upon entire vignette reading times; they do not offer the opportunity to establish the precise point in sentence processing at which participants first experienced difficulty. Sansosti et al. (2013) did, however, report that the ASD group made significantly more and longer fixations and an increased number of regressions in comparison to the TD group and concluded that this was evidence of an integration deficit when a bridging inference was required for the construction of a coherent discourse representation. However, as already noted, by only examining global eye movement measures it is not possible to explore the time course of such processing during normal reading. Local reading time measures associated with specific words and critical regions in carefully constructed experimental sentences are necessary to form conclusions about on-line processing during reading (Rayner, 1998; 2009).

A recent study required TD and ASD participants to read garden path sentences that contained an ambiguous prepositional phrase that could either be attached high to the verb (e.g., 2a, target word italicized) or low as a modifier to the noun phrase (e.g., 2b, Howard et al., 2017a), as their eye movements were monitored.

2a. Charlie demolished the dilapidated house with a huge *crane* last year.

2b. Charlie demolished the dilapidated house with a huge *fence* last year.

Typical readers show a preference to attach ambiguous prepositional phrases high (e.g. Rayner, Carlson & Frazier, 1983, but see also Taraban & McClelland, 1988). Therefore, when encountering sentences in which such a prepositional phrase attachment preference results in a semantic anomaly that conflicts with world knowledge (e.g., in 2b, a fence is not a tool and therefore not something that could be used to demolish a house), disruption to reading occurs as a result of readers having to re-evaluate their initial structural interpretation of the sentence. This disruption to reading results in increased fixation times upon the disambiguating target and increased regressions back to re-read previous portions of the text. Howard et al. (2017a) found adults with ASD to show an onset and magnitude of reading disruption when reading low attached sentences that was very comparable to TD controls. This suggests that not only did readers with ASD adopt a high attachment preference, but they also appeared to be as efficient as TD readers in the use of world knowledge on-line to detect an initial syntactic misanalysis.

The aim of the current experiment was to further examine the on-line evaluation of world knowledge during natural reading in ASD. To achieve this, we recorded eye movements as participants read sentences containing semantic oddities differing in the severity with which they violate world knowledge. This approach has been employed to investigate the immediacy with which world knowledge is activated and used in skilled adult readers (Rayner, Warren, Juhasz, & Liversedge, 2004).

3a. John used a knife to chop the large *carrots* for dinner last night. (Plausible)

3b. John used an axe to chop the large *carrots* for dinner last night. (Implausible)

3c. John used a pump to inflate the large *carrots* for dinner last night. (Anomalous)

Consider sentences 3b and 3c above. In order to recognise that the events described in these sentences are odd or unusual, each event must be evaluated against what is known to be true about the world, for example, knowledge about carrots and how they are normally prepared for a meal. When such sentences are understood to mean something that is inconsistent with such knowledge, the detection of that inconsistency has been demonstrated to result in disruption to eye movement behaviour during reading. The immediacy and the nature of such disruption provide insight into the time course of the use of world knowledge during reading. Rayner et al. (2004) demonstrated this by recording the eye movements of a TD group of participants as they read sentences that described events that were plausible (control e.g., 3a), implausible (possible but unlikely e.g., 3b) or anomalous (impossible e.g., 3c). In each of the sentences the target word is *carrots*, and it is at this word in the implausible and anomalous sentences that the semantic oddity first becomes apparent to the reader. Specifically, the anomalous sentences include a verb argument violation (i.e., a carrot cannot be inflated), whereas in the implausible sentences there is a mismatch in the co-occurrence of two quite reasonable verb arguments (i.e., an axe can be quite reasonably used to chop things, and carrots can be quite reasonably chopped, but the use of an axe to chop carrots, whilst possible, is unlikely). Rayner et al. (2004) found that the detection of an anomaly was almost immediate, with readers having significantly longer gaze durations (the duration of time spent fixating a word until the eyes leave that word to the left or right) on the target word in comparison to the control sentences. Implausibilities were also shown to be disruptive to reading, however disruption was less immediate, becoming apparent later in the eye movement record, with go past times being increased on the words that immediately followed the target (go past time sums the time from when a word is first fixated, until a fixation to the right of the word, therefore including any re-reading of previous text). These effects of anomaly and implausibility on linguistic processing have been replicated in adults and children (Joseph et al., 2008) and are found to occur extremely rapidly and incrementally, with disruption to initial processing occurring even when a prior context licenses a world knowledge violation, such as fictional contexts (Warren, McConnell, & Rayner, 2008) and counterfactual statements (Ferguson & Sanford, 2008).

The disruption caused by these manipulations is thought to reflect the difficulty readers have with building a mental representation of the events when these events conflict with their knowledge of the world. There are two possible reasons for the difference in the onset of disruption for anomalous and implausible sentences. Firstly, it may be a result of the difference in the severity of the semantic oddity between the sentences, with anomalies being more severe violations than implausibilities. Secondly, there is evidence that the anomalies may be detected at an earlier stage of processing independent of world knowledge evaluation, when thematic roles are assigned, as a result of the violation of a verb's selectional restrictions (semantic rules about what can and cannot be an argument to the verb e.g., Warren & McConnell, 2007).

In this study we adopted the paradigm used by Rayner et al. (2004) and invited adults with and without ASD to take part. Global off-line reading times for semantically anomalous words have previously been found to be similar between TD and ASD children (Lucas & Norbury, 2014), however, we will use the technique described above to establish whether there are any differences in the time course of world knowledge evaluation during natural reading in an adult sample of readers with ASD, in comparison to a TD group. We predict that, consistent with previous findings (Joseph et al. 2008; Rayner et al. 2004), the TD group will detect anomalies more rapidly than implausibilities and that anomalies will result in increased disruption to reading, relative to implausibilities. We also predict, based upon the hypothesis that ASD participants will be less efficient in the use of world knowledge and the assumption that both implausibilities and anomalies become apparent to the reader via world knowledge evaluation, that the detection of implausibilities and anomalies will be delayed in the ASD group, in comparison to the TD group.

3.2 Method

3.2.1 Participants

Two groups of adults were recruited (aged 18+), 24 with a clinical diagnosis of an ASD (five females), and 24 who were part of the TD control group (six females). All participants had normal or corrected to normal vision, were native English speakers and had no diagnosed reading difficulties (e.g., dyslexia). Participants with ASD were recruited through advertisement via local charitable organisations, with 21 members of the sample having received a clinical diagnosis of Asperger's syndrome, one member receiving a diagnosis of pervasive developmental disorder, and two members a diagnosis of autism. Diagnostic reports confirmed that all participants were primarily diagnosed using standard diagnostic instruments, including the Autism Diagnostic Observation Schedule (Lord, Rutter, DiLavore, & Risi, 2001), and/or the Autism Diagnostic Interview–Revised (Lord, Rutter, & Le Couteur, 1994). Control participants were recruited from the local community via on-line and poster advertisement. All participants gave written informed consent and were paid for their time.

All participants were assessed for oral language difficulties by completing the sentence repetition subtest of the Clinical Evaluation of Language Fundamentals II (CELF; Semel, Wiig & Secord, 2003), which is an assessment of expressive language production and verbal working memory that is sensitive to difficulties associated with specific language impairment (e.g., Conti-Ramsden, Botting, & Faragher, 2001). All TD participants and 22 of the ASD participants scored highly, with raw scores attained falling above the highest age equivalent score available (>12.11 years). The two participants in the ASD group who scored below this cut off (both males, one who had a diagnosis of Asperger's syndrome and one with a diagnosis of autism) were excluded from analysis to avoid any confounds associated with oral language impairment (e.g., Lucas & Norbury, 2014, 2015; Norbury & Nation, 2011; Norbury, 2005). The remaining sample of 22 ASD and 24 TD participants, did not differ on average for performance on the sentence repetition subtest of the CELF; t (43.73) = 0.54, p = .594. All participants were also in the normal range of intelligence (>80), as measured by the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) and the two groups did not differ in verbal IQ; t (41.06) = 0.24, p = .815, performance IQ; t (42.99) = 1.13, p = .266, or full scale IQ; t (42.53) = 0.62, p = .538. The Secondary Version of the York Assessment of Reading Comprehension (Snowling et al. 2010) was administered to all participants and raw scores from single word reading revealed no group differences in word identification accuracy; t (43.66) = 0.86, p = .396, or passage comprehension accuracy; t (42.42) = 1.38, p = .174. The ASD group did however have significantly higher levels of self-reported autistic traits in comparison to the TD group as measured by the Autistic Quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001); t (43.94) = 8.91, p < .001 and on average, were older than the TD group; t (39.54) = 2.09, p = .043. For group means and standard deviations on all the measures described above, see Table 11.

Table 11.
Means (standard deviations) for ASD and TD group's age, self reported autistic traits, intelligence, expressive language and reading skill.

	ASD			TD		
Measure	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Age	35.05	11.66	19-51	28.58	9.04	19-52
Autistic Quotient	36.86	7.15	17-49	16.79	8.12	7-35
Full scale IQ	119.50	11.18	91-140	117.54	10.14	96-139
Verbal IQ	116.73	11.31	96-137	116.00	9.42	97-138
Performance IQ	119.09	11.90	85-134	115.25	11.16	88-132
Expressive Language Raw (Max Score 96)	88.59	5.44	77-96	89.46	5.49	77-95
Single word Reading Raw (Max Score 70)	68.55	2.48	61-70	67.92	2.48	60-70
Passage Comprehension Raw (Max Score 13)	9.02	1.71	6-12	9.69	1.54	7-12

3.2.2 Materials

Sentences from Joseph et al. (2008) were used for this experiment. There were 36 experimental sentences in total, each of which had three versions (for the full stimulus set see Joseph et al., 2008). For an example of the stimuli and for an example of how the sentences were divided into regions of interest for analysis, see Table 12. Two minor adjustments were made to two of the sentences; *evening* was included as a final word in one sentence group and *afternoon* was included as the final word in another sentence group. This was done to create a final region of interest in both sentences, consistent with all the other stimuli. No alteration to the plausibility of the sentences occurred because these minimal changes were at the end of two of the sentences. In the implausible and anomalous sentences, the plausibility violation occurred at the target noun (*milk* in Table 12) that followed the infinitive verb (*to pour/grow* in Table 12). Sentences were matched across conditions such that there were no significant differences in the frequency of the noun prior to the infinitive verb (in Table 12 *bucket/jug/seed)*, nor in the frequency and length of the infinitive verb across conditions, and all words following the infinitive verb were exactly the same (Joseph et al., 2008). Three lists of 86 sentences were created, with each list containing a different version of each of the 36 sentences, 40 additional filler sentences and 10 practice sentences that were displayed prior to the experimental stimuli. Each participant only read one of the three lists of sentences.

Table 12.
An example of a plausible, implausible and anomalous sentence with region of interest boundaries marked.

	Regions of Interest				
	Start	Pre target	Target	Post target	Final
Plausible	The waiter used a jug to pour	the fresh	milk	in the	teacup.
Implausible	The waiter used a bucket to pour	the fresh	milk	in the	teacup.
Anomalous	The waiter used a seed to grow	the fresh	milk	in the	teacup.

3.2.3 Design

A 2 X 3 mixed design was employed with group (ASD vs. TD) as a between participants factor and sentence plausibility (plausible vs. implausible vs. anomalous) as a repeated measures factor.

3.2.4 Apparatus

Participant's eye movements were tracked using an Eyelink 1000 eye tracker (SR Research, Ottawa, Canada) operating at a sampling rate of 1000 Hz, as they read sentences presented on a computer monitor (19 inches). Sentences were displayed in black Courier New 14pt font, with a light grey background. The monitor was set at a distance of 70cm from a headrest that was used to minimize participant movement during testing, with each letter subsuming 0.30º of visual angle (3.32 letters equal to 1º). Viewing was binocular, but eye tracking was monocular. Forty-three participants had their right eye tracked and three had their left eye tracked.

3.2.5 Procedure

Participants were calibrated using a 3-point sequence of dots that covered the width of the screen in place of where each sentence would appear. Once participants had fixated each calibration point, a validation procedure followed to ensure that each fixation was within 0.50º of each point. Calibration was checked prior to each sentence presentation using a procedure whereby participants had to fixate a dot on the left hand side of the screen where the beginning of each sentence was set to appear. Recalibration was performed if the fixation was off centre.

Participants were warned that some of the sentences might appear "strange" but to read normally. Participants read at their own rate and were instructed to press a button on a controller to indicate when they had finished reading each sentence. Participants were also informed that there would be comprehension questions after approximately half of the sentences, and that they would be required to respond to these by pressing a button to indicate either a *Yes* or *No* response to the question. Instructions reminding participants of which button represented *Yes* and *No* were included underneath each comprehension question. These questions were factual and did not require detection of anomalies or implausibilities. These questions were included to ensure that participants read for comprehension. Before the experiment began, ten practice sentences were presented to allow participants to become accustomed to the procedure and to clarify any queries before the experimental materials were presented. The entire eye tracking session lasted approximately 25 minutes.

3.3 Results

3.3.1 Data Preparation and Analyses

Sentences were divided into five regions (see Table 12). Of these, three regions were of particular interest; the pre-target region that included the determiner and adjective, except for two stimuli where the pre-target region did not include an adjective, only the determiner ‘the’. We did not edit these sentences, as we did not wish to disrupt sentential context that previously had been pre-screened to result in an implausibility or anomaly. The target region included the critical noun where the plausibility violation occurred and the post-target region that included one long or two short words that immediately followed the target. These are where disruption in the eye movement record was expected to occur as a result of the plausibility violations.

Sentence comprehension was high and did not differ between ASD and TD groups (TD $M = 0.97$, $SD = 0.03$; ASD $M = 0.96$, $SD = 0.04$), with all participants correctly answering at least 86% of questions t (40.04) = 0.67, $p = 0.50$. A default cleaning process for reading experiments was carried out in DataViewer (SR Research, Ottawa, Canada), whereby contiguous fixations that had a duration of 80ms or less and were within .50° of one another were merged. Fixations were also merged in instances when there were three or more contiguous fixations, each less than 140ms within a region. Fixations below 80ms are unlikely to result in meaningful information being extracted from the text and fixations above 800ms are likely to be a result of tracker error and were therefore removed, resulting in a data loss of 3.49% (ASD = 1.74%, TD = 1.75%).

Trials were also excluded if there was tracker loss, if a participant blinked whilst fixating the target region, if participants failed to fixate at least two of the three ROI's, or if the trial had been disrupted during the testing session e.g., participant talking to the experimenter. These exclusions resulted in a total loss of 11.54% of experimental trials (ASD = 7.46%, TD = 4.08%).

For each ROI, each of the following eye movement measures were examined: first fixation duration (the duration of the first fixation made in a region), single fixation duration (the duration of a fixation in a region when this is the only fixation made in that region) and gaze duration (the sum of all fixations in a region from the first fixation on the region until the eyes leave the region from either left of right). These measures are usually taken to reflect early stages of linguistic processing in reading. We also analysed go past time (the sum of all fixations from the first fixation in a region until the eyes leave the region to the right, including any regressive fixations made to prior areas of the text) and total time (the sum of all fixations in a region), both of which are taken to reflect somewhat later stages of processing.

Data points from each eye movement measure were removed if more than 2.5 standard deviations away from the group by condition mean, which resulted in a loss of no more than 3.71% of data from each measure (approximately equal proportions of data were removed across groups for each measure). Each of the eye movement measures were log transformed and linear mixed effect models (Baayen, Davidson, & Bates, 2008) were computed in R (version 3.2.4; R Core Team, 2016) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015). The model computed for each measure examined whether there was a difference between groups, sentence plausibility or any interactions. Group and plausibility were both specified as categorical fixed effects and deviation contrasts were coded to examine whether there was a difference between ASD and TD readers, using the contr.sdif function from the MASS library (Venables & Ripley, 2002). In addition, two deviation contrasts were manually coded to examine the difference between anomalous and plausible sentences (anomalous -.5, implausible, 0, plausible, .5) and implausible and plausible sentences (anomalous 0, implausible -.5, plausible, .5). This user specified contrast matrix was inversed for analysis using the ginv function from the MASS library (Venables & Ripley, 2002). Age was included (centered) as a continuous fixed effect, in order to control for the age difference between ASD and TD readers and assure that any effects of group were a result of ASD. As is recommended, the full random structure was included (Barr, Levy, Scheepers & Tily, 2013), which meant that crossed random effects were included for participants and items, with random slopes for sentence plausibility at the participant level and random slopes for sentence plausibility, group and centered age at the item level. This resulted in the following syntax; Model = lmer(logDV ~ group* plausibility + centered_age + (1 + plausibility | participant_id) + (1 + group* plausibility + centered_age | item_id), data = data). The lmerTest package was used to compute *p* values (Kuznetsova, Brockhoff & Christensen, 2016). If a model would not converge, parameters were incrementally removed from the random structure, beginning with the items level. The model was initially re-run excluding the correlation. If this was unsuccessful, the correlation was re-entered and the model was re-run excluding the interaction. If the model would still not converge, a model excluding both the correlation and interaction was run, before removing random slopes one by one (age followed by condition followed by group). If the model would still not converge and only the random intercept for items remained, the correlation at the participant level was then removed, followed by the random slope. Prior to examining and interpreting model output, the distribution and normality of residuals (Pinheiro & Bates, 2000) was examined using QQ and density plots. The output for all fixed effect parameters can be viewed in Appendix D.

3.3.2 Global Measures

Before examining the effect of plausibility for the regions of interest, we examined whether there were any basic sampling differences between the ASD and TD groups. To do this, three global processing measures were analysed; mean fixation duration (the mean fixation duration calculated from all fixations in a trial), number of fixations (the sum of fixations made during a trial), and sentence reading time (time from trial onset until participants made a manual response). Means and standard deviations of these measures are included in Table 13. For clarity and succinctness, interactions are only reported if reliable. In addition, age did not have a reliable effect on any of the measures reported below, and therefore will not be discussed.

Analysis of mean fixation duration data indicated that there was no effect of group $b = -0.04$, $SE = 0.04$, $t = 1.14$, $p = .259$ and no difference between mean fixation durations for implausible $b < 0.01$, $SE = < 0.01$, $t = 0.35$ $p = .726$ or anomalous sentences $b = < 0.01$, $SE = < 0.01$, $t = 0.93$, $p = .355$, in comparison to the plausible sentences. For fixation count, there was a numerical trend to suggest ASD readers made more fixations than the TD group, but this was not reliable $b = -0.20$, $SE = 0.10$, $t = 1.92$ $p = .061$. However, there was an effect of sentence plausibility, with both TD and ASD readers making more fixations when reading anomalous sentences $b = -0.08$, $SE = 0.01$, $t = 6.89$, $p < .001$ in comparison to plausible sentences, but there was no difference between plausible and implausible sentences $b = -0.01$, $SE = 0.01$, $t = 1.47$, $p = .151$. Consistent with the numerical group effect for fixation count, analyses for sentence reading times indicated that ASD readers had longer sentence reading times overall $b = -0.26$, $SE = 0.12$, $t = 2.22$, $p = .032$, and both groups had longer reading times for implausible $b = -0.02$, $SE = 0.01$, $t = 2.18$, $p = .036$ and anomalous sentences $b = -0.08$, $SE = 0.01$, $t = 7.26$, $p < .001$ in comparison to plausible sentences.

From these global measures, we can tentatively conclude that there were no overall differences in the speed with which ASD and TD groups' extracted information from the text within individual fixations. The ASD readers did however have longer reading times overall, in comparison to the TD group. This is consistent with our previous studies examining reading in ASD that have found increased re-reading behaviour for these individuals (Au-Yeung, Kaakinen, Liversedge & Benson, 2015; Howard et al., 2017a). Importantly, there were no reliable interactions, with both groups showing comparable global effects of anomaly and implausibility upon the number of fixations made and sentence reading time. This indicates that these manipulations had a comparable overall impact upon language processing for both TD and ASD readers. Next, we will consider the fine-grained measures to examine the time course of anomaly and implausibility detection and processing in both groups.

Table 13.
Global eye movement measure means (standard deviations).

	Mean Fixation Duration (ms)		Mean Fixation Count		Mean Sentence Reading Time (ms)	
Condition	TD	ASD	TD	ASD	TD	ASD
Plausible	215 (30)	227 (42)	12 (4)	15 (7)	3122 (1037)	4245 (2161)
Implausible	217 (27)	225 (38)	12 (4)	16 (7)	3151 (1033)	4496 (2262)
Anomalous	216 (28)	228 (38)	15 (6)	18 (9)	3609 (1374)	5051 (2680)

3.3.3 Pre-target Region

At the pre-target region all sentence types were plausible, and as such, no differences between groups or sentence types were expected in early processing measures. For means and standard deviations for all pre-target, target and post target measures, see Table 14. Consistent with our expectations, no group differences were reliable for first fixation duration, single fixation duration, gaze durations or go past time (*ts* < 0.58, *ps* >.567). In addition, sentence plausibility also had no reliable effect on the duration of first fixations, single fixations, or gaze durations (*ts* < 1.64, *ps* >.102). However, sentence plausibility did affect the duration of go past times, with both groups taking significantly longer to proceed past the pre-target region when the upcoming target word was anomalous, in comparison to plausible $b = -0.06$, $SE = 0.01$, $t = 4.23$, $p <. 001$, but no difference was found between the implausible and plausible sentences $b = -0.02$, $SE = 0.01$, $t = 1.74$, $p = .087$.

The effect of anomaly on go past times was not predicted because at this point in time, participants had not yet fixated the target region where the plausibility violation occurred. However, this effect has been previously reported for experiments that have manipulated the plausibility of target words (e.g., Rayner et al., 2004) and there are two possible explanations. Firstly, it could be argued that the increased go past time for anomalous sentences are a parafoveal-on-foveal-effect. Such effects occur when the semantic characteristics of an upcoming word (*n+1*) influence the processing of the currently fixated word or region (*n*). This explanation is consistent with models of eye movement control during reading whereby attention is graded and permits the identification of multiple words in parallel (e.g., SWIFT; Engbert, Nuthmann, Richter & Kliegl, 2001). Alternatively, this effect might occur as a result of saccadic undershoots or small calibration errors that result in attention being allocated to the target word, but fixations located (or detected to be located) on the pre-target word (for a detailed discussion the mislocated fixations account, see Drieghe, Rayner & Pollatsek, 2008). This explanation is consistent with models of reading that predict attention to be allocated serially, with only low level information such as orthography and phonology being extracted from words in the parafovea (e.g., E-Z reader; Reichle, Rayner & Pollatsek, 2003). The exact cause of this effect, and whether it is evidence of parallel processing or something more trivial with regard to oculomotor or tracker error is not of critical concern for this experiment. What is important for this experiment is that this effect was constant across our groups, indicating that the processing of the pre-target region was comparable for TD and ASD readers.

3.3.4 Target Word

The target region was the word at which the plausibility violation occurred and disruption in the eye movement record was expected. Both first fixation and single fixation duration data showed the same pattern of results. No differences were found between the groups for first $b = -0.04$, $SE = 0.05$, $t = 0.83$, $p = .410$ or single fixation duration $b = -0.07$, *SE* = 0.05, *t* = 1.22, *p* = .229, but there was a significant increase in both first *b* = -0.04, *SE* = 0.01, *t* = 3.94, *p* < .001 and single fixation durations *b* = -0.06, *SE* = 0.01, *t* = 4.18, *p* < .001 upon the target when it was anomalous, in comparison to plausible. This suggests that during the earliest stages of foveal processing of the target, both TD and ASD participants detected the anomalies. No overall effect of implausibility was detected for first fixation durations *b* = -0.01, *SE* = 0.01, *t* = 1.39, *p* = .172, but the effect of implausibility was reliable for single fixation durations *b* = -0.04, *SE* = 0.01, *t* = 2.69, *p* = .009. However, this was qualified by a significant interaction between group and implausibility for both first *b* = -0.05, *SE* = 0.02, *t* = 2.41, *p* = .017 and single fixation durations *b* = -0.06, *SE* = 0.02, *t* = 2.32, *p* = .021.

In order to examine the nature of this interaction, the model was re-run separately for each group and each measure. The results indicated that for both first and single fixation durations, TD readers had longer fixation durations for both anomalous *b* = -0.05, *SE* = 0.01, *t* = 3.66, *p* < .001; *b* = -0.07, *SE* = 0.02, *t* = 3.82, *p* = .001 and implausible target words *b* = -0.04, *SE* = 0.01, *t* = 2.91, *p* = .006; *b* = -0.06, *SE* = 0.02, *t* = 3.82, *p* = .001, in comparison to plausible target words. In contrast, the ASD readers showed an increase in first and single fixation time for anomalous target words in comparison to the plausible *b* = -0.03, *SE* = 0.02, *t* = 1.84, *p* = .076; *b* = -0.05, *SE* = 0.02, *t* = 2.04, *p* = .050 (marginal for first fixation), but no difference between implausible and plausible targets *b* = 0.01, *SE* = 0.02, *t* = 0.36, *p* = .720; *b* = -0.01, *SE* = 0.02, *t* = 0.36, *p* = .722. These analyses indicate that both TD and ASD participants detected the anomalies upon initial fixation. However, detection of the implausibilities was present in the TD group, but absent for the ASD readers (See Figure 7).

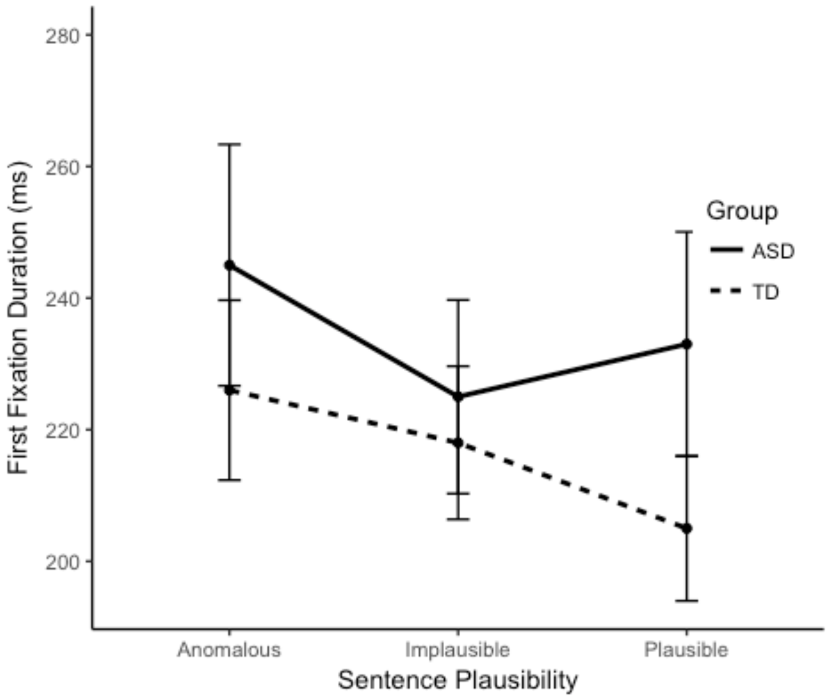

Figure 7. Mean first fixation duration on the target word for plausible, implausible and anomalous sentences. Error bars represent standard error.

There was no difference in gaze duration between groups *b* = -0.01, *SE* = 0.05, *t* = 0.26, *p* = .799, but a reliable effect of sentence plausibility was detected, with again both groups having longer gaze durations upon anomalous target words, in comparison to plausible target words *b* = -0.06, *SE* = 0.01, *t* = 4.44 *p* < .001, but no overall difference between implausible and plausible target words *b* = -0.03, *SE* = 0.02, *t* = 1.69, *p* = .102. The interaction term between the effect of implausibility and group was not significant for this measure *b* = -0.04, *SE* = 0.03, *t* = 1.59, *p* = .119. There was no difference overall between go past times for the TD and ASD groups *b* = -0.05, *SE* = 0.07, *t* = 0.81, *p* = .425. Both groups had longer go past times when the target word was anomalous *b* = -0.10, *SE* = 0.02, *t* = 5.24, *p* <. 001 and there was a marginal effect of implausibility *b* = -0.03, *SE* = 0.02, *t* = 1.98, *p* =. 054.

To summarise the findings for the target region; there were no reliable differences in the speed with which the TD and ASD groups detected the anomalies. Both groups detected anomalies very rapidly, as indexed by increased first and single fixation durations upon anomalous target words, relative to the plausible. The disruption to reading as a result of the implausibilities in these early measures, however, was only evident for the TD group. The TD group detected implausibilities as rapidly as anomalies, with first and single fixation durations being inflated. In contrast, the ASD group did not show disruption for any of the early stages of target word processing, as a result of the implausibility manipulation. This finding suggests that the ASD group did not detect the implausibilities during initial target word processing.

3.3.5 Post Target Region

The post target region included the words that immediately followed the target region. For first fixation duration, single fixation duration, gaze duration and go past time there was no reliable difference between the TD and ASD groups (*ts* < 1.21, *ps* > .233). There was also no reliable effect of sentence plausibility for first fixation durations, single fixation durations or gaze durations (*t*s < 1.48, *ps* > .148). However, an effect of anomaly was present for go past time $b = -0.11$, $SE = 0.03$, $t = 4.19$, $p <. 001$, which indicates that participants spent longer re-reading previous areas of the anomalous sentences in comparison to the plausible, prior to making a rightward saccade out of the post target region. There was no difference between go past times for implausible and plausible sentences $b = -0.02$, $SE = 0.02$, $t = 0.96$, $p = .340$. Together these results suggest that the disruption experienced when readers initially encountered the anomalies and implausibilities in the target region did not spill over and affect early processing of the words that followed, but the anomalies did result in increased go past times.

3.3.6 Total Times

Total time includes all fixations in a region, including those made during second pass reading (the period of time after the text has been read through once in entirety). No interactions between group and sentence condition were found for total times in any region of interest. For the pre-target region, ASD readers had increased total times, in comparison to TD readers $b = -0.24$ $SE = 0.11$, $t = 2.13$, $p = .039$. In addition, the total time spent in the pre-target region was affected by sentence plausibility, with longer total times occurring for both groups when the sentence was anomalous in comparison to plausible $b = -0.19$ $SE = 0.02$, $t = 9.25$, $p < .001$, but the implausible and plausible sentences did not differ from one another $b = -0.02$ $SE = 0.02$, $t = 0.93$, $p = .361$.

In the target region there was a difference between the TD and ASD groups total times $b = -0.20$ $SE = 0.09$, $t = 2.15$, p = .038, with the ASD group spending longer fixating this region overall. There was also a reliable effect of plausibility in the target region, with participants spending significantly longer in this region when the sentence was anomalous in comparison to plausible $b = -0.13$ $SE = 0.02$, $t = 6.07$, $p < .001$, but the implausible and plausible sentences did not differ $b = -0.02$ $SE = 0.02$, $t = 1.14$, $p = .263$.

In the post-target region, there was no reliable effect of group *b* = -0.17 *SE* = 0.11, *t* = 1.54, *p* = .130, but there was a reliable effect of sentence type, and identical to the findings for the previous regions, participants spent significantly longer amounts of time fixating the post target region when the sentences were anomalous in comparison to plausible *b* = -0.08 *SE* = 0.02, *t* = 3.80, p = .001, but the implausible and plausible sentences did not differ *b* = -0.02 *SE* = 0.02, *t* = 0.98, *p* = .329.

Table 14.
Observed means (standard deviations) of the eye movement measures (ms) for the pre-target, target and post target regions.

Condition	First Fixation Duration		Single Fixation Duration		Gaze Duration		Go Past Time		Total Time	
	TD	ASD	TD	ASD	TD	ASD	TD	ASD	TD	ASD
					Pre-target					
Plausible	209 (52)	221 (66)	227 (55)	221 (56)	294 (114)	325 (160)	316 (134)	352 (187)	368 (177)	524 (337)
Implausible	208 (53)	218 (67)	230 (47)	232 (74)	298 (115)	316 (158)	351 (181)	362 (207)	397 (209)	517 (370)
Anomalous	207 (53)	213 (61)	232 (55)	227 (70)	318 (130)	325 (158)	372 (196)	380 (195)	545 (288)	741 (442)
					Target					
Plausible	205 (54)	233 (80)	198 (50)	236 (75)	241(99)	247 (93)	267 (136)	302 (183)	312 (182)	388 (243)
Implausible	218 (57)	225 (69)	224 (57)	232 (75)	261(92)	251 (99)	295 (142)	300 (157)	312 (144)	393 (239)
Anomalous	226 (67)	245 (86)	232 (64)	261 (90)	266 (106)	281 (104)	337 (207)	361 (205)	396 (221)	461 (258)
					Post Target					
Plausible	229 (85)	239 (90)	253 (102)	256 (99)	314 (160)	332 (163)	409 (251)	578 (521)	415 (222)	509 (296)
Implausible	239 (76)	236 (80)	262 (92)	263 (84)	338 (164)	309 (144)	448 (281)	576 (584)	437 (223)	494 (274)
Anomalous	229 (79)	247 (91)	240 (79)	258 (97)	333 (164)	361 (187)	583 (494)	765 (800)	483 (257)	647 (403)

3.3.7 Supplementary Analyses

Considering the lack of difference between the ASD and TD groups first pass reading times (gaze durations), yet clear differences in total and sentence reading times, it seemed reasonable to explore the nature of this increased reading time in ASD. In the following supplementary analyses, we were keen to establish the time course of this increased re-reading in the ASD group and whether this was localised to a particular ROI. If the increased total times for the ASD readers arose due to a higher proportion of regressive fixations during first pass reading of the sentences, then this might suggest that they experienced difficulty constructing an initial interpretation of the sentence. Alternatively, if re-reading occurred during second pass (or later) reading, then this might indicate that whilst ASD readers did not differ from the TD group in their initial construction of an interpretation of the sentence, their evaluation of this interpretation caused them to re-read the sentences. Means and standard deviations for all supplementary analyses are presented in Table 15. Below we only report significant effects of group. No reliable interactions were detected. Those interested in how sentence type mediated these differences across groups are referred to the on-line supplementary material where full model output is presented.

Firstly, we examined the proportion of first pass regressions made out of each ROI (prior to a reader fixating information to the right of a ROI). This was to identify the time course of re-reading, in other words, whether the increased re-reading for ASD participants occurred during first pass of the sentence (prior to a participant proceeding to fixate new rightward information). No differences between the proportions of first pass regressions made out of the pre-target, target or post target regions were found (zs <1.10, ps > .274). Thus, ASD readers were no more likely than TD readers to regress in order to re-read during the first pass through the sentence.

Secondly, we examined the proportion and duration of re-reading (total time minus gaze duration), in order to examine whether a particular region re-reading for ASD participants was localised. For the pre-target region the ASD group were found to engage in re-reading on a higher proportion of trials in comparison to TD readers b = -0.80 SE = 0.37, z = 2.16, p = .031, but no difference was found between the groups for duration of re-reading b = -0.23 SE = 0.13, t = 1.76, p = .086. Similarly, for the target region ASD readers were found to re-read on a higher proportion of trials, in comparison to TD readers b = -0.88 SE = 0.37, z = 2.39, p = .017. However, there was no evidence that there was any difference in the amount of time the two groups spent re-reading when they revisited this region b = -0.08 SE = 0.10, t = 0.82, p = .419. For the post target region, a marginal difference between groups was found for the proportion of re-reading b = -0.63 SE = 0.35, z = 1.82, p = .069, with a trend suggesting ASD participants revisited this region to re-read on a higher proportion of trials than TD participants. There was also a marginal difference between groups for re-reading duration b = -0.21 SE = 0.11, t = -1.94, p = .060, indicating that there was a tendency for ASD readers to spend longer re-reading information in the post-target region too.

Table 15.
Observed means (standard deviations) for the three measures analysed as part of the supplementary analyses.

	Proportion of Re-reading		Re-reading Duration (ms)		Proportion of First Pass Regressions Out	
	TD	ASD	TD	ASD	TD	ASD
			Pre-target			
Plausible	.26 (.44)	.45 (.50)	295 (159)	465 (383)	.06 (.23)	.06 (.24)
Implausible	.31 (.46)	.41 (.49)	325 (189)	589 (579)	.08 (.27)	.10 (.30)
Anomalous	.58 (.49)	.73 (.44)	412 (237)	571 (432)	.10 (.30)	.14 (.35)
			Target			
Plausible	.24 (.43)	.41 (.49)	277 (141)	364 (266)	.11 (.32)	.12 (.33)
Implausible	.21 (.41)	.40 (.49)	280 (150)	380 (287)	.11 (.32)	.14 (.34)
Anomalous	.39 (.49)	.53 (.50)	324 (186)	345 (236)	.17 (.38)	.19 (.40)
			Post target			
Plausible	.32 (.47)	.41 (.49)	309 (190)	428 (283)	.23 (.42)	.30 (.46)
Implausible	.30 (.46)	.45 (.50)	347 (198)	418 (276)	.23 (.42)	.31 (.46)
Anomalous	.44 (.50)	.55 (.50)	363 (227)	546 (400)	.35 (.48)	.40 (.49)

3.4 Discussion

The on-line use of world knowledge during reading in ASD was examined by monitoring the eye movements of participants as they read sentences that were plausible, implausible or anomalous. Both the TD and ASD groups detected the anomalies almost immediately, as indexed by increased first fixation durations on the target word. The anomalies also disrupted later sentence processing in both groups, as indexed by go past times for the target and post target region, and total times for all critical regions. The TD group detected the implausibilities as rapidly as the anomalies; with disruption occurring during first fixations on the target word and this effect was also evident for single fixation durations. This is the first study to report that TD readers detect implausibilities as rapidly as anomalies. Previous studies have reported disruption as a result of implausibilities in later measures (Rayner et al., 2004; Joseph et al., 2008). However, the disruption as a result of the implausibilities in the current study was shorter lived in comparison to the disruption as a result of the anomalies, and was only evident in these very early measures. Therefore, although the speed of detection is inconsistent with previous findings, the reduced disruption as a result of implausibilities relative to anomalies is comparable (e.g., Joseph et al. 2008; Rayner et al. 2004). However, the speed with which TD participants in this study detected implausibilities is similar to what was found by Matsuki et al. (2011), who normed their plausible stimuli to more carefully match participant event knowledge. In addition Matsuki et al., (2011) used a fully counterbalanced design (i.e., target words/sentence frames occurred in both plausible and implausible sentence conditions e.g., *Donna used the hose/shampoo to wash her filthy hair/car after she came back from the beach*). No anomalous stimuli were included in Matsuki et al.'s (2011) study, but they found implausible target words to result in longer first fixation durations, as was the case in the current study. Matsuki et al. (2011) highlighted that in previous studies (e.g., Rayner et al., 2004) that the plausible (control) sentences despite being probable may not have matched undergraduate event knowledge closely and therefore may have masked some of the early influences of implausibility. Therefore, one possible explanation for the differential time course of implausibility effects for the TD readers in the current and previous studies (e.g., Joseph et al., 2008; Rayner et al., 20014) is the age of our TD participants. Previous studies that have used similar manipulations have recruited undergraduate students who are approximately 18 years of age. In the current study individuals were recruited from the local community and had an average age of 29 years. It's therefore possible that the increased life and language experience of our participants resulted in the plausible sentences matching their event knowledge more closely and resulting the detection of implausibilities, relative to plausible sentences occurring more immediately within the eye movement record than has been previously reported for undergraduate readers.

Our critical finding was the interaction between group and the effect of implausibility for first and single fixation durations in the target region. This revealed that the ASD readers, unlike TD readers, failed to detect implausibilities upon initial fixation of the target. Moreover, the ASD readers did not appear to show any disruption as a result of the implausibilities at any point during the processing of the critical regions. Disruption was found however for the global measure of sentence reading time, which indicates that ASD readers did detect and experience disruption to reading as a result of the implausible semantic oddities relative to the plausible sentences. The time course difference indicates that the detection of implausibilities was delayed for ASD readers, relative to TD readers.

This finding partially supports our predictions. Based on the assumption that both types of linguistic manipulation require the evaluation of world knowledge for the oddities to be detected, we predicted that there would be a delay in the detection of both anomalies and implausiblities in ASD. However, we found ASD readers to be delayed in the detection of implausibilities, but not in anomaly detection. Recall that the anomalous sentences not only violated world knowledge, but also violated a verb's selectional restrictions, which are semantic rules about what can and cannot be an argument to the verb. This information is activated when a verb is lexically identified and is then used to assign thematic roles (e.g., Carlson & Tanenhaus, 1988). Therefore, it is possible that the reason the participants with ASD immediately detected the anomalies, but not the implausibilities, is because the anomalies could be detected without the use of world knowledge, on the basis of information activated during relatively early lexical stages of processing (e.g., Warren & McConnell, 2007). In contrast, the evaluation of world knowledge was critical for the detection of implausibilities that were not detectable based on verb argument violations. What this means in relation to our hypothesis is that the detection of semantic oddities that require the evaluation of world knowledge is less efficient (delayed) in ASD, but the detection of semantic anomalies which are a result of verb-argument violations, and which may be detected on the basis of selectional restriction information, is not.

One might consider these results to be in conflict with Howard et al.'s (2017a) finding that ASD readers detected that they had misinterpreted an ambiguous prepositional phrase, as quickly as TD readers, based upon their evaluation using world knowledge. However, a closer look at the materials used in the Howard et al. (2017a) experiment indicates that a high proportion (70%) of the stimuli were anomalous as a result of a violation of a verb's selectional restrictions. Therefore, it is possible that the quite immediate disruption seen for ASD readers by Howard et al. (2017a) was not evidence for intact world knowledge use, but instead evidence in support of intact detection of selectional restriction violations at an earlier stage of processing.

What our data very clearly demonstrate is that consistent with what CIP theory predicts, when the use of world knowledge is required during reading, subtle differences in the time-course of sentence processing are apparent for TD and ASD readers. These findings are inconsistent with the WCC theory, that would predict a lack or delay in both implausibility and anomaly detection, given that both of these sentence types required integrative processes. These findings are also in contrast with Saldaña and Frith's (2007) conclusion that the speed and access to world knowledge during reading in ASD is as efficient as TD readers and Sansosti et al.'s (2013) finding that readers with ASD have longer fixation durations. It is possible that the difference between our own and Sansosti et al.'s (2013) findings may be related to differences in the stimuli they used, which required an inference to be computed, a demand that was not required in our own study and one which may have induced such processing differences. We did however replicate the finding that overall readers with ASD take longer to read sentences (Au-Yeung et al., 2015; Howard et al., 2017a; Sansosti et al. 2013).

A very recent study asked adults with ASD to read passages of text that either contained sentence level thematic anomalies (e.g., *The authorities were trying to decide where to bury the survivors*) or passage level anomalies that required the processing of the entire passage context (e.g., *Scott was worried that his inability to speak Japanese would stop him from communicating with people* following a passage context that explained Scott was moving to China) (Au-Yeung, Kaakinen, Liversedge, & Benson, 2017). An interaction was detected whereby adults with ASD detected sentence level thematic anomalies more rapidly than TD controls, but the reverse was found for passage level anomalies, with TD readers detected these more rapidly than ASD readers. These findings are partially in line with our current data, with both studies finding ASD readers to rapidly detect severe thematic violations, but show a delay in the detection of anomalies that rely upon the processing of broader passage and situational context. In contrast, Au-Yeung et al.'s (2017) finding that TD readers detected sentence level anomalies less rapidly than ASD readers is in conflict to our own results, but is likely a result of TD readers higher reliance upon broader passage context, which was not provided within the current study. Overall, the pattern of results reported by Au-Yeung et al. (2017) appear to support our conclusion that the requirement to process situational knowledge (e.g., what language should be learnt if moving to China) influences processing efficiency in ASD.

The supplementary analyses demonstrated that ASD readers revisit each ROI to re-read on a higher proportion of trials than TD readers. Moreover, this re-reading did not appear to be localised to any particular ROI but reflected the ASD participants re-reading once the sentences had been read through entirely. The lack of difference found in first pass regressions and lack of group interactions specific to the re-reading of anomalous and implausible sentences suggests that this increased re-reading is not a result of a linguistic processing difference *per se*. Thus, the re-reading ASD participants engaged in may have been related to the evaluation of their initial interpretation. This idea is consistent with what has been previously reported, when the time-course of re-reading in ASD has been examined (Howard et al., 2017a).

It is possible that the inclusion of comprehension questions may have led the ASD group to be especially aware of the requirement to comprehend the sentences correctly, leading these readers to be more hesitant to press a button and confirm that they had finished reading each sentence. Note that we are not arguing that the ASD participants are simply slower to react. Instead, we are suggesting that it may take ASD participants longer to develop a sense of confidence in relation to any response they may make about their interpretation of what they have just read. The sensitivity of ASD groups to instruction requirements and task demands is increasingly recognised in the literature to be a factor that affects performance on tasks assessing aspects of cognitive processing (e.g., see the review of performance on executive functioning tasks in White, 2013). It is also noteworthy that several of the participants with ASD who took part in this experiment vocalized anxieties about the prospect of answering comprehension questions, indicating that this was a task they had had difficulty with in the past. Therefore, the possibility that the increased re-reading in our ASD sample reflects an increased ‘checking’ of an interpretation of a sentence as a result of apprehension concerning upcoming comprehension questions, seems potentially reasonable, but remains to be empirically tested. Similar reports of repeated sampling of task relevant information has also been recently observed during scene inspection in ASD (Benson, Castelhano, Au-Yeung & Rayner, 2012; Benson, Castelhano, Howard, Latif & Rayner, 2015).

We have championed the use of eye tracking to examine language processing in this paper, because of it's capacity to provide detailed information about on-line language processing in ASD. We realise that this is an indirect measure of world knowledge processing, but we believe that this method clearly provides much more information processing detail in comparison to traditional RT and Accuracy measures. Further research using methods that examine both on-line behavioural measures and neural activity, for example, examining fixation related potentials through the co-registration of eye tracking and EEG would provide insight into the qualitative differences in the neural systems that underlie temporal processing differences in language processing in ASD. Since the current impact of this research is predominantly theoretical, this could be noted as a limitation to the work, however, these findings and the research that they subsequently motivate, have potential to contribute to the development of more effective application techniques and guidelines in relation to reading development and comprehension in ASD.

To conclude, differences in the speed with which world knowledge was used in written language processing were present between an ASD and TD group when reading single sentences containing implausibilities. ASD readers did, however, detect anomalies that were more severe semantic violations and a result of selectional restriction violations as quickly as TD readers. Thus, this study demonstrates both that there are subtle differences in the time course with which world knowledge is used to evaluate sentence meaning during reading in ASD. It would seem reasonable to conclude that the performance differences found in ASD groups during higher order linguistic tasks may in part be a consequence of less efficient world knowledge processing.

Chapter 4: Discourse Processing

Published: Howard, P. L., Liversedge, S. P., & Benson, V. (2017). Processing of Co Reference in Autism Spectrum Disorder. *Autism Research*. DOI: 10.1002/aur.1845

4.1 Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition that is diagnosed when an individual has significant difficulty with social interaction and communication, in addition to restricted and repetitive patterns of behaviour (American Psychiatric Association, 2013). Basic reading ability (e.g., word identification) and the efficiency of such processing has repeatedly been reported to be intact in individuals with ASD and no associated learning difficulties or additional language impairment (e.g., Howard, Liversedge & Benson, 2016; Huemer & Mann, 2010; Minshew, Goldstein & Siegel, 1995; Saldaña, Carreiras, & Frith, 2009). However, ASD is associated with atypical performance for higher order reading tasks, such as comprehension and inferencing.

In general, comprehension accuracy is reported as reduced for readers with ASD, relative to typically developing (TD) controls (Huemer & Mann, 2010; Jones et al., 2009; Nation et al., 2006 cf. Åsberg et al., 2010). A meta-analysis indicated that ASD does not independently cause comprehension difficulties, but increases the likelihood of such difficulties occurring (Brown, Oram-Cardy, & Johnson, 2013). The presence of comprehension difficulties has been found to be highly associated with additional language impairment and general verbal proficiency (e.g., Brown, Oram-Cardy, & Johnson, 2013; Lucas & Norbury, 2015; Norbury & Nation, 2011). Therefore, it would seem that ASD and the cognitive processing differences associated with this condition may contribute, but are not an autonomous cause or predictor of the comprehension difficulties often experienced in individuals with ASD.

The findings in relation to inferencing accuracy in ASD however are more consistent. For operational purposes, we adopt the broad definition that an inference is any implicit information or link that readers draw from text (e.g., Graesser, Singer & Trabasso, 1994; McKoon & Radcliff, 1992). This definition, therefore, includes aspects of referential processing (e.g., identifying that *he* refers to *Dave* when reading *Trevor admired Dave, he had an excellent work ethic)*, where a reader simply has to infer that two words refer to the same semantic entity, in order for a co-referential link to be formed (e.g., Ehrlich & Rayner, 1983). Other types of inferential processing include causal inferences, where an implicit event is inferred that links two portions of text together (e.g., inferring that it had rained when reading *Sally had forgotten her umbrella, she was soaked when she arrived at work* e.g., Haviland & Clark, 1974). Causal inferences are generally considered to be more cognitively effortful than referential processing, because of the requirement to infer more complex information (i.e., causal relations in events). In addition, readers often compute global pragmatic inferences on-line (e.g., inferring a character's intent e.g., Poynor & Morris, 2003) that embellish global text coherence. Such inferences may be considered to be more complex than both referential and causal inferences, as they involve a reader generating elaborative inferences that often relate to text at a global discourse level[1]. Different types of inference have previously been categorized into a hierarchy according to various criteria, for example, whether an inference is considered to be automatically or strategically computed (e.g., McKoon & Ratcliff, 1992), and, whether an inference is text connecting and often necessary for local coherence, or 'extratextual' serving to embellish the global mental representation of a text (e.g., Graesser et al., 1994). Irrespective of the deemed complexity/categorisation of the inference itself, readers engage in such processing and integrate inferred information into the discourse model, in order to maximise local and global text coherence that is often necessary for proficient comprehension.

There are multiple reports of individuals with ASD performing with reduced accuracy in comparison to TD controls, on reading and aural tasks that require some form of inference to be computed (e.g., Bodner, Engelhart, Minshew & Williams, 2015; Dennis, Lazenby & Lockyer, 2001; Jolliffe & Baron-Cohen, 1999, 2000; Minshew et al., 1995; Norbury & Bishop, 2002; Norbury & Nation, 2011; O'Connor & Klein, 2004; Tirado & Saldaña, 2016 cf. Saldaña & Frith, 2007). Therefore, it is possible that ASD specific difficulties associated with inferential processing during reading is a contributing factor to reports of poor comprehension. Jolliffe and Baron-Cohen (1999) found adults diagnosed with autism and Asperger's Syndrome to be less accurate at answering multiple choice questions about two sentences that evoked a bridging inference (see Example 1 below, where two sentences are connected by an implicit event, correct answer in bold), in comparison to TD controls. Also, individuals with autism took longer to respond in comparison to both the TD controls and participants with Asperger's syndrome.

---

[1] Note that this is not an exhaustive list. There are many other inferences that readers compute. For a comprehensive description of these, see Graesser et al. (1994).

1. George left his bath water running. George cleared up the mess in the bathroom. Question: George cleared up the mess in the bathroom because:

A. **The bath had overflowed**

B. His brother had left it untidy

C. The workman hadn't cleared up his mess

Further, there are reports of individuals with ASD having reduced accuracy for comprehension questions that require inferential processing, but intact comprehension accuracy when the answer can be derived from information explicitly provided within a text (Jolliffe & Baron-Cohen, 2000; Norbury & Bishop, 2002; Norbury & Nation, 2011). What these studies suggest is that inferential difficulties in ASD cannot necessarily be attributed to reduced comprehension in general, and that inferencing efficiency (speed) may be associated with the severity of ASD symptoms.

Similarly to what has been found for comprehension, inferencing accuracy in ASD is related to general language proficiency (as is also the case for TD individuals e.g., Norbury & Nation, 2011). Lucas and Norbury (2015) found vocabulary knowledge and verbal working memory to predict reduced inferencing accuracy over and above ASD status. However, the authors highlight that there was a numerical trend that indicated that a much higher proportion of participants in both ASD with language impairment (ALI, 50%) and ASD without language impairment (ALN, 33.3%) had specific difficulties with inferencing, in comparison to the TD controls (12.5%). Consistent with what this trend suggests, the cognitive differences associated with ASD have also been reported to additionally and significantly contribute to inferencing difficulties. Norbury and Bishop (2002) found a higher percentage of children with ASD to have difficulty making inferences in comparison to children who had specific or pragmatic language impairement. ASD has also been found to uniquely account for approximately 10% of the variance in inferencing accuracy scores for both aural and reading tasks (Bodner et al., 2015; Norbury & Bishop, 2002; Norbury & Nation, 2011). Furthermore, reading interventions that aim at assisting adolescents with ASD to compute referential links on-line (e.g., pronoun resolution), prior to continuing reading, have been found to improve overall comprehension (e.g., O'Connor & Klein, 2004). However, based upon off-line behavioural studies, it is difficult to identify the nature and time course of mechanistic processing differences that exist in relation to the computation of inferences during reading in ASD.

An important question, therefore, that remains to be addressed relates to how the cognitive processing differences associated with ASD impact upon on-line inferential processing? One study that attempted to answer this question asked adolescents to read two sentences that evoked a bridging inference (replicating Saldaña & Frith's, 2007 experiment), as their eye movements were monitored (Sansosti et al., 2013). The readers with ASD were reported to have longer average fixation durations, to make more regressive eye movements back through the text, and to have longer reading times overall. Together these measures suggest that the computation of an inference was more effortful for readers with ASD, and the authors concluded that this result reflected an atypicality in the integration of world knowledge into the discourse model. However, only global eye movement measures were reported (averaged across the entire reading of the two sentences), and as such, the precise time course and nature of these differences are unclear. In order to investigate the precise differences in on-line eye movement behaviour that occur during reading, and thereby assess with more precision, differences in the specific cognitive processes that occur in ASD reading, assessment of multiple reading measures localised to critical regions within sentences is necessary. Nevertheless, it is certainly the case that Sansosti et al.'s study provides data suggesting that the moment to moment computation of inferences is atypical in ASD.

Very recently, Micai, Joseph, Vulchanova and Saldaña (In press) did precisely this. Adolescents with and without ASD who were matched on a wide range of cognitive variables, including oral language skill and reading comprehension, were asked to read passages as their eye movements were monitored. The passage of text required an inference to be formed and the question directly probed participant's computation of this inference. For example, in example 2 below, participants were expected to infer that Mico was a cat, upon identification of the target (underlined) word *mouse.*

2. It was Monday morning and was really warm. Mr. Francisco fed his parrot and then went over to check the little Mico was ok. He was in a deep sleep and appeared to be dreaming. Mico's legs were moving back and forth as if he was imagining chasing a mouse very fast, trying to catch it.

What animal is Mico?

A. Dog

B. Parrot

C. **Cat**

The two groups did not differ in terms of comprehension question accuracy, therefore indicating that both TD and ASD participants had generated the correct inference. However, ASD participants had longer gaze durations in comparison to TD readers upon the critical word that informed the inference (*mouse*). In addition, ASD readers regressed back to words that supported and further informed this inference (e.g., little), on a higher proportion of trials, in comparison to TD readers. This therefore demonstrates that there are subtle differences in the efficiency of inferential processing during reading in individuals with ASD.

Both the Weak Central Coherence Theory (WCC; Frith & Happé, 1994) and the Theory of Complex Information Processing (CIP; Minshew & Goldstein, 1998) predict integrative processes to be atypical in ASD. Based upon the literature, it would appear that readers with ASD are as efficient as TD readers at constructing a mental representation of what a text explicitly conveys (Au-Yeung, Kaakinen, Liversedge & Benson, 2015; Howard et al., 2017). Therefore, the hypothesis that readers with ASD have a universal difficulty with text integration during reading is not supported. However, it is possible that there are atypicalities in processing that are specifically related to the on-line integration of implicit (inferred) information into the discourse model. This process is essential for an inference to be formed. Therefore, if this process is atypical in ASD, this could contribute to the reports of poorer performance for inferencing tasks.

The aim of this experiment was to examine the on-line formation of co-referential links within the discourse model in reading in ASD. Anaphoric links are a common form of co-referential processing, which often require a reader to make an inference in order to compute a link between words that co-refer. Previous studies have demonstrated that reading times and fixations upon anaphoric category nouns (e.g., *bird*) are longer, following an atypical exemplar (e.g., *penguin*), in comparison to a typical exemplar (e.g., *pigeon*; Garrod & Sanford, 1977; Duffy & Rayner, 1990; Rayner, Kambe & Duffy, 2000; Myers, Cook, Kambe, Mason & O'Brien, 2000; c.f. Van Gompel, Liversedge, & Pearson, 2004). This increased fixation time is thought to reflect the greater difficulty associated with inferring and forming a link between nouns and atypical exemplars that are semantically less well connected than are more typical exemplars. By adopting this paradigm, comparing the speed with which TD and ASD individuals form anaphoric inferences, we can examine the efficiency with which a very basic inference is computed (i.e., that *bird* co-refers to *pigeon*/*penguin*) and is used to form a co-referential link that is then incorporated into the discourse model in ASD. If readers with ASD compute an anaphoric link less efficiently than TD readers, then we predict interactive effects across participant group, whereby TD readers will demonstrate standard typicality effects upon fixation of the category noun, but these effects will be reduced, less immediate, or even absent in individuals with ASD.

4.2 Method

4.2.1 Participants

Two groups of participants were recruited, one that consisted of 16 adults (1 female, aged between 24-54) with a formal diagnosis of an ASD, 14 were diagnosed with Asperger's syndrome, 1 with autism and 1 with pervasive developmental disorder. These participants were recruited through local charitable organisations on a voluntary basis. ASD diagnoses were confirmed using module four of the ADOS-2 (Lord et al., 2012) that was administered by the first author who is fully trained and has received accreditation to administer this assessment for the purposes of research. All participants reached criteria for ASD. The second group of participants were 16 TD volunteers from the local community (1 female, aged between 24-65) and were recruited through on-line advertisement on Gumtree (a free local advertising website). Participants were paid for their time and either travelled to the University to take part (costs reimbursed) or were visited at their homes to be tested using the Universities mobile research unit. Both groups of participants were native English speakers, had no learning difficulties (e.g., dyslexia) and did not differ in age t (29.77) = 0.88, p = .387 (ASD M = 37.13 SD = 11.55, TD M = 33.69, SD = 10.58). On average the two groups did not differ in verbal IQ t (28.98) = 0.16, p = .876 (ASD M = 116.60 SD = 10.11, TD M = 116.00, SD = 11.08), performance IQ t (26.00) = 0.17, p = .863 (ASD M = 116.33 SD = 13.04, TD M = 117.06, SD = 9.83) or full scale IQ t (27.51) = 0.44, p = .662 (ASD M = 116.38 SD = 13.17, TD M = 118.25, SD = 10.04), as assessed using the Wechsler Abbreviated Scale of Intelligence[2] (Wechsler, 1999). In addition, both groups completed the recalling subtest from the Clinical Evaluation of Language Fundamentals (Semel, Wiig & Secord, 2003) that is sensitive to the detection of language impairment (e.g., Conti-Ramsden & Botting, 2001, max score 96: ASD M = 85.19 SD =

[2] One ASD participant could not complete all 4 subtests because of time constraints, and therefore verbal and performance IQ could not be estimated. Full scale IQ was estimated based on performance on the vocabulary and matrix reasoning subtests.

6.12, TD *M* = 91.19, *SD* =5.11). All participants scored above the highest age equivalent cut off (>12.11 years), however, on average the ASD group's raw score (standard scores not available for this age range) was lower on this assessment, in comparison to the TD group *t* (29.08) = 3.01, *p* = .005. The York Assessment of Reading Comprehension (Snowling et al. 2010) was administered to assess general reading ability and the two groups did not differ in raw scores on the single word reading test *t* (29.91) = 0.15, *p* = .884 (max score 70; ASD *M* = 68.13 *SD* = 2.33, TD *M* = 68.25, *SD* = 2.46), but the ASD group were found to have lower accuracy than the control group for a passage comprehension task *t* (27.93) = 2.77, *p* = .010 (max score 13; ASD *M* = 8.38 *SD* = 1.95, TD *M* = 10.06, *SD* = 1.82). As expected the two groups differed in the number of self-reported autistic traits, as measured by the Autism Quotient Questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), with the ASD group reporting a significantly higher number of autistic traits in comparison to the TD group *t* (29.32) = 5.85, *p* = < .001 (ASD *M* = 35.81 *SD* = 8.18, TD *M* = 17.44, *SD* = 9.54).

4.2.2 Materials

Forty mini discourse pairs that consisted of two sentences each were developed. The mini discourses included an exemplar noun in the first sentence that co-referred to a category noun in the second sentence. The mini discourse pairs were identical apart from the exemplar noun in the first sentence that was either a typical or an atypical instance of the category noun. Stimuli were divided into seven regions of interest. This included the start of the first sentence; the antecedent, that consisted of the category instance; the post-antecedent region that included the remainder of the first sentence; the pre-target region which included the beginning of the second line of text; the target region that included the category noun; the post-target region that consisted of one long or two short words; and the end region. See Table 16 for an example of the stimuli and regions of interest.

Twenty of the category nouns and exemplars were chosen on the basis of Van Overschelde, Rawson and Dulonsky's (2004) updated version of Battig and Montague's (1969) category noun typicality norms, and twenty were selected based upon the first author's judgement. To ensure that all of the exemplars chosen were correctly categorised as typical or atypical, 16 undergraduates were asked to list as many instances of the 40 category nouns as they could, in the order that they thought of them (see Overschelde et al. 2004). The probability that each of the two instances used for a particular category noun in an experimental stimulus was then calculated. It was assumed that instances listed by a high percentage of participants were typical of that category and those listed by few participants were relatively atypical exemplars of that category. From 40 item pairs, 32 were selected that differed significantly in the likelihood that they were listed, that is, their typicality (Typical *M* = .84 *SD* = .15, Atypical *M* = .04, *SD* = .03). The full set of materials can be seen in Appendix E.

Table 16.
An example of the experimental stimuli and region of interest boundaries.

Start	**Antecedent**	**Post Antecedent**	
Jane quietly watched the elderly	pigeon/penguin	shuffling around next to the water. She	
Pre-target	**Target**	**Post target**	**End**
managed to take a photograph, just as the	bird	flapped	its wings.

4.2.3 Procedure

The text was presented across two lines and the target category noun was positioned at approximately the middle of the second line. In total participants read 67 mini discourses, 5 that were for practice and occurred at the beginning of the session, 32 that were the experimental discourses and 30 filler discourses. The experimental and filler trials were presented in a random order. Participants were asked to read normally for comprehension and to answer a *Yes/No* comprehension question (for which *Yes* and *No* answers were equally likely) after half of trials using a button controller.

4.2.4 Apparatus

The text was displayed on a 21inch CRT monitor set at a refresh rate of 100Hz. Participant's eye movements were monitored using a desktop mounted Eyelink 1000 (SR Research, Ottawa, Canada) that was operating at a sampling rate of 1000Hz and head movements were minimised using a chin and forehead rest. A 13 point calibration procedure was used, and it was required that fixation on each of the points was within .5 degrees of error, prior to the start of the experiment. Recalibration was performed throughout the experiment when needed.

4.2.5 Design

A 2 (Exemplar Typicality: typical vs. atypical) X 2 (Group: TD vs. ASD) design was employed with exemplar typicality as a within participants factor, and group as a between subjects factor. The stimuli were split into two lists of equal length that each contained one version of each stimulus, 16 typical and 16 atypical exemplars. Participants were split into two groups with each group receiving one of these lists. Thus, sentences containing typical and atypical instances of the category were rotated across subject groups according to a Latin Square.

4.3 Results

4.3.1 Data Preparation and Analyses

The default DataViewer (SR Research, Ottawa, Canada) cleaning process for reading experiments was used (as detailed in Chapter 3). The removal of fixations less than 80ms and more than 800ms resulted in a loss of 4.03% data. In addition, trials were removed when participants blinked whilst fixating the target (4.79%) and when there was some form of trial disruption (e.g., tracker loss, movement, 0.21%), which resulted in a further loss of 5% data. In addition, as per previous experiments, data points that fell more than 2.5 standard deviations away from the group by condition mean were excluded, which resulted in a loss of no more than 3% of data from each eye movement measure.

Data were analysed with linear mixed effect models (Baayen, Davidson & Bates, 2008) using the lme4 library (Bates, Maechler, Bolker & Walker, 2015) in R (version 3.2.4; R Core Team, 2016). Group and typicality were coded as categorical fixed effects using sliding contrasts to attain main effects, specified using the contra.sdif function from the MASS library (Venables & Ripley, 2002). This resulted in the following syntax lmer(dv ~ group*typicality + (1+typicality|participant_ID) + (1 + condition*group|stimuli_ID), data = data). For each measure, this initial model was compared to two additional models using likelihood-ratio tests; a model that included expressive language scores (centred) as an additional continuous predictor, and a model that specified a group by expressive language interaction. These model comparisons were run given the group differences in expressive language skill to assure these differences were not misattributed to be a consequence of ASD. If the inclusion of expressive language improved model fit (main effect or interaction), this predictor was kept within the model. However in general, the inclusion of expressive language as a predictor did not improve model fit. For conciseness and clarity only instances when the inclusion of this variable improved model fit are highlighted below.

The distribution and normality of residuals (Pinheiro & Bates, 2000) was examined using QQ and density plots. As is recommended, the full random structure was included (Barr, Levy, Scheepers & Tily, 2013), with intercepts allowed to vary for each participant and stimuli number. In addition, random slopes were included at the participant level for typicality, and at the item level for group, typicality, and expressive language (if this was found to significantly improve model fit). If a model did not converge parameters were systematically removed from the random structure. Initially the correlation at the items level was removed. If a model still did not converge, this was re-entered and the model was re-run excluding the interaction between random slopes for group and typicality. If the model did not then converge both the correlation and interaction were removed, and then as necessary, each random slope was removed one-by-one in the following order; expressive language (if included), typicality, group. If the model still did not converge, the same procedure was followed for the participant level of the random structure.

4.3.2 Accuracy

Recall that participants had to answer comprehension questions about the content of the mini discourses following 50% of trials. These questions were not related to the co-referential link. Comprehension was very high and there were no reliable differences in accuracy between the ASD and TD participants. See Table 17 for accuracy measure means and model parameters.

4.3.3 Global Measures

Prior to examining region specific localised analyses of eye movement behaviour we considered global measures of processing in order to determine whether there were any basic sampling differences between the two groups (See Table 17 for all global analyses means and model parameters). Firstly, we analysed average fixation duration calculated across an entire trial in order to assess the speed with which each group extracted information from the text within a single fixation. We found no differences between the groups, typicality conditions. Thus, on average, both groups extracted information at a similar speed and this was not influenced by verbal language competency. Following this we examined the average number of fixations each participant made during a trial. For average fixation count the inclusion of expressive language as a main effect improved model fit $\chi2(1) = 4.72$, $p = .030$. No differences between groups or typicality conditions were found, but expressive language was negatively associated with fixation count, where the number of fixations participants made increased, as expressive language skill decreased. This indicates that both ASD and TD readers with reduced verbal language proficiency made more fixations in order to comprehend the texts. The same pattern was also found for overall reading times. Model fit was significantly improved when expressive language was included as a main effect $\chi2(1) = 5.27$, $p = .022$, with participants with lower expressive language scores taking longer to read the passages. There was also a numerical tendency for ASD readers to take longer to read the passages than TD controls, but this did not reach significance and there was no effect of typicality. Although not statistically reliable, the trend for readers with ASD to make more fixations and have longer reading times overall is consistent with previous reports of ASD readers engaging in increased re-reading (e.g., Au-Yeung et al., 2015; Howard et al., 2017a; Sansosti et al., 2013). The time course of this re-reading behaviour is examined in more detail in the Supplementary Analyses.

Table 17.
Model parameters and observed means (standard deviations) for global analyses.

	Model parameters					TD		ASD	
Measure		*b*	SE	*z*	*p*				
Accuracy	Intercept	4.12	0.60	6.88	<. 001	.97 (.18)		.98 (.13)	
	Group	0.63	0.62	1.02	.307				
		b	SE	*t*	*p*	Typical	Atypical	Typical	Atypical
Mean Fixation Duration	Intercept	204.06	3.41	59.93	<. 001	200 (23)	200 (22)	207 (26)	209 (25)
	Group	7.78	6.75	1.15	0.258				
	Typicality	1.61	1.03	1.55	0.124				
	Typicality X Group	2.13	2.07	1.03	0.306				
Fixation Count	Intercept	25.53	1.05	24.27	<. 001	22 (7)	23 (6)	28 (9)	28 (8)
	Group	3.51	2.17	1.61	0.117				
	Typicality	0.42	0.36	1.16	0.251				
	Expressive Language	-0.36	0.17	-2.18	0.038				
	Typicality X Group	0.05	0.71	0.07	0.944				
Total Reading Time	Intercept	6422.97	301.59	21.30	<. 001	5368 (1793)	5510 (1716)	7225 (2567)	7289 (2407)
	Group	1257.26	631.28	1.99	0.055				
	Typicality	119.50	94.89	1.26	0.213				
	Expressive Language	-107.70	47.57	-2.26	0.031				
	Typicality X Group	-35.68	190.79	-0.19	0.852				

4.3.4 Target Word

First fixation durations (the duration of the first fixation upon the target word) and single fixation durations (the duration of a fixation when there is only one fixation made upon the target during first pass reading) did not differ between groups or with antecedent typicality (see Table 18 for target word mode parameters and observed means). An effect of antecedent typicality was found however for gaze durations (the sum of fixations from when the target was first fixated until the eyes moved to either the left or right of the word), with both groups having longer gaze durations upon the category noun when it's antecedent was atypical, in comparison to typical (an 11ms effect). There was no difference between the two groups for gaze duration, but the inclusion of expressive language skill as a main effect improved model fit $\chi2(1) = 4.59$, $p = .032$, with participants who had lower expressive language scores having longer gaze durations, which is suggestive that those with poorer verbal language skill, from both TD and ASD groups, took longer to compute anaphoric links. Antecedent typicality and expressive language score did not influence total times (total amount of time spent fixating the target), but ASD readers were found to spend longer fixating this region in comparison to TD participants.

Table 18.
Model parameters and observed means (standard deviations) for target region analyses.

	Model parameters					TD		ASD	
Measure		*b*	SE	*t*	*p*	Typical	Atypical	Typical	Atypical
First Fixation Duration	Intercept	199.42	3.94	50.62	<.001	199 (54)	202 (57)	197 (57)	201 (62)
	Group	-2.10	8.12	-0.26	.798				
	Typicality	3.70	4.07	0.91	.366				
	Typicality X Group	1.72	7.86	0.22	.827				
Single Fixation Duration	Intercept	200.35	4.26	47.07	<.001	199 (55)	204 (57)	197 (58)	200 (62)
	Group	-0.76	8.59	-0.09	.930				
	Typicality	4.51	4.57	0.99	.327				
	Typicality X Group	-1.58	9.05	-0.18	.862				
Gaze Duration	Intercept	215.22	4.79	44.92	<.001	210 (66)	224 (76)	211 (72)	218 (78)
	Group	-15.00	10.98	-1.37	.181				
	Typicality	11.16	5.27	2.12	.037				
	Expressive Language	-2.00	0.82	-2.44	.021				
	Typicality X Group	-8.45	10.28	-0.82	.412				
Total Time	Intercept	254.68	9.01	28.27	<.001	239 (94)	236 (86)	275 (129)	275 (134)
	Group	36.21	15.37	2.36	.025				
	Typicality	0.40	8.03	0.05	.961				
	Typicality X Group	5.14	15.95	0.32	.750				

4.3.5 Bayes Factor Analysis

Given the small sample size and the effect of typicality being numerically smaller for gaze duration in the ASD group, in comparison to the TD group, we carried out Bayes Factor analyses to evaluate evidence in favour of the null effect (Kass & Raftery, 1995; Rouder, Morey, Speckman & Province, 2012). These analyses provide an estimation of the relative evidence for different models/hypotheses (including null effects), based upon the data. Therefore, to examine whether the lack of difference we found between groups was a 'true' null effect, or a type II error, we directly compared the relative evidence from our original model that included a group by typicality interaction to a model that did not include group as a fixed effect (only typicality and expressive language). This was calculated using the BayesFactor Package (Morey & Rouder, 2015) in R (R Core Team, 2016). We used 100,000 Monte Carlo iterations and with *g*-priors scaled to $r = 0.5$ for fixed effects, as is recommended for small effect sizes (Rouder et al., 2012). A Bayes Factor score that is larger than 1 would suggest that the evidence (data) is in favour of the original model and hypotheses (that included a group by typicality interaction), whereas a score of below 1 would suggest evidence in favour of the comparison model that excluded group as a predictor. The BayesFactor was < 0.001, which indicates strong evidence in favour of the model excluding group as a predictor, according to Jeffries (1961) evidence categories. Therefore, upon the basis of this additional analysis, we can confidently conclude that in the current study TD and ASD readers did not differ in the immediacy with which they computed an anaphoric link.

4.3.6 Post Target Region

Previous studies examining referential processing have occasionally found effects to occur or to continue to occur on words following the target word. However, we found no reliable effects of typicality or any interactions for this region. An effect of group for total times was found, with ASD readers spending longer fixating this region overall in comparison to TD readers. Fixed effect model parameters along with group means and standard deviations are presented in Table 19.

Table 19.
Model parameters and observed means (standard deviations) for post target region analyses.

	Model parameters					TD		ASD	
Measure		*b*	SE	*t*	*p*	Typical	Atypical	Typical	Atypical
First Fixation Duration	Intercept	205.14	4.27	48.04	<.001	200 (54)	207 (57)	207 (59)	208 (58)
	Group	3.73	8.02	0.47	.645				
	Typicality	4.78	3.72	1.29	.207				
	Typicality X Group	-5.47	7.12	-0.68	.496				
Single Fixation Duration	Intercept	211.52	8.06	26.26	<.001	207 (57)	213 (63)	212 (63)	207 (56)
	Group	4.22	10.70	0.39	.700				
	Typicality	5.63	7.36	0.76	.451				
	Typicality X Group	-9.95	11.40	-0.87	.391				
Gaze Duration	Intercept	284.89	13.62	20.92	<.001	290 (137)	279 (119)	293 (138)	289 (131)
	Group	5.29	24.21	0.22	.828				
	Typicality	-5.47	10.30	-0.53	.600				
	Typicality X Group	5.31	18.90	0.28	.781				
Total Time	Intercept	366.21	19.21	19.06	<.001	334 (175)	334 (159)	403 (231)	399 (216)
	Group	66.48	32.55	2.04	.049				
	Typicality	-2.48	12.50	-0.20	.844				
	Typicality X Group	-5.82	29.02	-0.19	.851				

4.3.7 Supplementary Analyses

In order to examine the time course of the numerically increased total reading times and number of fixations made by ASD readers, a series of supplementary analyses was run. This was to identify whether any increased reading time occurred during first pass, or, whether this effect occurred at a later stage of processing. Increased first pass times would be indicative of a difficulty constructing an initial representation of the text, whereas increased second pass times would be indicative of ASD readers taking longer to evaluate or check their interpretation of the text. For conciseness, below we only describe group differences. Readers interested in effects of typicality and language proficiency are referred to Tables 20-23 where means, standard deviations and model parameters for all supplementary analyses are reported in full.

To investigate the first possibility, that the increased reading times were a result of longer first pass times, gaze durations for each of the seven regions of the mini discourses and the proportion of first pass regressions (prior to fixating a later region) made out of each region was calculated. Recall that there were no differences between groups for the gaze duration in the target or post target region. Similarly, there were no differences in gaze durations between groups for any other region. First pass reading times were equivalent for TD and ASD readers. For first pass regressions out of the post antecedent and post target regions, there was an effect of group, with ASD readers making more regressions out of these regions than TD participants for both sentence conditions. There were no differences in first pass regressions were found for any other region. Together, these results suggest that on the whole, first pass processing of the mini discourses was very similar between our participant groups.

To examine the second possibility, that the increased reading times occurred later, re-reading time was calculated for each region (i.e., total time minus gaze duration). This measure contained a large proportion of zero values (when no re-reading occurred) and therefore we considered these data in two different ways; first, we computed a binomial variable representing the proportion of re-reading for each region; second, we considered how long participants spent re-reading each region, when they did actually re-read (i.e., zero re-reading times were removed). Participants with ASD re-read the start, antecedent, pre-target, target, and end regions on a higher proportion of trials, in comparison to TD readers . In addition, ASD participants had longer re-reading times for the start, pre-target, and post target regions, in comparison to TD readers. These analyses indicate that whilst the ASD and TD readers' first pass reading times were very comparable, the ASD participants re-read the mini discourses more frequently and spent longer doing so than the TD readers. It seems reasonable to conclude that the increased overall reading times for ASD participants was a result of a general tendency to engage in increased re-reading.

Table 20.
Model parameters for supplementary analyses of the regions within the first sentence.

		Start				Antecedent				Post Antecedent			
		b	SE	*t / z*	*p*	*b*	SE	*t / z*	*p*	*b*	SE	*t / z*	*p*
GD	Intercept	1046.07	114.30	9.15	<.001	244.25	11.81	20.69	<.001	802.37	67.76	11.84	<.001
	Group	95.81	132.44	0.72	.475	-2.48	16.55	-0.15	.881	71.95	78.60	0.92	.367
	Typicality	-9.06	34.44	-0.26	.795	84.24	21.10	3.98	<.001	-51.14	32.86	-1.56	.129
	Typicality X Group	-34.10	49.23	-0.69	.495	18.24	28.89	0.63	.531	-87.58	54.81	-1.60	.113
RO	Intercept	--	--	--	--	-1.74	0.19	-8.92	<. 001	-1.50	0.15	-9.76	<. 001
	Group	--	--	--	--	0.64	0.34	1.89	.059	0.53	0.24	2.17	.030
	Typicality	--	--	--	--	-0.18	0.31	-0.61	.544	0.51	0.22	2.30	.022
	Typicality X Group	--	--	--	--	-0.58	0.60	-0.97	.334	-0.04	0.39	-0.10	.920
PR	Intercept	-0.02	0.22	-0.08	.933	-0.80	0.19	-4.09	<. 001	-0.73	0.19	-3.76	<. 001
	Group	0.95	0.48	1.99	.046	0.94	0.37	2.56	.011	0.54	0.40	1.35	.177
	Typicality	0.12	0.16	0.73	.465	0.82	0.23	3.58	<. 001	0.06	0.18	0.34	.737
	Expressive Language	-0.09	0.04	-2.33	.020	-0.07	0.03	-2.36	.018	-0.07	0.03	-2.07	.038
	Typicality X Group	0.42	0.32	1.31	.192	0.16	0.41	0.39	.700	0.11	0.34	0.33	.744
RT	Intercept	504.63	49.97	10.10	<. 001	326.77	17.81	18.354	<. 001	629.47	57.42	10.96	<. 001
	Group	293.98	96.28	3.05	.004	62.83	35.41	1.78	.087	139.01	79.32	1.75	.090
	Typicality	-61.48	51.20	-1.20	.235	55.56	32.36	1.72	.092	92.58	55.31	1.67	.097
	Typicality X Group	-111.24	100.33	-50.89	-1.11	72.89	61.91	1.17	.242	106.22	117.83	0.90	.372

Note. GD = gaze duration; RO = proportion of first pass regressions out; PR = proportion of re-reading; RT = re-reading time.

Table 21.
Model parameters for supplementary analyses of pre-target and target regions.

Measure		Pre-target				Target			
		b	SE	*t / z*	*p*	*b*	SE	*t / z*	*p*
Gaze Duration	Intercept	714.46	56.31	12.69	<. 001	--	--	--	--
	Group	49.02	77.93	0.63	.534	--	--	--	--
	Typicality	26.73	21.61	1.24	.225	--	--	--	--
	Typicality X Group	-2.44	36.00	-0.07	.946	--	--	--	--
Regressions Out	Intercept	-6.62	1.41	-4.69	<. 001	-1.57	0.19	-8.08	<. 001
	Group	1.01	2.75	0.37	.713	0.36	0.35	1.03	.303
	Typicality	1.82	2.90	0.63	.531	-0.31	0.22	-1.40	.163
	Typicality X Group	-3.08	5.59	-0.55	.581	0.02	0.40	0.05	.962
Proportion of re-reading	Intercept	-1.02	0.23	-4.40	<. 001	-1.89	0.23	-8.18	<. 001
	Group	1.31	0.40	3.27	<. 001	1.17	0.39	3.03	.002
	Typicality	-0.41	0.27	-1.53	.125	-0.66	0.30	-2.23	.026
	Typicality X Group	0.49	0.38	1.30	.195	0.49	0.53	0.92	.355
Re-reading time	Intercept	421.79	47.27	8.92	<. 001	233.07	13.11	17.79	<. 001
	Group	202.05	76.47	2.64	.014	26.59	24.95	4.07	.294
	Typicality	35.28	69.45	0.51	.615	22.26	25.14	0.89	.382
	Typicality X Group	21.15	117.21	0.18	.858	31.12	47.35	0.66	.515

Table 22.
Model parameters for supplementary analyses of post target and end regions.

		Post Target				End			
Measure		*b*	SE	*t* / *z*	*p*	*b*	SE	*t* / *z*	*p*
Gaze Duration	Intercept	--	--	--	--	614.92	44.42	13.84	<. 001
	Group	--	--	--	--	96.59	50.24	1.92	.064
	Typicality	--	--	--	--	-41.34	21.86	-1.89	.067
	Typicality X Group	--	--	--	--	-6.22	41.91	-0.15	.882
Regressions Out	Intercept	-2.81	0.28	-10.138	<. 001	0.58	0.22	2.57	.010
	Group	1.01	0.49	2.05	.040	0.19	0.50	0.39	.701
	Typicality	0.42	0.51	0.83	.409	-0.10	0.16	-0.59	.553
	Expressive Language	--	--	--	--	-0.12	0.04	-2.93	.003
	Typicality X Group	-0.55	0.94	-0.58	.560	0.40	0.36	1.13	.260
Proportion of re-reading	Intercept	-1.05	0.17	-6.28	<. 001	-1.43	0.26	-5.50	<. 001
	Group	0.49	0.32	1.54	.123	1.04	0.48	2.17	.030
	Typicality	0.06	0.19	0.34	.730	-0.08	0.25	-0.33	.744
	Typicality X Group	-0.20	0.34	-0.59	.555	0.17	0.45	0.39	.700
Re-reading time	Intercept	302.83	12.47	24.28	<. 001	634.38	47.95	13.23	<. 001
	Group	75.69	25.99	2.91	.007	102.69	86.98	1.18	.249
	Typicality	-9.37	22.97	-0.41	.684	-35.79	63.09	-0.57	.573
	Typicality X Group	-16.46	44.83	-0.37	.714	178.04	123.05	1.45	.154

Table 23.
Observed means (standard deviations) for all measures calculated for the supplementary analyses.

Measure	Group	Condition	Gaze Duration	First pass Regressions	Proportion of Re-reading	Re-reading Time
Start	TD	Typical	1025 (534)	--	.36 (.48)	381 (284)
		Atypical	1018 (510)	--	.35 (.48)	363 (270)
	ASD	Typical	1133 (685)	--	.60 (.49)	823 (711)
		Atypical	1084 (617)	--	.65 (.48)	631 (486)
Antecedent	TD	Typical	245 (85)	.15 (.35)	.19 (.39)	291 (144)
		Atypical	330 (165)	.16 (.37)	.28 (.45)	310 (230)
	ASD	Typical	245 (104)	.26 (.44)	.39 (.49)	313 (181)
		Atypical	356 (215)	.21 (.41)	.56 (.50)	415 (301)
Post Antecedent	TD	Typical	745 (479)	.14 (.35)	.27 (.44)	460 (589)
		Atypical	746 (484)	.20 (.40)	.27 (.45)	498 (602)
	ASD	Typical	857 (612)	.21 (.41)	.44 (.50)	525 (691)
		Atypical	757 (528)	.29 (.46)	.46 (.50)	647 (827)
Pre-target	TD	Typical	664 (316)	.01 (.09)_	.24 (.43)	307 (197)
		Atypical	704 (375)	.05 (.23)	.20 (.40)	382 (377)
	ASD	Typical	722 (408)	.04 (.20)	.45 (.50)	509 (397)
		Atypical	749 (411)	.10 (.30)	.43 (.50)	681 (584)

Table 23.
Observed means (standard deviations) for all measures calculated for the supplementary analyses.

Measure	Group	Condition	Gaze Duration	First pass Regressions	Proportion of Re-reading	Re-reading Time
Target	TD	Typical	--	.20 (.40)	.14 (.34)	217 (75)
		Atypical	--	.15 (.36)	.09 (.28)	231 (100)
	ASD	Typical	--	.28 (.45)	.27 (.44)	226 (87)
		Atypical	--	.22 (.41)	.24 (.43)	276 (171)
Post Target	TD	Typical	--	.05 (.21)	.22 (.41)	268 (159)
		Atypical	--	.07 (.26)	.26 (.44)	266 (117)
	ASD	Typical	--	.12 (.33)	.33 (.47)	352 (198)
		Atypical	--	.14 (.34)	.34 (.47)	331 (184)
End	TD	Typical	581 (365)	.56 (.50)	.18 (.39)	684 (411)
		Atypical	545 (311)	.50 (.50)	.21 (.41)	536 (354)
	ASD	Typical	690 (412)	.67 (.47)	.33 (.47)	730 (526)
		Atypical	634 (434	.68 (.47)	.35 (.48)	745 (496)

4.4 Discussion

In this experiment we examined the efficiency of co-reference computation during reading in ASD. Participants read mini discourses containing an anaphoric link between category nouns and typical or atypical exemplars. No group differences or group by typicality interactions were detected. Both groups had longer gaze durations at the category noun when it was preceded by an atypical exemplar, in comparison to a typical exemplar. This is consistent with previous studies that have used a typicality manipulation (e.g., Duffy & Rayner, 1990; Rayner, et al., 2000; Myers, et al., 2000) and suggests that the efficiency with which ASD readers computed a very basic inference and formed a co-reference link between instance and category words was comparable to TD readers. This is the first study to examine the time course of on-line co-reference computation in ASD and the findings clearly demonstrate that the efficiency with which a co-reference link is initially established is comparable in TD and ASD adult readers. Our results do not support the hypotheses that the integration of information between sentences or the incorporation of an implicit link into the discourse model is impaired in ASD (as per e.g., CIP, WCC theories). It therefore, seems that comprehension difficulties previously reported in the literature for ASD readers do not arise due to ASD readers less immediately establishing co-referential links. Instead, our findings are consistent with recent studies reporting intact integrative processing during reading in ASD (e.g., Au-Yeung et al., 2015; Howard et al., 2017a).

Our results however appear to be in contrast to several of the studies considered in the Introduction that report poor performance accuracy and reduced processing efficiency in ASD for tasks that require an inference to be formed. It is possible that such results occur for studies tasking participants with reading text that requires the formation of causal and pragmatic inferences (e.g., Bodner et al., 2015; Dennis, et al., 2001; Jolliffe & Baron-Cohen, 1999, 2000; Minshew et al., 1995; Micai et al., 2016; Norbury & Bishop, 2002; Norbury & Nation, 2011; Tirado & Saldaña, 2015). As noted earlier, forming a casual inference could be considered more complex and cognitively demanding relative to the type of inference that participants computed in the current study. In the present study, participants needed only to form a referential link between two words on the basis of semantic knowledge (e.g., lexical/sematic knowledge that a *penguin/pigeon* is a *bird*). In contrast, causal inferences require a reader to infer an event structure that captures a causality relation that is usually derived from complex situational world knowledge.

Therefore, one explanation for the inconsistency between our own and previous work is that inferential processing is not universally atypical in ASD, but may vary dependent upon the degree of processing complexity associated with the formation a particular inference. Moreover, differences in the efficiency of the use of situational world knowledge have been recently reported during on-line reading in ASD (Howard, Liversedge & Benson, 2017b) and the requirement to engage with situational world knowledge may therefore be a factor that modulates inferential processing in ASD.

Potential differences in world knowledge processing, however, cannot account for why our findings contrast with O'Connor and Klein's (2004) report that comprehension accuracy scores for adolescents with ASD improve when prompts to make anaphoric links are provided. This finding implies that the spontaneous formation of anaphoric links is less efficient in ASD, but this is not consistent with the present findings. There are two possible reasons why our data may not coincide with O'Connor and Klein's (2004) work. Firstly, we tested an adult sample, whereas O'Connor and Klein (2004) recruited adolescents. Perhaps the development of co-referential processing is delayed in ASD, and this difference diminishes with age. Consistent with this suggestion, Bodner et al., (2015) reported the difference in inferencing accuracy between their TD and ASD participants to reduce as age increased. Alternatively, it is possible that differences in verbal language proficiency could account for O'Connor and Klein's (2004) findings. O'Connor and Klein (2004) administered the Test of Language Development (TOLD) to their participants as a measure of general language proficiency and grammatical skill. TOLD scores were found to correlate negatively with comprehension scores during their anaphoric cueing task. Therefore, perhaps this intervention was more beneficial to students with lower verbal language proficiency, suggesting that differences in verbal proficiency may have underpinned differences in anaphoric processing in O'Connor and Klein's (2004) sample of adolescents with ASD, as opposed to the presence of ASD *per se*.

The measure of expressive language we used (sentence repetition; CELF) taps into multiple processes related to language proficiency, such as working memory, phonological and syntactic processing. This measure was found to be predictive of the number of fixations participants made and the time it took them to read the texts, with lower expressive language scores leading to more fixations and increased reading times. These data suggest that reduced verbal language proficiency was related to general reading proficiency, and the finding is consistent with previous studies that have demonstrated how expressive language is predictive of general reading skill in both TD and ASD populations (e.g., Lucas & Norbury, 2014; Norbury & Nation, 2011). In addition, expressive language was found to be predictive of gaze duration on the target words, which is where we first observed evidence of the formation of the anaphoric link in the eye movement record for both TD and ASD groups. Note that expressive language was not found to predict average fixation duration, nor was it found to predict any other localised fixation measures on the target region. Together, these findings suggest that general language skill is also specifically associated with inferential processing, and again is consistent with previous studies reporting similar results (e.g., Perez, Joseph, Bajo & Nation, 2015; Lucas & Norbury, 2015; Singer, Andrusiak, Reisdorf & Black, 1992; Singer & Richot, 1996).

Consistent with a number of previous studies that have examined eye movements during reading in ASD, we found our ASD participants to be more likely to re-read and often spend longer re-reading, in comparison to TD readers (Au-Yeung et al., 2015; Howard et al., 2017a, 2017b; Sansosti et al., 2013). Note that there was no differences in the proportion of first pass regressions made by each group. Therefore, the likelihood that ASD and TD readers would initiate a regression to re-read the sentence was comparable; however, the time spent re-reading after such a saccade was greater in the ASD than the TD readers. Re-reading was not concentrated on any particular region of the texts, rather, increased proportions of re-reading were found for the majority of regions or the texts. In addition, participants with ASD were as likely to re-read in both typical and atypical conditions. The findings for the re-reading measures indicate this behaviour is unlikely to result from ASD participants having particular difficulty engaging in basic linguistic processing required for the construction of a mental representation of the text (e.g., Howard et al., 2017a; 2017b). Instead it seems likely that this re-reading behaviour may be a result of increased evaluation of the text content. We have speculated in previous papers in which we have reported a very similar pattern and time course of re-reading in ASD, that this may be a “cautious” strategy, or a “checking” strategy that readers with ASD adopt. However, it is also quite possible that the factor(s) underpinning this re-reading behaviour might also be a task effect (see Howard et al., 2017a), or alternatively may reflect a repetitive behaviour that is characteristic of ASD. These possibilities remain to be empirically investigated. Suffice to say that the current findings represent another independent demonstration of these re-reading effects in adults with ASD.

In summary, here we have demonstrated that typicality effects associated with the formation of a co-reference link between a category anaphor noun and a subsequent noun that is an instance of that category occur with the same immediacy in ASD readers as in

TD readers. This result is inconsistent with the suggestion that integrative processes required for the computation of co-reference are impaired in ASD readers.

Chapter 5: General Discussion

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by impairments in social communication, social interaction, and restricted and repetitive patterns of behaviour (American Psychiatric Association, 2013). These behavioural symptoms are underpinned by cognitive processing differences that are a consequence of differential neurological development (e.g., Frith, 2012). Language is one of the predominant cognitive domains whereby information processing differences manifest in ASD. In the first Chapter of this thesis, the literature that has examined reading in ASD was reviewed. From this it was evident that there is a dissociation between performance on low-level reading tasks (e.g., word identification) and high level reading tasks (e.g., comprehension) in ASD, with performance for the latter often reported as reduced in comparison to typically developing (TD) controls. The key findings of this literature review were that I) in general, performance accuracy for word identification tasks are comparable between TD and ASD readers, II) few studies have examined syntactic processing during reading in ASD, and III) individuals with ASD are vulnerable to both reading comprehension and inferencing difficulties. The performance differences found for higher order reading tasks for individuals with ASD do not appear to be a result of reduced basic reading skill, and have often been attributed to ASD specific cognitive processing atypicalities (e.g., Weak Central Coherence; Frith & Happé, 1994; Executive Dysfunction; Hughs & Russell, 1993, Theory of Mind; Baron-Cohen, 1989, Complex Information Processing; Minshew & Goldstein, 1998). However, the literature review revealed that no single cognitive theory of ASD could adequately account for this dissociation. Therefore, this thesis aimed to extend previous work and develop a more precise insight into mechanistic language processing differences during reading in ASD. This was achieved by conducting four experiments where individuals with ASD read text as their eye movements were monitored. Eye movements are tightly linked to and reflect moment-to-moment linguistic processing (Liversedge & Findlay, 2000). Therefore, by adopting this method, the efficiency of lexical, syntactic, semantic and discourse processing was examined in real-time and the findings of each of these experiments are summarized below.

5.1 Chapter 2: Lexical Processing

Previous research has demonstrated that readers with ASD who do not have additional language impairment perform comparably to TD controls at word identification tasks (e.g., Frith & Snowling, 1983; Huemer & Mann, 2010; Mayes & Calhoun, 2006;

Minshew, Goldstein, & Siegel, 1995; Saldaña, Carreiras, & Frith, 2009). However, there are also reports that suggest there may be a difference in the on-line time course of lexical identification in ASD (e.g., Kamio et al., 2007; Sansosti et al., 2009). Therefore, the first experiment that was presented in Chapter 2, examined whether the time-course of word identification is similar between TD and ASD readers. If on-line lexical identification is qualitatively different in nature in ASD, or if the efficiency of word identification is reduced, this would have the potential to cascade forward and impact upon later stages of processing, potentially impeding reading comprehension and inferencing. This experiment was therefore necessary, to examine the efficiency of lexical processing in ASD, given this is a fundamental process of reading.

Two groups of adults were recruited to take part; one group had a formal diagnosis of ASD and the other was a group of TD controls recruited from the local community. The two groups did not differ on average in age, IQ or oral language skill. Furthermore, the two groups did not differ in performance accuracy for an offline assessment of single word reading or passage comprehension. Both TD and ASD participants read single sentences as their eye movements were monitored. Sentences included target words that were manipulated to be high (e.g., *people*) or low (e.g., *zombie*) in frequency. The eye movement recordings revealed that both participant groups had longer fixation durations upon the target word, when this word was low frequency, in comparison to high frequency. Thus, no differences in the time-course of lexical processing were evident between TD and ASD readers.

The finding that readers with ASD show a typical frequency effect suggests that the cognitive processes engaged in to identify words, and the efficiency of lexical processing is similar between TD and ASD participants. This indicates, that not only is word identification accuracy intact in ASD (e.g., Frith & Snowling, 1983; Huemer & Mann, 2010; Mayes & Calhoun, 2006; Minshew, et al., 1995; Saldaña, et al., 2009), but the time-course of lexical processing is also comparable between TD and ASD readers. Broadly, this finding suggests that there does not appear to be an ASD specific difference in lexical processing.

5.2 Chapter 2: Syntactic and Semantic Processing

Previous studies suggest that individuals with ASD are able to accurately complete offline reading tasks that require syntactic processing (Lucas & Norbury, 2014; Stockbridge, Happé & White, 2014). However, there is also evidence to suggest that the efficiency of syntactic processing may be reduced in ASD (Koolen et al., 2014). Syntactic processing is a necessary process from which comprehension is built upon and if parsing were atypical in ASD, this would likely have an impact upon reading comprehension outcomes. Therefore, Experiment 2 that was also presented in Chapter 2, examined the efficiency of on-line syntactic processing in ASD

The primary aim of Experiment 2 was to investigate whether readers with ASD hold similar syntactic parsing preferences to TD readers. The same TD and ASD groups who took part in Experiment 1 also took part in Experiment 2. Participants read sentences that contained ambiguous prepositional phrases that could either be attached high as a modifier to the verb (e.g., *The girl whacked her older brother with a red cushion for making fun of her*), or attached low, as a modifier to the noun phrase (e.g., *The girl whacked her older brother with a red blister for making fun of her*). It is well documented that TD readers have a high attachment preference (e.g., Frazier & Rayner, 1983) and this experiment examined whether readers with ASD also hold this preference.

The secondary aim of Experiment 2 was to examine the speed with which individuals with ASD evaluate world knowledge during reading. World knowledge is incrementally and rapidly activated in long-term memory as reading takes place (e.g., Rayner, Warren, Juhasz, & Liversedge, 2004). Readers use world knowledge to evaluate the events conveyed in a text and elaborate the discourse model, via the computation of inferences (McKoon & Ratcliff, 1992; Graesser, et al., 1994). Therefore, world knowledge processing is an important aspect of reading often necessary for proficient comprehension. If atypical in ASD, this would likely impede reading comprehension and inferencing. Furthermore, the Theory of Complex Information Processing (e.g., Minshew & Goldstein, 1998) predicts world knowledge processing to be atypical in ASD but the few studies have examined this process during reading in ASD, report mixed results (e.g., Saldaña & Frith, 2007; Wahlberg & Magliano, 2004). To examine world knowledge processing, sentences were designed so that in order to detect a syntactic misanalysis (the inappropriate attachment of a prepositional phrase high to a main verb, rather than low to the object noun phrase), a reader had to evaluate the events described in the text against their own knowledge of the world.

The eye movement records demonstrated that both TD and ASD readers experienced disruption to reading upon fixation of the target and post-target regions of the sentences in the garden path conditions. In addition, the time course and magnitude of this disruption did not differ between groups. The findings suggest that readers with ASD hold a similar high attachment parsing preference to TD readers, and that they are as efficient in the on-line reanalysis of structural form. These findings are consistent with the experiments that have found intact performance outcomes for ASD readers when syntactic processing is required (e.g., Lucas & Norbury, 2014; Stockbridge, Happé & White, 2014). Hence, previous reports of reduced comprehension and inferencing accuracy in ASD are unlikely to be a result of differences in the processing of syntactic information.

In addition, the lack of difference between groups in the onset of reading disruption suggests that ASD participants were as efficient in the on-line processing and evaluation of world knowledge, in comparison to TD readers. In retrospect however, one limitation of this experiment was that a high proportion (70%) of the low attached sentences that had previously been assumed to require world knowledge processing in order to detect semantic anomalies, also included a verb argument selectional restriction violation. What this means is that it was possible that participants with ASD had detected initial syntactic misanalyses via lexical information about what can and cannot be an argument to the verb (e.g., Warren & McConnell, 2007), as opposed to detecting an anomaly based upon world knowledge evaluation. Therefore, although Experiment 2 provides convincing evidence that readers with ASD parse sentences similarly to TD readers; any conclusion in relation to world knowledge processing in ASD is tentative based on this experiment.

5.3 Chapter 3: Semantic Processing

World knowledge processing is often critical for text comprehension and is predicted to be less efficient in ASD by the theory of Complex Information Processing (Minshew & Goldstein, 1998). Moreover, findings from studies that have examined world knowledge processing during reading in ASD, including those reported in Experiment 2 from this thesis are inconsistent (e.g., Howard et al., 2017a; Wahlberg & Magliano, 2004, c.f. Saldaña & Frith, 2007). Experiment 3 aimed to examine the on-line time course of world knowledge processing during reading in ASD in more detail.

Two groups of adults were recruited; one group had a formal diagnosis of ASD and the second group acted as TD controls but did not differ in IQ, oral language skill or offline reading accuracy. The participants were asked to read sentences that contained plausible (e.g., *The waiter used a jug to pour the fresh milk in the teacup*), implausible (possible but unlikely e.g., *The waiter used a bucket to pour the fresh milk in the teacup*) and anomalous (impossible e.g., *The waiter used a seed to grow the fresh milk in the* *teacup*) thematic relations, as their eye movements were monitored. Anomalies violated world knowledge in addition to the verb's selectional restrictions. Therefore, for anomalous sentences, the semantic violation could be detected upon the basis of both world knowledge evaluation and/or lexical information (similar to garden path effect detection in Experiment 2). However, implausibilities could only be detected via the evaluation of world knowledge.

Both TD and ASD readers detected anomalies very rapidly, upon fixation of the target word and similar overall disruption to reading was found as a result of the anomalies, for both participant groups. Therefore, we replicated the finding from Experiment 2, that readers with ASD detect anomalous violations that are a result of a selectional restriction violation, as rapidly as TD readers. Disruption as a result of the implausibilities was also observed very early in the eye movement record for TD readers; however, ASD readers did not show any evidence of disruption to target or post target word processing, for implausible sentences. Disruption as a result of implausibility was only found for total sentence reading time for ASD participants, and this indicates that the ASD readers were delayed in the detection of implausible world knowledge violations, relative to TD readers.

These findings suggest that the efficiency and time course with which readers with ASD process world knowledge on-line during reading is reduced, relative to TD readers. Less efficient world knowledge processing may result in reduced coherence in the text representation, resulting in implausibilities going undetected (at least temporarily). Thus, the speed with which difficulties are initially detected and then resolved may be delayed. It therefore seems reasonable to suggest that that the performance differences found for comprehension and inferencing tasks in ASD readers may in part be a consequence of less efficient world knowledge processing.

5.4 Chapter 4: Discourse Processing

For proficient text comprehension, a reader must engage in processes whereby text information is connected and integrated together, to form a coherent discourse model (e.g., Kintsch, 1988, 1998; Kintsch & van Dijk, 1978; Gernsbacher, 1990, 1991; Zwaan, Langston, & Graesser, 1995). Both the Weak Central Coherence Theory (Frith & Happé, 1994) and the Theory of Complex Information Processing (Minshew & Goldstein, 1998) predict integrative processes to be atypical in ASD. However, based upon the findings from Experiments 1-3 in this thesis, it would appear that readers with ASD are as efficient as TD readers at constructing a mental representation of explicit text information (Au-Yeung et al., 2015; Howard et al., 2017a, 2017b). Thus, the hypothesis that readers with ASD have a universal difficulty with text integration during reading is not supported. The aim of Experiment 4 was to examine the efficiency with which ASD readers' process and integrate implicit knowledge into the discourse model. To examine this, the efficiency with which TD and ASD readers compute co-referential links that require a very basic inference to be formed was investigated.

Two groups of participants were recruited. Participants with ASD did not differ on average to the TD participants in age, IQ or single word reading accuracy. ASD participants whose oral language skill scores suggested they might have language impairment were excluded, however on average the ASD participants had reduced oral language skill, in comparison to TD readers. In addition, the ASD group was found to have reduced offline passage comprehension accuracy, relative to TD controls. Oral language skill was included in all statistical models to assure that processing differences associated with verbal proficiency and ASD could be disentangled.

Both participant groups read mini discourses that were two sentences long as their eye movements were monitored. The second sentence contained a category noun (e.g., *bird*) that was preceded by a typical (e.g., *pigeon*) or atypical (e.g., *penguin*) antecedent in the first sentence. TD and ASD readers were found to show a typicality effect whereby fixation durations upon the category noun were longer when it was preceded by an atypical antecedent, in comparison to when it was preceded by a typical antecedent. No differences in the time course of this processing that could be attributed to ASD were found. However, individuals with reduced oral language skill were found to have reduced inferential processing efficiency and reduced general reading skill.

From this study, it would therefore seem that the on-line formation of anaphoric links is intact in adult readers with ASD. Moreover, this finding is inconsistent with predictions that integrative processing is atypical in ASD (e.g., Frith & Happé, 1994; Minshew & Goldstein, 1998) and previous studies that report individuals with ASD to have reduced accuracy and processing efficiency for reading tasks that require an inference to be formed (Jolliffe & Baron-Cohen, 1999, 2000; Minshew et al., 1995; Micai, Joseph, Vulchanova & Saldaña, in press; Norbury & Bishop, 2002; Norbury & Nation, 2011; O'Connor & Klein, 2004; Tirado & Saldana, 2015). It would therefore seem that previous reports of reduced performance accuracy and processing efficiency for inferencing tasks in ASD cannot be attributed to a universal atypicality in text integration or connecting processes. Previous studies examining inferential processing in ASD have predominantly used texts that evoke inferences that require the processing of situational world knowledge (e.g., causal relations). In contrast, the inferences participants had to form during the current experiment required participants to form a referential link upon the basis of lexical/semantic information about category members. Given that situational world knowledge processing was found to be atypical in Experiment 3 for ASD readers, it seems plausible to suggest that the requirement to process situational world knowledge may be a determining factor as to whether inferential difficulties are observed or experienced in ASD.

5.5 Re-reading

For each of the four experiments, ASD readers were found to make more fixations (marginal in Experiment 4) and have longer overall sentence reading times, in comparison to TD readers. This effect did not interact with sentence condition in any experiment, indicating that increased reading time in ASD was not mediated by the linguistic manipulations of the text. This effect was an unexpected, yet consistent finding and therefore merited further analyses. To examine the time course and location of the extra fixations ASD participants made, additional supplementary analyses that examined both first-pass and second (or later) sentence processing were run. For each experiment, no group differences in first pass measures were found. Instead, a higher proportion of re-reading was found to occur for ASD readers, following the initial processing of a sentence. This re-reading did not appear to be localized to any particular sentence region, for any experiment. The findings from the re-reading analyses suggest overall that the re-reading ASD participants engage in, reflect a tendency to make a regression back to the (near) beginning of a sentence and re-read the text, once they had reached the (near) end of a sentence. The lack of differences found for first-pass processing of the sentences, with increased re-reading for all sentence types and sentence regions following first pass, suggests that this re-reading in ASD reflected a reading strategy, as opposed to any difference or difficulty associated with the initial construction of a sentence interpretation.

5.6 Key Findings and Theoretical Implications

Collectively, these experiments extend the specificity with which we understand linguistic processing in ASD. The first key finding of this thesis, is that the efficiency of lexical identification, syntactic parsing and co-referential processing do not appear to differ between TD and ASD readers. Critically, these findings suggest that previous reports of reduced comprehension and inferential performance cannot be attributed to ASD specific difficulties with these processes. The second key finding is that individuals with ASD appear to be delayed in the processing of world knowledge. This suggests that there may be an ASD specific on-line processing difference in the employment of top-down knowledge during reading. Moreover, this suggests that the connection between world knowledge and the language processor may be weaker for readers with ASD, in comparison to TD readers.

Overall what these two key findings highlight is that the processing differences associated with reading in ASD are much more subtle than first imagined. Initially it was predicted that stark differences in the on-line processing of written text would be apparent in ASD, particularly when world knowledge and integrative processing are required. However, in this thesis, more similarities than differences between readers with and without ASD were found. It would appear that at a basic level, linguistic processing is intact in ASD, irrespective as to whether integrative processing is required or not. However, it would seem that the specific requirement for on-line processing of situational knowledge of the world, might be a determining factor of reading efficiency in ASD. For example, in Experiment 3 semantic processing was found to be intact when oddities could be detected upon the basis of a lexical information (i.e., anomaly detection), but reduced efficiency was observed when situational world knowledge processing was required (i.e., implausibility detection). Furthermore, in Experiment 4 co-reference processing was also found to be intact. Note that although the formation of this link required processing of knowledge, this was lexical/semantic knowledge about category members. Lexical/semantic knowledge is quite different to situational world knowledge about probable events that would have been necessary for implausibility detection in Experiment 3.

Any atypicality in situational world knowledge processing would most predominantly impact upon semantic and discourse levels of processing. This provides some explanation as to why reading difficulties in ASD have most commonly been reported for higher order reading tasks. Moreover, the difference in situational world knowledge processing also provides further explanation as to why previous findings for reading comprehension in ASD accuracy are mixed, whereas inferencing has consistently been reported as reduced, relative to TD controls. Situational world knowledge processing is not always necessary for comprehension. For example, if comprehension questions probe understanding of information explicitly stated within the text, efficiency in the use of situational world knowledge during comprehension will not influence accuracy. In contrast, if accuracy in the response to comprehension questions relies upon inferential processing, then it is likely that less effective and efficient world knowledge processing may impede response accuracy. Therefore, it might be the case that specific characteristics of text may determine the requirement for the use of situational world knowledge for successful comprehension, and these may be determinants of comprehension performance for individuals with ASD. Moreover, this atypicality in the time-course of world knowledge processing found for adults with ASD who presumably have reached developmental maturity, would suggest more broadly that the development of language is atypical in ASD, as opposed to delayed.

The third key finding of this research is that individuals with ASD adopt a reading strategy whereby they re-read text on a higher proportion of trials, in comparison to TD readers. Arguably, this re-reading could reflect text integration difficulties. However, the time course of the re-reading suggests that this is unlikely to be the case. Any difference in the initial linguistic processing of text, would have been evident in first pass reading measures, however, re-reading was only found for later measures that occurred after the initial processing of text. It has been speculated post-hoc, that this re-reading reflects a 'cautious' reading strategy whereby ASD participants re-read to 'check' that their interpretation of the text is accurate, but there are multiple reasons as to why readers with ASD might adopt a re-reading strategy. It is possible that a lack of confidence in the reader's own understanding of the sentences may underpin re-reading in ASD. This lack of confidence may ordinarily be present during everyday reading for individuals with ASD. However, any lack of confidence may also be exacerbated as a consequence of knowing that there would be comprehension questions following a proportion of the sentences throughout the experiments. Alternatively, re-reading may reflect meticulousness, and a strive for accuracy in comprehension that may be present in everyday reading behaviour in ASD, or may be exacerbated by the presence of the experimenter, the experimental set up, and expectations about how they are expected to 'perform'. Or, such re-reading could even reflect the repetitive characteristics of ASD.

The relevance and impact of these findings in relation to each of the cognitive theories discussed in Chapter 1 are discussed separately below, however, no current cognitive theory of ASD can holistically account for the findings reported in this thesis.

5.6.1 The Mentalizing Theory

The Mentalizing theory (Baron-Cohen et al., 1989; Frith et al., 1991) suggests that individuals with ASD have delayed Theory of Mind development and that this results in a number of the social difficulties associated with this disorder. Mentalizing processes are necessary for comprehension of specific types of texts (e.g., figurative), but are not formally specified as a fundamental process necessary for comprehension by any computational models of typical text comprehension. Therefore, processing of such text was not directly examined as part of this thesis and it is difficult to draw conclusions as to whether the requirement to engage in such processes affects or impedes text processing in ASD, at least on the basis of the present data. However, what is important to highlight is that theory of mind understanding often relies upon an individual processing relevant situational world knowledge, such as previous experience to aid the detection and understanding of implicit social cues during dynamic social interaction. Therefore, it seems reasonable to speculate that performance differences found for everyday communication tasks that require theory of mind processes may be related to subtle world knowledge processing differences in ASD.

5.6.2 Executive Dysfunction Theory

The Executive Dysfunction Theory (Hughs & Russell, 1993; Hughs, Russell & Robbins, 1994; Pennington & Ozonoff, 1996) suggests that the efficiency of spontaneous text monitoring is reduced in ASD. Monitoring is recognized as a process important for comprehension (e.g., Perfetti, Landi, & Oakhill, 2005), but is not a process in itself that is specified as part of typical models of reading comprehension. Therefore, Executive Dysfunction theory was not directly examined as part of this thesis. However, some conclusions regarding text monitoring can be inferred post-hoc from the data obtained in the experiments in the thesis. Both Experiment 2 (syntactically ambiguous sentences) and Experiment 3 (plausibility manipulation) included linguistic manipulations that aimed to require participants to detect an oddity within the text. If there were a universal reduction in text monitoring in ASD, one would predict a delay of detection for semantic oddities in both experiments, regardless of the linguistic manipulation (selectional restriction violation vs. world knowledge violation). However, the speed of detection was found to depend upon the type of linguistic processing required. Therefore, there does not appear to be any evidence in our data for a general text-monitoring deficit in ASD. As a result, it is difficult to predict how differences in monitoring, as proposed by the Executive Function Theory, could solely explain comprehension difficulties in ASD.

5.6.3 Weak Central Coherence Theory

The Weak Central Coherence Theory (Frith, 1989; Frith & Happé, 1994) posits that individuals with ASD have a detail focused, local processing bias coupled with a lack of spontaneous global processing. More specifically, the Weak Central Coherence Theory suggests that individuals with ASD are less efficient at integrating (local) information in order to process a gestalt whole (global). In the context of reading, this hypothesis is difficult to operationalize, given that what might be considered local vs. global information can be quantified in a number of different ways. For example, one could justifiably reason that words are local information and sentence meaning/context is global information. Consequently, single word comprehension would be predicted to be intact, but sentence level comprehension would be predicted to be impaired. In contrast, one could also reasonably argue that sentence meaning/context is local information, but passage meaning/context is global information, and that in contrast to the previous example, sentence level comprehension will be intact, but passage level comprehension will be impaired. That is to say, the linguistic granularity over which the theory is operationalized during reading is not specified. Furthermore, integration is a fundamental aspect of reading comprehension at multiple levels of language processing (e.g., contextual integration; integration of information between sentences; construction of a discourse model). Regardless of the exact aspect of reading where integration differences might manifest, if present in individuals with ASD, this would be evident in the eye movement record. However, no evidence of integration difficulties were found for any of the experiments conducted in this thesis. For example, the Weak Central Coherence Theory would predict that individuals with ASD would fail to detect semantic oddities, as this task requires readers to engage in connecting processes in order to develop a global semantic interpretation of a sentence. This would not be predicted to alter depending upon the linguistic characteristics of a text, because such connecting processes are imperative, irrespective of subtle linguistic variations. However, it was found that ASD readers were able to detect oddities in both Experiment 2 and 3, and, that the speed of detection of these oddities in Experiment 3 was shown to depend upon the linguistic characteristics of the text. Moreover, in Experiment 4, readers with ASD were found to compute co-referential links, which required the integration of information across sentences, as efficiently as TD readers. The data from the experiments in this thesis are consistent with the literature that has used multiple methodologies and adopted varying local/global distinctions, yet report evidence of comparable integrative processing between TD and ASD readers (Au-Yeung, Kaakinen, Liversedge & Benson, 2015; Brock & Bzishvili, 2013; Brock & Caruana, 2014; Brock, Norbury, Einav, & Nation, 2008; Caruana & Brock, 2014 Hala, Pexman, &

Glenwright, 2007; Henderson, Clarke, & Snowling, 2011; Norbury, 2005). It would therefore seem that individuals with ASD *do* (spontaneously) engage in integrative processing necessary for text comprehension. These data suggest that although intended as a domain general account of cognition in ASD, the local processing bias the Weak Central Coherence theory proposes may not generalize to the language processing domain and as such, the local/global distinction may not apply.

5.6.4 Theory of Complex Information Processing

The Theory of Complex Information Processing claims that individuals with ASD will have intact processing for "simple" (e.g., low-level) tasks, but will exhibit deficits in the processing of "complex" tasks involving higher order processes and/or the integration of information (Minshew & Goldstein, 1998; Williams, Goldstein, & Minshew, 2006). Overall, the data from this thesis are most compatible with this theory. There is clear evidence (Experiment 3) that higher order (top down) processing during reading may be less efficient in ASD, and Experiments 1 and 2 demonstrate that low-level (bottom up) processing is intact. Therefore, these data would support the theory of Complex Information Processing's proposal that the requirement to process world knowledge (top-down) determines when a task becomes 'complex'. However, these data do not support the proposal that the requirement for integrative determines whether a task is considered 'complex'. As discussed in the previous section, there is no evidence in this thesis for a difficulty in the basic construction of a discourse model, or, in the integration of information across sentences to form a co-referential link. Therefore, if the Theory of Complex Information Processing is to be used as an explanation of reading difficulties in ASD, the definition of when and how integrative processing differ in ASD, if at all, needs to be revised. It would seem based upon the data presented in this thesis that integrative processing is intact during reading in ASD and therefore cannot be used as a factor used to determine task 'complexity' during reading. It would seem instead that text requirements for the processing of situational world knowledge might determine task 'complexity' for individuals with ASD.

5.7 Broader Implications

Situational world knowledge processing is the key aspect of language processing found to differ for ASD in this thesis, and situational world knowledge processing is important for proficient comprehension. It is likely that differences in the on-line processing of such information is a contributing factor to the difficulties associated with

ASD in reading comprehension and in the formation of appropriate inferences. Based upon this data, it is difficult to conclude whether these findings can be generalized to other forms of language. However, given similar performance differences (e.g., inferencing accuracy) have been found in ASD for other language constructs (e.g., auditory processing, Dennis et al., 2001), one can speculate that on-line situational world knowledge processing differences may also be present across language constructs. Any delays in situational world knowledge processing may be more detrimental during auditory language comprehension, given the rate with which new information is delivered is determined by the speaker, as opposed to the reader (as was the case during our expeirments), and may not allow for any additional processing time required by individuals with ASD.

Moreover, world knowledge processing is not domain specific. The employment of prior situational knowledge is central across many other cognitive domains, in addition to the language processing system. For example, dynamic social interactions rely to some extent upon an individual being able to respond appropriately, based upon knowledge of subtle social cues and norms. Therefore, any temporal differences in the evaluation of, or access to situational world knowledge could also impact upon social cognition. For example during a social exchange, TD individuals process the interlocutor's expression, gesture, prosody, and body language, and simultaneously monitor and alter their own behaviour and responses based upon their knowledge of what these cues implicitly suggest based upon their situational world knowledge of the present social context. If individuals with ASD are delayed in the processing and detection of these cues based upon their situation world knowledge, this is likely to severely disturb and interfere with interaction ease and fluidity. There is evidence of a temporal difference in the detection of social oddities in ASD when situational social context has to be processed (e.g., Benson et al., 2012; 2015). In addition, a model of perceptual processing in ASD has recently been proposed that is based upon Bayesian inference, and suggests that sensory and perceptual atypicalities in ASD are a result of reduced reliance upon prior knowledge and experience (Pellicano & Burr, 2012). Thus, it could be the case that temporal differences in the processing of situational world knowledge may be a domain general processing difference in ASD, and one that can account for a number of behavioural differences associated with ASD, in addition to reading comprehension and inferencing difficulties. Based upon previous studies that have demonstrated a link between the severity of ASD symptomology and the severity of reading comprehension difficulties, one would assume that the delay in situational world knowledge processing observed within this research would become more pronounced, as ASD severity increases. In other words, the processing of such knowledge would be more delayed or even absent in individuals who have more severe ASD symptoms, and could therefore contribute to an explanation for the variance in language comprehension and social interaction skill observed across the spectrum.

5.8 Strengths and Limitations

A crucial strength of this research has been the employment of eye-tracking methodology to investigate language processing in ASD. This technique allowed for on-line processing differences (and similarities) to be revealed between TD and ASD readers. Although eye tracking is one of the predominant methods adopted in reading research, this is a technique that has yet to be exploited fully to examine on-line cognitive processing in ASD. By using this method, new information about the efficiency and qualitative nature of text processing in ASD has been revealed, and this new knowledge in relation to language processing in ASD would not have been available through the measurement of behavioural responses alone.

A second strength of this research was the measurement of oral language skill. Previous literature has clearly demonstrated that oral language difficulties are more prominent in the ASD population and that these skills are a key-determining factor as to whether individuals experience comprehension difficulties. However, a significant proportion of previous studies have not accounted for this individual difference. In each experiment in this thesis differences in oral language skill were accounted for by matching groups on average on oral language skill, or by including this measure within statistical models, allowing for ASD *specific* processing difficulties to be separated from those associated with oral language skill.

One limitation of this research was that the majority of participants with ASD had received a diagnosis of Asperger's Syndrome. Recall that diagnostic criteria have recently been altered, so that individuals previously diagnosed with Asperger's syndrome, now receive a diagnosis of ASD. However, these individuals have no delay in language development, and fewer difficulties with language processing, in comparison to individuals who receive a diagnosis of ASD (Iwanga et al. 2000; Klin et al. 1995; Ozonoff et al. 1991, 2000). It is therefore possible that the participants recruited for this research represented a selective group who may not be representative of the more diverse population of adults with ASD. Nonetheless, the lack of difference in off-line performance measures means that the finding of a delay in the on-line processing of world knowledge is even more critical in the ASD sample in this thesis. It would appear that even for individuals with ASD that do not demonstrate atypical performance for reading comprehension outcomes, that subtle differences in the on-line processing of such information are present. In turn, it has been speculated throughout this thesis that world knowledge processing differences are likely to impact upon off-line comprehension in ASD. However as already noted, these on-line differences in situational world knowledge processing found in Experiment 3, were not coupled with any differences in comprehension in this group of ASD readers. Therefore, how and when on-line world knowledge processing differences impact upon off-line comprehension outcomes is an issue beyond the scope of the present thesis.

5.9 Future Directions

This thesis presents experiments that systematically examine on-line linguistic processing during reading in ASD. However, because eye movements and reading in ASD is a developing field, there are still a multitude of questions and issues that need to be addressed. Some of the key questions that remain to be answered and that have developed from the experiments reported in this thesis are described below.

5.9.1 World knowledge

It would seem, based on the data in this thesis, that world knowledge processing is delayed for ASD readers, relative to TD readers. However, the exact mechanisms that underpin this delay are currently unknown. More research is needed in order to identify whether differences stem from delayed activation of world knowledge, reduced access to world knowledge, or less efficient integration of world knowledge into the discourse model. Although such differences are extremely subtle and may not influence the practical impact of these findings, such technicalities are important for theoretical development and the accurate characterization of language processing in ASD. Furthermore, continued work is needed to determine the relationship between on-line processing and off-line performance. In other words, research into how and when world knowledge differences impede performance is required, to inform the development of remedial tools and reading instruction for ASD.

5.9.2 Inferential Work

Further work is needed to examine why off-line performance for inferential tasks is poor in ASD. Based on the data in this thesis, there does not appear to be a difference in the efficiency with which readers with ASD form co-referential links, when these are formed upon the basis of lexical/semantic knowledge. However, performance accuracy for inferencing tasks has consistently been reported as reduced for readers with ASD. Therefore, research that systematically examines inferential processing is needed in order to determine exactly when the processing of such information becomes atypical, and when performance accuracy is reduced. This research is necessary in order to inform current remedial practice. For example, if it is known what types of inferential processing in ASD are atypical, these could be avoided (e.g., in expository texts), and be targeted by reading instruction (e.g., in education).

5.9.3 Re-reading

The underlying cause of the re-reading behaviour observed across each experiment is currently unknown. It has been speculated throughout this thesis that re-reading reflects a reading strategy, however, the function and necessity of this re-reading requires further investigation. It has been assumed that this re-reading is not necessary for comprehension, based on equivalence in the eye movement metrics for ASD and TD controls in first pass processing. However, this needs to be empirically tested, for example, by examining comprehension outcomes when re-reading is prevented. Furthermore, if experimentation confirms that re-reading is not necessary for comprehension, the different underlying causes of this behaviour, such as reduced confidence, sensitivity to comprehension questions, or meticulousness, should be empirically examined.

5.10 Concluding Remarks

Individuals with ASD have previously been reported to have reduced performance accuracy for higher order reading tasks, in comparison to TD controls. By using eye tracking, this thesis challenges previous suggestions that on-line integrative processing is atypical in ASD. The findings reported in Chapters 2 and 4 demonstrated that when oral language is controlled and on-line measures of processing efficiency are monitored during a naturalistic reading paradigm, lexical, syntactic and co-reference processing are all intact in ASD. In contrast, the findings reported in Chapter 3 demonstrated that specific processing differences are apparent for text reading in ASD when the employment and evaluation of situational world knowledge is required. Therefore, it would appear that subtle differences in the processing of situational world knowledge might underpin reading comprehension and inferential difficulties in ASD. Furthermore, in each empirical chapter, individuals with ASD were found to adopt a ‘cautious’ reading style, which could be related to intentional re-evaluation of text information. In conclusion, these novel findings contribute to the specificity with which we understand how ASD impacts upon written language comprehension, and to the field in general in terms of on-line language processing in ASD.

Appendices

Appendix A Eye Movement Measures 165

Appendix B Experiment 1 Stimuli 167

Appendix C Experiment 2 Stimuli 171

Appendix D Experiment 3 Model Output 177

Appendix E Experiment 4 Stimuli 185

Appendix A Eye Movement Measures

When examining a reader's eye movements, we must first define regions of interest (ROI) within a sentence. These will differ dependent upon the linguistic manipulation implemented and can include any amount of information from one letter to multi word units. There are a number of eye movement measures that can be computed in order to gain a detailed understanding about how the manipulated variable has effected the readers on-line cognitive processing. The measures that are computed are dependent upon the linguistic manipulation. For experiments that manipulate lexical variables, 'early' eye movement measures are computed and analysed. This is because lexical processing occurs extremely rapidly and therefore any differences in processing are detectible in eye movement measures that reflect initial processing of a word (e.g., first fixation duration, single fixation duration and gaze duration). For experiments that manipulate higher order linguistic variables (e.g., the presence of an ironic phrase vs. non ironic phrase), early eye movement measures are computed in order to identify the stage of which processing differences occur. But, in addition, 'later' eye movement measures are also computed (e.g. go past time, total time and regressions) because it is in these later stages of processing that higher order variables tend to most predominantly impact upon processing. In these instances, it is important to examine measures that reflect both spatial and temporal fixations in order to have a detailed account of the manipulated variables effect on language processing. Measures that reflect spatially contiguous fixations (e.g., total times, because it groups fixations in relation to where they landed, such as all on one word) are informative about the level of processing disruption a word or multi word unit causes, whereas measures that reflect temporally contiguous fixations (e.g., go past time because this groups fixations together in relation to their concurrency) are informative about the nature of this disruption, such as the amount and location of a readers re-reading (Liversedge, Paterson & Pickering, 1998). For a definition of each of the most commonly calculated eye movement measures used in reading research, see the Table below.

Definition of commonly analysed eye movement measures in reading experiments.

		Definition
Early Measures (first pass)	Skipping	The probability that a region is skipped.
	First Fixation Duration	The duration of the first fixation in a region.
	Single Fixation Duration	The duration of the first fixation in a region, when it is the only fixation made in that region.
	Gaze Duration	The sum of all fixations in a region from the first fixation until the reader leaves that region for the first time to the left or right.
	Go Past Time	The sum of fixations from the first fixation, until a reader leaves the region to the right. This measure includes fixations back to earlier regions and represents the time a reader takes to progress past a region for the first time.
Later Measures	Total Time	The sum of all fixations in a region.
	Regressions In	The probability that a reader regresses into a region.
	Regressions Out	The probability that a reader regresses out of a region.

Appendix B Experiment 1 Stimuli

Stimuli used for Experiment 1. The frequency of target words (in bold) was manipulated. The first example (a) in each stimuli pair includes a high frequency target word (e.g., office) and the second version (b) includes a low frequency word (e.g., cavern).

1a. John walked to the large **office** yesterday morning.

1b. John walked to the large **cavern** yesterday morning.

2a. The dog ran excitably towards the scared **couple** in the park.

2b. The dog ran excitably towards the scared **rodent** in the park.

3a. Jane watched the scary **people** handing out sweets on Halloween.

3b. Jane watched the scary **zombie** handing out sweets on Halloween.

4a. Sandra placed a single **bottle** in each picnic basket.

4b. Sandra placed a single **lychee** in each picnic basket.

5a. The group of friends went to the newly opened **market** last weekend.

5b. The group of friends went to the newly opened **bistro** last weekend.

6a. Kate was concerned about her worsening **health** so made a doctors appointment.

6b. Kate was concerned about her worsening **bunion** so made a doctors appointment.

7a. The girls stared with awe at the pretty **things** Olivia had bought.

7b. The girls stared with awe at the pretty **frocks** Olivia had bought.

8a. Ben's favourite dish was breadcrumbed **turkey** fillet with chips.

8b. Ben's favourite dish was breadcrumbed **plaice** fillet with chips.

9a. Tourist's visited the traditional **temple** regularly.

9b. Tourist's visited the traditional **friary** regularly.

10a. Samantha lived next door to a kind **priest** for years.

10b. Samantha lived next door to a kind **banker** for years.

11a. The young **family** visited the theatre with friends.

11b. The young **fellow** visited the theatre with friends.

12a. John had never met Sarah's **father** before today.

12b. John had never met Sarah's **auntie** before today.

13a. Charles packed his new **camera** for the wedding.

13b. Charles packed his new **cravat** for the wedding.

14a. Carrie admired the elaborate **design** on the wall.

14b. Carrie admired the elaborate **rapier** on the wall.

15a. Annie served the delicious **cheese** at the buffet.

15b. Annie served the delicious **bisque** at the buffet.

16a. The village **school** was full of excited children.

16b. The village **crèche** was full of excited children.

17a. Ruth made some tasty **coffee** for her friends.

17b. Ruth made some tasty **tiffin** for her friends.

18a. The student proofread their long **report** before handing it in.

18b. The student proofread their long **thesis** before handing it in.

19a. Reports about the sudden **attack** were all over the news.

19b. Reports about the sudden **mayhem** were all over the news.

20a. The police discussed the shocking **matter** in depth.

20b. The police discussed the shocking **affray** in depth.

21a. The girl had chosen the unusual **career** carefully.

21b. The girl had chosen the unusual **bangle** carefully.

22a. The house had a large **toilet** downstairs.

22b. The house had a large **larder** downstairs.

23a. The group of leary **adults** stumbled out of the pub.

23b. The group of leary **blokes** stumbled out of the pub.

24a. Alan had paid a fortune for the new **window** to be fitted.

24b. Alan had paid a fortune for the new **gasket** to be fitted.

25a. The man reluctantly walked into the grey **church** yesterday morning.

25b. The man reluctantly walked into the grey **morgue** yesterday morning.

26a. The tour group examined the detailed **system** on display at the museum.

26b. The tour group examined the detailed **goblet** on display at the museum.

27a. Mary complained that her **memory** wasn't very good.

27b. Mary complained that her **muesli** wasn't very good.

28a. Betty had never seen a large **street** like this one before.

28b. Betty had never seen a large **urchin** like this one before.

29a. The man asked if he could take the delicious **recipe** home.

29b. The man asked if he could take the delicious **scampi** home.

30a. George quickly put on the black **jumper** before leaving.

30b. George quickly put on the black **tuxedo** before leaving.

31a. The man grinned with happiness when he saw the perfect **result** on the screen.

31b. The man grinned with happiness when he saw the perfect **foetus** on the screen.

32a. Greg saw the cheerful **driver** every day.

32b. Greg saw the cheerful **busker** every day.

33a. Karla fed her brother's **horses** every day.

33b. Karla fed her brother's **geckos** every day.

34a. The child was excited to see the baby **monkey** at the zoo.

34b. The child was excited to see the baby **ocelot** at the zoo.

Appendix C Experiment 2 Stimuli

Experiment 2 Stimuli. Sentences were manipulated to contain either a high attached or low attached prepositional phrase. The first version of each sentence pair is high attached and the second version is low attached. Target words are in bold.

1a. The doctor treated the young patient with a rare form of **penicillin** yesterday.

1b. The doctor treated the young patient with a rare form of **meningitis** yesterday.

2a. The child poked the funny clown with a large **stick** and ran away laughing.

2b. The child poked the funny clown with a large **smile** and ran away laughing.

3a. Charlie demolished the dilapidated house with a huge **crane** last year.

3b. Charlie demolished the dilapidated house with a huge **fence** last year.

4a. Sharon stitched the smart shirt together with a pointed **needle** last night.

4b. Sharon stitched the smart shirt together with a pointed **collar** last night.

5a. Chris dug up the root vegetable with a green **spade** yesterday morning.

5b. Chris dug up the root vegetable with a green **stalk** yesterday morning.

6a. Lucy polished the silver tankard with a black **duster** each day.

6b. Lucy polished the silver tankard with a black **handle** each day.

7a. Jessy cleaned the downstairs bathroom with the blue **bleach** every week.

7b. Jessy cleaned the downstairs bathroom with the blue **tiles** every week.

8a. The fisherman gutted the freshwater fish with a silver **knife** next to the river.

8b. The fisherman gutted the freshwater fish with a silver **body** next to the river.

9a. The chef injured the rich woman with a long **blade** by accident.

9b. The chef injured the rich woman with a long **dress** by accident.

10a. The doctor sedated the ill child with a painful **injection** at the hospital.

10b. The doctor sedated the ill child with a painful **infection** at the hospital.

11a. The cook served the tomato soup with a deep **ladle** to the customers.

11b. The cook served the tomato soup with a deep **smell** to the customers.

12a. The man sliced the citrus tart with a sharp **knife** for his friends.

12b. The man sliced the citrus tart with a sharp **taste** for his friends.

13a. The man hit the unexpected intruder with a long **cosh** without thinking.

13b. The man hit the unexpected intruder with a long **scar** without thinking.

14a. The robber threatened the scared cashier with a black **rifle** for money.

14b. The robber threatened the scared cashier with a black **beard** for money.

15a. Ashleigh groomed the stray cat with the slightly odd **comb** before phoning the vet.

15b. Ashleigh groomed the stray cat with the slightly odd **limp** before phoning the vet.

16a. Dave lit the stylish cigarette with the brown **lighter** after work.

16b. Dave lit the stylish cigarette with the brown **tobacco** after work.

17a. The man washed his old car with a large **sponge** in the garage.

17b. The man washed his old car with a large **scratch** in the garage.

18a. Dan caught the small mouse with a delicate **trap** in the kitchen.

18b. Dan caught the small mouse with a delicate **tail** in the kitchen.

19a. The scientist examined the planet with an enormous **telescope** last night.

19b. The scientist examined the planet with an enormous **crater** last night.

20a. The jockey whipped the muscular horse with a brown **crop** during the race.

20b. The jockey whipped the muscular horse with a brown **mane** during the race.

21a. Sheila stirred the cake mixture with the orange **spatula** before baking it in the oven.

21b. Sheila stirred the cake mixture with the orange **flavour** before baking it in the oven.

22a. Jeremy pierced the spicy sausages with a firm **skewer** before putting them under the grill.

22b. Jeremy pierced the spicy sausages with a firm **texture** before putting them under the grill.

23a. Isaac burnt his middle finger with a long **match** whilst lighting the fire.

23b. Isaac burnt his middle finger with a long **nail** whilst lighting the fire.

24a. The woman assaulted the aggressive man with a nasty **razor** this morning.

24b. The woman assaulted the aggressive man with a nasty **wart** this morning.

25a. The vandal destroyed the house with a large **baton** last month.

25b. The vandal destroyed the house with a large **pool** last month.

26a. Tim unlocked the front door with the gold **key** for the first time.

26b. Tim unlocked the front door with the gold **wreath** for the first time.

27a. The guard hit the angry yob with a bronze **truncheon** at the festival.

27b. The guard hit the angry yob with a bronze **earring** at the festival.

28a. The decorator painted the lounge wall with a large **brush** this morning.

28b. The decorator painted the lounge wall with a large **stain** this morning.

29a. Sandra cut the coloured paper with the big **scissors** to make a birthday card.

29b. Sandra cut the coloured paper with the big **creases** to make a birthday card.

30a. The boy stuck the toy plane together with the white **glue** this morning.

30b. The boy stuck the toy plane together with the white **wings** this morning.

31a. The drunk attacked the local publican with a broken **glass** last night.

31b. The drunk attacked the local publican with a broken **ankle** last night.

32a. The boy caught a big fish with a long **rod** on the pier.

32b. The boy caught a big fish with a long **fin** on the pier.

33a. The girl smacked the annoying boy with a thin **ruler** at school.

33b. The girl smacked the annoying boy with a thin **smirk** at school.

34a. The thug beat the innocent man with a black **weapon** yesterday evening.

34b. The thug beat the innocent man with a black **tattoo** yesterday evening.

35a. Mary cleaned her son's grazed knee with a blue **cloth** when he got home.

35b. Mary cleaned her son's grazed knee with a blue **bruise** when he got home.

36a. The headmaster smacked the mischievous boy with a long **cane** in the playground.

36b. The headmaster smacked the mischievous boy with a long **nose** in the playground.

37a. The crying woman shot the man with a black **gun** to protect herself.

37b. The crying woman shot the man with a black **eye** to protect herself.

38a. The sniper shot the government spy with a vintage **revolver** outside parliament.

38b. The sniper shot the government spy with a vintage **briefcase** outside parliament.

39a. The man murdered his lifelong enemy with a grey **pistol** last night.

39b. The man murdered his lifelong enemy with a grey **toupee** last night.

40a. The girl whacked her older brother with a red **cushion** for making fun of her.

40b. The girl whacked her older brother with a red **blister** for making fun of her.

41a. The soldiers blasted open the heavy door with an old fashioned **grenade** last night.

41b. The soldiers blasted open the heavy door with an old fashioned **knocker** last night.

42a. The killer strangled his latest victim with the golden **rope** in the dungeon.

42b. The killer strangled his latest victim with the golden **tooth** in the dungeon.

43a. The boy walloped his friend with the gold **club** by accident.

43b. The boy walloped his friend with the gold **ring** by accident.

44a. The butcher chopped the meat with a heavy **cleaver** for a customer.

44b. The butcher chopped the meat with a heavy **marinade** for a customer.

Appendix D Experiment 3 Model output

Global Analyses Model Output

	Average Fixation Duration				Average Fixation Count				Sentence Reading Time			
	B	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	5.39	0.02	298.06	<.001	2.63	0.05	51.57	<.001	8.19	0.06	144.25	<.001
Group	-0.04	0.04	-1.14	.259	-0.20	0.10	-1.92	.061	-0.26	0.12	-2.22	.032
Anomalous	<0.01	<0.01	-0.93	.355	-0.08	0.01	-6.89	<.001	-0.08	0.01	-7.26	<.001
Implausible	<0.01	<0.01	-0.35	.726	-0.01	0.01	-1.47	.151	-0.02	0.01	-2.18	.036
Age (centred)	<0.01	<0.01	-0.29	.774	<0.01	<0.01	-0.09	.929	<0.01	0.01	0.13	.898
Group*Anomalous	0.01	0.01	0.87	.387	0.01	0.02	0.30	.766	0.02	0.02	1.03	.307
Group*Implausible	-0.01	0.01	-0.83	.406	0.01	0.02	0.85	.401	0.01	0.02	0.86	.390

Appendix D

Pre-Target Analysis For First Fixation Duration, Single Fixation Duration And Gaze Duration.

	First Fixation Duration				Single Fixation Count				Gaze Duration			
	B	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	5.32	0.02	261.23	<.001	5.40	0.03	175.94	<.001	5.64	0.04	144.12	<.001
Group	-0.02	0.04	-0.58	.567	<0.01	0.06	0.02	.981	-0.02	0.08	-0.21	.834
Anomalous	0.01	0.01	1.41	.160	-0.01	0.02	-0.31	.756	-0.02	0.01	-1.64	.102
Implausible	0.01	0.01	0.65	.516	-0.01	0.01	-0.72	.477	0.01	0.01	0.45	.657
Age (centred)	<0.01	<0.01	0.57	.571	<0.01	<0.01	-0.14	.891	<0.01	<0.01	-0.13	.895
Group*Anomalous	-0.01	0.02	-0.65	.518	0.02	0.03	0.78	.436	-0.03	0.03	-1.00	.317
Group*Implausible	-0.01	0.02	-0.32	.753	0.01	0.03	0.54	.596	-0.02	0.03	-0.60	.552

Pre-Target Analyses for Go Past And Total Time.

	Go Past Time				Total Time			
	B	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	5.74	0.05	122.65	<.001	6.07	0.06	100.44	<.001
Group	-0.02	0.09	-0.24	.812	-0.24	0.11	-2.13	.039
Anomalous	-0.06	0.01	-4.23	<.001	-0.19	0.02	-9.25	<.001
Implausible	-0.02	0.01	-1.74	.087	-0.02	0.02	-0.93	.361
Age (centred)	<0.01	<0.01	-0.03	.975	<0.01	0.01	0.38	.706
Group*Anomalous	-0.01	0.03	-0.24	.813	0.01	0.03	0.30	.766
Group*Implausible	-0.02	0.03	-0.64	.523	-0.03	0.03	-0.76	.455

Target Region Analyses For First Fixation And Single Fixation Durations.

	First Fixation Duration				Single Fixation Duration			
	B	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	5.37	0.02	222.20	<.001	5.39	0.03	189.16	<.001
Group	-0.04	0.05	-0.83	.410	-0.07	0.05	-1.22	.229
Anomalous	-0.04	0.01	-3.94	<.001	-0.06	0.01	-4.18	<.001
Implausible	-0.01	0.01	-1.39	.172	-0.04	0.01	-2.69	.009
Age (Centred)	<0.01	<0.01	1.15	.256	<0.01	<0.01	0.48	.635
Group*Anomalous	-0.02	0.02	-0.90	.366	-0.02	0.03	-0.77	.445
Group*Implausible	-0.05	0.02	-2.41	.017	-0.06	0.02	-2.32	.021
TD Participants Only								
Intercept (Plausible)	5.35	0.03	184.72	<.001	5.36	0.03	178.26	<.001
Anomalous	-0.05	0.01	-3.66	<.001	-0.07	0.02	-3.82	.001
Implausible	-0.04	0.01	-2.91	.006	-0.06	0.02	-3.82	.001
Age	<0.01	<0.01	0.76	.457	<0.01	<0.01	0.70	.493
ASD Participants Only								
Intercept (Plausible)	5.38	0.04	129.18	<.001	5.43	0.05	105.98	<.001
Anomalous	-0.03	0.02	-1.84	.076	-0.05	0.02	-2.04	.050
Implausible	0.01	0.02	0.36	.720	-0.01	0.02	-0.36	.722
Age	<0.01	<0.01	1.09	.291	<0.01	<0.01	0.05	.961

Target Region Analyses For Gaze Duration; Go Past Time And Total Time.

	Gaze Duration				Go Past Time				Total Time			
	B	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	5.47	0.03	180.60	<.001	5.61	0.04	143.74	<.001	5.79	0.05	119.45	<.001
Group	-0.01	0.05	-0.26	.799	-0.05	0.07	-0.81	.425	-0.20	0.09	-2.15	.038
Anomalous	-0.06	0.01	-4.44	<.001	-0.10	0.02	-5.24	<.001	-0.13	0.02	-6.07	<.001
Implausible	-0.03	0.02	-1.69	.102	-0.03	0.02	-1.98	.054	-0.02	0.02	-1.14	.263
Age (Centred)	<0.01	<0.01	0.08	.934	<0.01	<0.01	<0.01	.997	<0.01	<0.01	0.07	.945
Group*Anomalous	0.01	0.02	0.51	.613	-0.02	0.04	-0.43	.668	-0.02	0.04	-0.53	.598
Group*Implausible	-0.04	0.03	-1.59	.119	-0.05	0.03	-1.49	.145	-0.03	0.03	-0.98	.332

Post Target Region Analyses For First Fixation, Single Fixation Duration And Gaze Duration.

	First Fixation Duration				Single Fixation Duration				Gaze Duration			
	B	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	5.40	0.03	214.07	<.001	5.48	0.03	157.35	<.001	5.66	0.04	145.14	<.001
Group Main Effect	<0.01	0.05	-0.08	.937	-0.06	0.07	-0.91	.369	0.01	0.07	0.19	.847
Anomalous	-0.01	0.01	-0.81	.420	<0.01	0.02	0.03	.980	-0.03	0.02	-1.48	.148
Implausible	-0.01	0.01	-1.14	.261	-0.02	0.02	-1.17	.247	-0.01	0.02	-0.45	.654
Age (Centred)	<0.01	<0.01	0.91	.368	<0.01	<0.01	-0.49	.626	<0.01	<0.01	1.01	.319
Group*Anomalous	0.01	0.02	0.24	.809	0.03	0.05	0.61	.547	0.01	0.03	0.24	.810
Group*Implausible	-0.03	0.02	-1.12	.266	-0.03	0.04	-0.64	.526	-0.06	0.03	-1.84	.067

Post Target Region Analyses For Go Past And Total Time.

	Go Past Time				Total Time			
	B	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	6.03	0.06	108.02	<.001	6.02	0.06	103.59	<.001
Group Main Effect	-0.12	0.10	-1.21	.233	-0.17	0.11	-1.54	.130
Anomalous	-0.11	0.03	-4.19	<.001	-0.08	0.02	-3.80	.001
Implausible	-0.02	0.02	-0.96	.340	-0.02	0.02	-0.98	.329
Age (centred)	0.01	<0.01	1.61	.113	0.00	0.00	0.52	.607
Group*Anomalous	-0.02	0.05	-0.38	.706	0.03	0.04	0.59	.558
Group*Implausible	-0.06	0.05	-1.27	.205	-0.04	0.04	-1.00	.323

Appendix D

Pre-target region supplementary analyses.

	Proportion of Re-reading				First Pass Regressions Out				Re-reading Duration			
	B	*SE*	*z*	*p*	*B*	*SE*	*z*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	-0.17	0.18	-0.94	.348	-2.62	0.18	-14.54	< .001	5.74	0.06	92.25	< .001
Group Main Effect	-0.80	0.37	-2.16	.031	0.29	0.33	0.89	.376	-0.23	0.13	-1.76	.086
Anomalous	-0.79	0.09	-9.06	<.001	-0.42	0.13	-3.28	.001	-0.17	0.03	-5.03	< .001
Implausible	-0.01	0.08	-0.17	.864	-0.25	0.13	-1.90	.058	-0.05	0.04	-1.34	.188
Age	0.01	0.02	0.74	.462	-0.01	0.02	-0.62	.535	<0.01	0.01	-0.60	.553
Group*Anomalous	-0.05	0.18	-0.27	.788	-0.15	0.25	-0.59	.552	0.02	0.06	0.26	.793
Group*Implausible	-0.25	0.16	-1.51	.132	-0.06	0.26	-0.22	.823	0.01	0.07	0.09	.928

Target region supplementary analyses.

	Proportion of Re-reading				First Pass Regressions Out				Re-reading Duration			
	B	*SE*	*z*	*p*	*B*	*SE*	*z*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	-0.69	0.19	-3.59	<.001	-2.00	0.16	-12.68	< .001	5.57	0.05	113.19	< .001
Group	-0.88	0.37	-2.39	.017	0.12	0.27	0.44	.661	-0.08	0.10	-0.82	.419
Anomalous	-0.39	0.10	-4.08	<.001	-0.28	0.10	-2.74	.006	-0.05	0.04	-1.26	.216
Implausible	0.12	0.10	1.19	.235	-0.04	0.11	-0.32	.750	0.01	0.04	0.14	.893
Age	0.02	0.02	1.23	.220	< 0.01	0.01	0.28	.783	< 0.01	0.00	0.24	.809
Group*Anomalous	< 0.01	0.19	0.01	.989	-0.02	0.20	-0.10	.923	-0.03	0.07	-0.47	.638
Group*Implausible	0.09	0.20	0.43	.666	-0.03	0.22	-0.14	.886	-0.01	0.07	-0.08	.940

Post target region supplementary analyses.

	Proportion of Re-reading				Regressions First Pass Regressions Out				Re-reading Duration			
	B	*SE*	*z*	*p*	*B*	*SE*	*z*	*p*	*B*	*SE*	*t*	*p*
Intercept (global mean)	-0.48	0.20	-2.46	.014	-1.06	0.22	-4.80	< .001	5.72	0.05	108.84	< .001
Group Main Effect	-0.63	0.35	-1.82	.069	0.39	0.35	1.10	.274	-0.21	0.11	-1.94	.060
Anomalous	-0.35	0.09	-4.16	<.001	-0.35	0.09	-3.90	< .001	-0.09	0.04	-2.07	.049
Implausible	-0.05	0.08	-0.58	.563	-0.04	0.09	-0.43	.670	-0.03	0.04	-0.69	.494
Age	< 0.01	0.02	-0.04	.970	0.02	0.02	0.91	.364	< 0.01	0.01	0.07	.948
Group*Anomalous	-0.02	0.17	-0.11	.916	0.08	0.18	0.45	.652	0.04	0.09	0.49	.631
Group*Implausible	0.08	0.17	0.49	.623	-0.05	0.18	-0.26	.795	-0.03	0.08	-0.34	.738

Appendix E Experiment 4 Stimuli

Experiment 4 Stimuli. The second sentence contains the target category noun (in bold). The first sentence contains the instance category manipulation (italics). The first instance to be listed (e.g., pigeon) is a typical exemplar, the second instance to be listed (e.g., penguin) is an atypical exemplar.

1. Whilst relaxing in the garden on Saturday, Sally picked a *daisy/ geranium* from the ground. She tucked the flower behind her dog's ear and took a photograph.
2. The family sat watching a *pigeon/ penguin* that was shuffling around next to the pond. The youngest child pointed at the **bird** and laughed.
3. Once a fortnight Jackie played the *guitar/ glockenspiel* in a local jazz band. She carefully polished and tuned the **instrument** before each performance.
4. Charles met Carly's *sister/ granddaughter* at a house warming party. He was surprised to hear the **relative** was planning to move to Spain.
5. Jane sighed as she unpicked the stiches from the *cotton/ taffeta* item she was making. She had been warned the **fabric** would be difficult to work with.
6. Fred wanted to paint his bedroom walls bright *green/ cyan* to match his favourite t-shirt. His mother said the **colour** was too garish.
7. Derek bid for the antique *table/ futon* with excitement. There were a lot of dealers who wanted the **furniture** for their collections.
8. Ellen sliced the *apple/ cantaloupe* and placed it in her lunch box. As a child she was allergic to the **fruit** but had thankfully had grown out of it.
9. For safety reasons the *gun/ taser* was kept in a locked glass cabinet. The owners were afraid somebody would steal the **weapon** for criminal activity.
10. The young energetic *Labrador/ Schnauzer* bounded into the kitchen covered in mud. The children weren't meant to let the **dog** outside when it was raining.
11. The instruction booklet said that Tom would need a *hammer/ plunger* to fix the kitchen sink. He borrowed the **tool** from his next door neighbour.
12. Jeremy was a trainee *doctor/ masseuse* at the local clinic. At times the **profession** could be very challenging.
13. Jake had recently begun playing *rugby/ curling* for the University team. He was amazed by the strong following the **sport** had from members of the public.
14. Robin wanted to study *chemistry/ genetics* at Cambridge University. He had always been fascinated by the **science** since he was a young boy.

15. Brett had bought his younger brother a *teddy/ yoyo* for his birthday. He wrapped the **toy** up in yellow shiny paper before giving it to him.
16. The gardener planted the *peas/ radish* much earlier in the year than usual. He was confident the **vegetable** was hardy enough to cope with the cold.
17. At school the children inspected an *ant/ earwig* through a microscope. The exact species of the **insect** was difficult to identify because of its odd colouring.
18. Sarah squealed with excitement as she held the *cat/ snail* for the first time. Her mother had bought her the **pet** as a Christmas present.
19. The chef picked some fresh *thyme/ sorrel* from his restaurants allotment. He was planning to use the **herb** to flavour some roasted vegetables.
20. The smell of *paprika/ cloves* floated through the café and reminded Ralph of his travels in Asia. He used to buy the **spice** by the pound from the market.
21. Vivian was surprised at how much she enjoyed *geography/ citizenship* at college. She had dreaded the **subject** when it first appeared on her timetable.
22. Transporting the old *car/ tank* to the museum was difficult. On the small, winding country roads the **vehicle** held up a lot of traffic.
23. Whilst staying in Australia Linda had a *snake/ terrapin* living near the pond in her garden. She would sit and watch the **reptile** whilst drinking her morning coffee.
24. The group of tourists visited the secluded *house/ igloo* on Tuesday. They were told the **dwelling** had been abandoned for years.
25. Zac ordered *chicken/ lobster* for his main course at the fancy restaurant. He thought that the **meat** had a unique taste and texture.
26. As soon as he got home Ben threw his *trousers/ overalls* in the washing basket. He had noticed the **garment** was covered in oil.
27. Tessa selected the *ruby/ topaz* for her hand designed pendant. She knew the **jewel** would sparkle brightly when she wore it.
28. The deli owner gave free tasters of *cheddar/ roquefort* to his customers. Many said the **cheese** was the best they had ever tasted.
29. Freya eventually found her red *boot/ clog* under the bed. She had no idea how the **shoe** had got there, it had been missing for months.
30. Neil had been a devoted *Christian/ Quaker* since he was a child. He had grown up learning about the **religion** and enjoyed being part of the community.
31. Everyone stared in fear as Wayne struggled to get the *canoe/ catamaran* across the lake. When the wind changed direction the **boat** almost capsized.

32. James had been addicted to *heroin/ valium* for two years. The price of the **drug** had doubled in recent months.

List of References

Abrahams, B. S., & Geschwind, D. H. (2008). Advances in autism genetics: on the threshold of a new neurobiology. *Nature Reviews Genetics*, *9*(5), 341-355.

Adams, N. C., & Jarrold, C. (2009). Inhibition and the Validity of the Stroop Task for Children with Autism. *Journal of Autism and Developmental Disorders, 39*(8), 1112-1121. doi: 10.1007/s10803-009-0721-8

Altmann, G. T. M., Garnham, A., & Dennis, Y. (1992). Avoiding the garden path: eye-movements in context. *Journal of Memory and Language, 31*(5), 685-712. doi: 10.1016/0749-596x(92)90035-v

Altmann, G., & Steedman, M. (1988). Interaction with context during human sentence processing. *Cognition*, *30*(3), 191-238. Doi: 10.1016/0010-0277(88) 90020-0.

American Psychiatric Association, & American Psychiatric Association. (1994). Diagnostic and statistical manual of mental disorders (DSM). *Washington, DC: American psychiatric association*, 143-7.

American Psychiatric Association. (1980). Diagnostic and statistical manual of mental disorders.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®)*. American Psychiatric Pub.

Åsberg, J., & Sandberg, A. D. (2012). Dyslexic, delayed, precocious or just normal? Word reading skills of children with autism spectrum disorders. *Journal of Research in Reading*, *35*(1), 20-31. Doi: 10.1111/j.1467-9817.2010.01452.x

Åsberg, J., Dahlgren, S., & Sandberg, A. D. (2008). Basic reading skills in high-functioning Swedish children with autism spectrum disorders or attention disorder. *Research in Autism Spectrum Disorders*, *2*(1), 95-109. Doi: 10.1016/j.rasd.2007.03.006.

Åsberg, J., Kopp, S., Berg-Kelly, K., & Gillberg, C. (2010). Reading comprehension, word decoding and spelling in girls with autism spectrum disorders (ASD) or attention-deficit/hyperactivity disorder (AD/HD): performance and predictors. *International Journal of Language & Communication Disorders, 45*(1), 61-71. doi: 10.3109/13682820902745438

Au-yeung, B., Baron-Cohen, S., Ashwin, E., Knickmeyer, R., Taylor, K., & Hackett, G. (2009). Fetal testosterone and autistic traits. *British Journal of Psychology*, *100*(1), 1-22. Doi: 10.1348/000712608X311731

Au-Yeung, S. K., Kaakinen, J. K., Liversedge, S. P. & Benson, V. (2015). Processing of Written Irony in Autism Spectrum Disorder: An Eye-Movement Study. *Autism Research*. doi: 10.1002/aur.1490

Au-Yeung, S. K., Kaakinen, J. K., Liversedge, S. P., & Benson, V. (2017). Would Adults with Autism be less likely to Bury the Survivors? An Eye Movement Study of Anomalous Text Reading. *The Quarterly Journal of Experimental Psychology*, 1-27.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of memory and language*, *59*(4), 390-412. Doi: 10.1016/j.jml.2007.12.005

Baron-Cohen, S. (1989). The autistic child's theory of mind: A case of specific developmental delay. *Journal of Child Psychology and Psychiatry*, *30*, 285-298. Doi: 10.1111/j.1469-7610.1989.tb00241.x

Baron-Cohen, S. (2002). The extreme male brain theory of autism. *Trends in Cognitive Sciences, 6*(6), 248-254. doi: 10.1016/s1364-6613(02)01904-6

Baron-Cohen, S. (2009). Autism: The Empathizing-Systemizing (E-S) Theory. *Year in Cognitive Neuroscience 2009, 1156*, 68-80. doi: 10.1111/j.1749-6632.2009.04467.x

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another advanced test of theory of mind: Evidence from very high functioning adults with autism or Asperger syndrome. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 38*(7), 813-822. doi: 10.1111/j.1469-7610.1997.tb01599.x

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a theory of mind. *Cognition, 21*(1), 37-46. doi: 10.1016/0010-0277(85)90022-8

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5-17. doi: 10.1023/a:1005653411471

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another advanced test of theory of mind: Evidence from very high functioning adults with autism or Asperger syndrome. *Journal of Child Psychology and Psychiatry*, *38*(7), 813-822. Doi: 10.1111/j.1469-7610.1997.tb01599.x

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*(3), 255-278. doi:10.1016/j.jml.2012.11.001

Bates D, Maechler M, Bolker B and Walker S (2014). *lme4: Linear mixed-effects models using Eigen and S4*. R package version 1.1-7, http://CRAN.R-project.org/package=lme4.

Bates, D., Maechler, M., Bolker, B., Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1-48. doi:10.18637/jss.v067.i01.

Battig, W. F., & Montague, W. E. (1969). Category norms of verbal items in 56 categories A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology*, *80*(3 pt. 2), 1-46. Doi: 10.1037/h0027577

Benson, V., Castelhano, M. S., Au-Yeung, S. K., & Rayner, K. (2012). Eye movements reveal no immediate “WOW”(“which one's weird”) effect in autism spectrum disorder. *The Quarterly Journal of Experimental Psychology*, *65*(6), 1139-1150. Doi: 10.1080/17470218.2011.644305

Benson, V., Castelhano, M. S., Howard, P. L., Latif , N. ,& Rayner, K. (2015). Looking, seeing and believing in autism: Eye movements reveal how subtle cognitive processing difference impact in the social domain. *Autism Research*, doi: 10.1002/aur.1580

Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2003). Motion perception in autism: a “complex” issue. *Cognitive Neuroscience, Journal of*, *15*(2), 218-225. doi:10.1162/089892903321208150

Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain*, *128*(10), 2430-2441. Doi: 10.1093/brain/awh561

Blythe, H., & Joseph, H. (2011). Children's eye movements during reading. In S. P. Liversedge, I. D., & S. Everling (Eds.), *The Oxford Handbook Of Eye Movements* (643-686). New York: Oxford University Press.

Bodner, K. E., Engelhardt, C. R., Minshew, N. J., & Williams, D. L. (2015). Making inferences: Comprehension of physical causality, intentionality, and emotions in discourse by high-functioning older children, adolescents, and adults with autism. *Journal of Autism and Developmental Disorders*, *45*(9), 2721-2733. Doi: 10.1007/s10803-015-2436-3

Bonnel, A. M., Mottron, L., Peretz, I., Trudel, M., & Gallun, E. (2003). Enhanced pitch sensitivity in individuals with autism: a signal detection analysis. *Cognitive Neuroscience, Journal of*, *15*(2), 226-235. Doi: doi:10.1162/089892903321208169

Boucher, J. (2012). Research Review: Structural language in autistic spectrum disorder - characteristics and causes. *Journal of Child Psychology and Psychiatry, 53*(3), 219-233. doi: 10.1111/j.1469-7610.2011.02508.x

Bowler, D. M. (1992). " Theory of mind" in Asperger's syndrome. *Child Psychology and Psychiatry*, 33(5), 877-893. Doi: 10.1111/j.1469-7610.1992.tb01962.x

Braeutigam, S., Swithenby, S. J., & Bailey, A. J. (2008). Contextual integration the unusual way: a magnetoencephalographic study of responses to semantic violation in individuals with autism spectrum disorders. *European Journal of Neuroscience, 27*(4), 1026-1036. doi: 10.1111/j.1460-9568.2008.06064.x

Buescher, A.V., Cidav, Z., Knapp, M., & Mandell, D.S.(2014). Costs of autism spectrum disorders in the United Kingdom and the United States. *JAMA pediatrics*, *168*(8), doi: 10.1001/jamapediatrics.2014.210

Briskman, J., Frith, U., & Happé, F. (2001). Exploring the cognitive phenotype of autism: weak “central coherence” in parents and siblings of children with autism: II. Real-life skills and preferences. *Journal of Child Psychology and Psychiatry*, *42*(03), 309-316. Doi: 10.1017/S0021963001006904

Brock, J. & Caruana, N. (2014). Reading for sound and reading for meaning in autism: Frith and Snowling (1983) revisited. In Arciuli, J. & Brock, J (Eds.), *Communication in Autism* (125-145). Amsterdam: John Benjamins Publishing Co.

Brock, J., & Bzishvili, S. (2013). Deconstructing Frith and Snowling's homograph-reading task: Implications for autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, *66*(9), 1764-1773. doi:10.1080/17470218.2013.766221

Brock, J., Norbury, C., Einav, S., & Nation, K. (2008). Do individuals with autism process words in context? Evidence from language-mediated eye-movements. *Cognition*, *108*(3), 896-904. doi: 10.1016/j.cognition.2008.06.007.

Brown, H. M., Oram-Cardy, J., & Johnson, A. (2013). A meta-analysis of the reading comprehension skills of individuals on the autism spectrum. *Journal of autism and developmental disorders, 43*(4), 932-955. doi: 10.1007/s10803-012-1638-1

Brysbaert, M., & New, B. (2009). Moving beyond Kucera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Measures, 41 (4)*, 977-990. doi: 10.3758/BRM.41.4.977

Bryson, S. E. (1983). Interference effects in autistic-children - evidence for the comprehension of single stimuli. *Journal of Abnormal Psychology, 92*(2), 250-254. doi: 10.1037/0021-843x.92.2.250

Burd, L., Kerbeshian, J., & Fisher, W. (1985). Inquiry into the incidence of hyperlexia in a statewide population of children with pervasive developmental disorder. *Psychological Reports, 57*(1), 236-238. Doi: https://doi.org/10.2466/pr0.1985.57.1.236

Carlson, G.N., & Tanenhaus, M. K. (1988). Thematic roles and language comprehension. In W. Wilkins, (Ed), *Thematic Relations* (pp. 263-288). New York: Academic Press.

Caruana, N., & Brock, B. (2014). No association between autisitic traits and contextual influences on eye-movements during reading. *PeerJ*, 2:e446.

Clark, F., Scharaschkin, A., & Xu, D. (2009). Supporting autism through adulthood. National Audit Office. TSO (The Stationary office), Norwich, UK.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological review*, *108*(1), 204. Doi: 10.1037/0033-295X.108.1.204

Conti-Ramsden, G., Botting, N., & Faragher, B. (2001). Psycholinguistic markers for specific language impairment (SLI). *Journal of Child Psychology and Psychiatry*, *42*(6), 741-748. Doi: 10.1111/1469-7610.00770

Davis, C. J. (2001). *The self-organising lexical acquisition and recognition (SOLAR) model of visual word recognition* (Doctoral dissertation, ProQuest Information & Learning).

Dawson, M., Soulières, I., Gernsbacher, M. A., & Mottron, L. (2007). The level and nature of autistic intelligence. *Psychological science*, *18*(8), 657-662. Doi: 10.1111/j.1467-9280.2007.01954.x

Dennis, M., Lazenby, A. L., & Lockyer, L. (2001). Inferential language in high-function children with autism. *Journal of Autism and Developmental Disorders*, *31*(1), 47-54. Doi: 10.1023/A:1005661613288

Drieghe, D., Rayner, K., & Pollatsek, A. (2008). Mislocated fixations can account for parafoveal-on-foveal effects in eye movements during reading. *The Quarterly Journal of Experimental Psychology*, *61*(8), 1239-1249. Doi: 10.1080/17470210701467953

Duffy, S. A., & Rayner, K. (1990). Eye movements and anaphor resolution: Effects of antecedent typicality and distance. *Language and Speech*, *33*(2), 103-119. Doi: 10.1177/002383099003300201

Ehrlich, K., & Rayner, K. (1983). Pronoun assignment and semantic integration during reading: Eye movements and immediacy of processing. *Journal of Verbal Learning and Verbal Behavior*, *22*(1), 75-87. Doi: 10.1016/S0022-5371(83)80007-3

Ehrlich, S. F., & Rayner, K. (1981). Contextual effects on word perception and eye movements during reading. *Journal of Verbal Learning and Verbal Behavior*, *20*(6), 641-655. Doi: 10.1016/S0022-5371(81)90220-6

Eigsti, I. M., Bennetto, L., & Dadlani, M. B. (2007). Beyond pragmatics: Morphosyntactic development in autism. *Journal of autism and developmental disorders*, *37*(6), 1007-1023. Doi:10.1007/s10803-006-0239-2

Eigsti, I. M., de Marchena, A. B., Schuh, J. M., & Kelley, E. (2011). Language acquisition in autism spectrum disorders: A developmental review. *Research in Autism Spectrum Disorders*, *5*(2), 681-691. doi:10.1016/j.rasd.2010.09.001

Eigsti, I., & Bennetto, L. (2009). Grammaticality judgments in autism: Deviance or delay. *Journal of Child Language*, *36*(05), 999-1021. Doi: 10.1017/S0305000909009362

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112*(4), 777-813. doi: 10.1037/0033-295x.112.4.777

Eskes, G. A., Bryson, S. E., & McCormick, T. A. (1990). Comprehension of concrete and abstract words in autistic children. *Journal of Autism and Developmental Disorders, 20*(1), 61-73. doi: 10.1007/bf02206857

Ferguson, H. J., & Sanford, A. J. (2008). Anomalies in real and counterfactual worlds: An eye-movement investigation. *Journal of Memory and Language, 58*(3), 609-626. doi: 10.1016/j.jml.2007.06.007

Ferreira, F., Bailey, K. G., & Ferraro, V. (2002). Good-enough representations in language comprehension. *Current directions in psychological science*, *11*(1), 11-15. Doi: 10.1111/1467-8721.00158

Ferreira, F., Christianson, K., & Hollingworth, A. (2001). Misinterpretations of garden-path sentences: Implications for models of sentence processing and reanalysis. *Journal of psycholinguistic research*, *30*(1), 3-20. Doi: 10.1023/A:1005290706460

Filik, R., & Moxey, L. M. (2010). The on-line processing of written irony. *Cognition, 116*(3), 421-436. doi: 10.1016/j.cognition.2010.06.005

Fodor, J. A. (1983). *The modularity of mind: An essay on faculty psychology*. MIT press.

Frazier, L., & Clifton, C. (1996). *Construal*. MIT Press.

Frazier, L., & Clifton, C. (1997). Construal: Overview, motivation, and some new evidence. *Journal of psycholinguistic research*, *26*(3), 277-295. Doi:10.1023/A:1025024524133

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: eye-movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology, 14*(2), 178-210. doi: 10.1016/0010-0285(82)90008-1

Frisson, S., Rayner, K., & Pickering, M. J. (2005). Effects of contextual predictability and transitional probability on eye movements during reading. *Journal of Experimental Psychology-Learning Memory and Cognition, 31*(5), 862-877. doi: 10.1037/0278-7393.31.5.862

Frith, C., & Frith, U. (2005). Theory of mind. *Current Biology*, *15*(17), R644-R645.

Frith, U. (1989). *Autism: Explaining the Enigma*. Oxford, UK: Basil Blackwell.

Frith, U. (2012). The 38th Sir Frederick Bartlett Lecture Why we need cognitive explanations of autism. *Quarterly Journal of Experimental Psychology, 65*(11), 2073-2092. doi: 10.1080/17470218.2012.697178

Frith, U., & Happé, F. (1994). Autism - Beyond the theory of mind. *Cognition, 50*(1-3), 115-132. Doi: 10.1016/0010-0277(94)90024-8

Frith, U., & Snowling, M. (1983). Reading for meaning and reading for sound in autistic and dyslexic children. *British Journal of Developmental Psychology, 1,* 329-342. Doi: 10.1111/j.2044-835X.1983.tb00906.x

Frith, U., Morton, J., & Leslie, A. M. (1991). The cognitive basis of a biological disorder: Autism. *Trends in neurosciences*, *14*(10), 433-438. Doi: 10.1016/0166-2236(91)90041-R

Frost, R. (2012). A universal approach to modeling visual word recognition and reading: Not only possible, but also inevitable. *Behavioral and Brain Sciences*, *35*(05), 310-329. Doi: 10.1017/S0140525X12000635

Garrod, S., & Sanford, A. (1977). Interpreting anaphoric relations - integration of semantic information while reading. *Journal of Verbal Learning and Verbal Behavior, 16*(1), 77-90. doi: 10.1016/s0022-5371(77)80009-1

Garrod, S., Obrien, E. J., Morris, R. K., & Rayner, K. (1990). Elaborative inferencing as an active or passive process. *Journal of Experimental Psychology-Learning Memory and Cognition, 16*(2), 250-257. doi: 10.1037//0278-7393.16.2.250

Gernsbacher, M. A. (1991). Cognitive-processes and mechanisms in language comprehension - the structure building framework. *Psychology of Learning and*

Motivation-Advances in Research and Theory, 27, 217-263. doi: 10.1016/s0079-7421(08)60125-5

Gernsbacher, M. A. (1993). Less skilled readers have less efficient suppression mechanisms. *Psychological Science, 4*(5), 294-298. doi: 10.1111/j.1467-9280.1993.tb00567.x

Gernsbacher, M. A., & Faust, M. E. (1991). The mechanism of suppression - a component of general comprehension skill. *Journal of Experimental Psychology-Learning Memory and Cognition, 17*(2), 245-262. doi: 10.1037/0278-7393.17.2.245

Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(3), 430. Doi: 10.1037/0278-7393.16.3.430

Geurts, H. M., & Embrechts, M. (2008). Language profiles in ASD, SLI, and ADHD. *Journal of autism and developmental disorders*, *38*(10), 1931-1943. Doi: 10.1007/s10803-008-0587-1

Ghaziuddin, M., Thomas, P., Napier, E., Kearney, G., Tsai, L., Welch, K., & Fraser, W. (2000). Brief report: Brief syntactic analysis in Asperger syndrome: A preliminary study. *Journal of Autism and Developmental Disorders, 30*(1), 67-70. doi: 10.1023/A:1005416212615

Gold, R., Faust, M., & Goldstein, A. (2010). Semantic integration during metaphor comprehension in Asperger syndrome. *Brain and Language, 113*(3), 124-134. doi: 10.1016/j.band1.2010.03.002

Goldenfeld, N., Baron-Cohen, S., & Wheelwright, S. (2005). Empathizing and systemizing in males, females and autism. *Clinical Neuropsychiatry*, *2*(6), 338-345.

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review, 101*(3), 371-395. doi: 10.1037//0033-295x.101.3.371

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: a multiple read-out model. *Psychological review*, *103*(3), 518. Doi: 10.1037/0033-295X.103.3.518

Grainger, J., Oregan, J. K., Jacobs, A. M., & Segui, J. (1989). On the role of competing word units in visual word recognition: the neighborhood frequency effect. *Perception & Psychophysics, 45*(3), 189-195. doi: 10.3758/bf03210696

Grigorenko, E. L., Klin, A., & Volkmar, F. (2003). Annotation: Hyperlexia: disability or superability?. *Journal of Child Psychology and Psychiatry*, *44*(8), 1079-1091. Doi: 10.1111/1469-7610.00193

Grigorenko, E. L., Klin, A., Pauls, D. L., Senft, R., Hooper, C., & Volkmar, F. (2002). A descriptive study of hyperlexia in a clinically referred sample of children with developmental delays. *Journal of Autism and Developmental Disorders*, *32*(1), 3-12. doi: 10.1023/A:1017995805511

Hagoort, P., Hald, L., Bastiaansen, M., & Petersson, K. M. (2004). Integration of word meaning and world knowledge in language comprehension. *Science, 304*(5669), 438-441. doi: 10.1126/science.1095455

Hahn, N., Snedeker, J., & Rabagliati, H. (2015). Rapid linguistic ambiguity resolution in young children with autism spectrum disorder: Eye tracking evidence for the limits of weak central coherence. *Autism Research, 8*, 717–726. Doi: 10.1002/aur.1487

Hala, S., Pexman, P. M., & Glenwright, M. (2007). Priming the meaning of homographs in typically developing children and children with autism. *Journal of Autism and Developmental Disorders, 37*(2), 329-340. doi: 10.1007/s10803-006-0162-6

Happé, F. (1999). Autism: cognitive deficit or cognitive style? *Trends in Cognitive Sciences, 3*(6), 216-222. doi: 10.1016/s1364-6613(99)01318-2

Happé, F. G. (1996). Studying weak central coherence at low levels: children with autism do not succumb to visual illusions. A research note. *Journal of Child Psychology and Psychiatry*, *37*(7), 873-877. Doi: 10.1111/j.1469-7610.1996.tb01483.x

Happé, F. G. E. (1994). An advanced test of theory of mind - understanding of story characters thoughts and feelings by able autistic, mentally-handicapped, and normal-children and adults. *Journal of Autism and Developmental Disorders, 24*(2), 129-154. doi: 10.1007/bf02172093

Happé, F. G. E. (1995). Understanding minds and metaphors - insights from the study of figurative language in autism. *Metaphor and Symbolic Activity, 10*(4), 275-295. doi: 10.1207/s15327868ms1004_3

Happé, F. G. E. (1997). Central coherence and theory of mind in autism: Reading homographs in context. *British Journal of Developmental Psychology, 15*, 1-12. doi: 10.1111/j.2044-835X.1997.tb00721.x

Happé, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5-25. doi: 10.1007/s10803-005-0039-0.

Happé, F., Briskman, J., & Frith, U. (2001). Exploring the cognitive phenotype of autism: weak "central coherence" in parents and siblings of children with autism: I. Experimental tests. *Journal of child psychology and psychiatry*, *42*(3), 299-307. Doi: 10.1017/S0021963001006916

Haviland, S. E., & Clark, H. H. (1974). Whats new - acquiring new information as a process in comprehension. *Journal of Verbal Learning and Verbal Behavior, 13*(5), 512-521. doi: 10.1016/s0022-5371(74)80003-4

Henderson, L. M., Clarke, P. J., & Snowling, M. J. (2011). Accessing and selecting word meaning in autism spectrum disorder. *Journal of Child Psychology and Psychiatry*, *52*(9), 964-973. doi: 10.1111/j.1469-7610.2011.02393.x

Henderson, L. M., Clarke, P. J., & Snowling, M. J. (2011). Accessing and selecting word meaning in autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 52*(9), 964-973. doi: 10.1111/j.1469-7610.2011.02393.x

Hill, E. L. (2004a). Evaluating the theory of executive dysfunction in autism. *Developmental Review, 24*(2), 189-233. doi: 10.1016/j.dr.2004.01.001

Hill, E. L. (2004b). Executive dysfunction in autism. *Trends in cognitive sciences*, *8*(1), 26-32. Doi: 10.1016/j.tics.2003.11.003

Howard, P. L., Liversedge, S. P., & Benson, V. (2017a). Benchmark Eye Movement Effects During Natural Reading in Autism Spectrum Disorder. *Journal of Experimental Psychology: Learning, Memory & Cognition.* http://dx.doi.org/10.1037/xlm0000289

Howard, P. L., Liversedge, S. P., & Benson, V. (2017b). Investigating the Use of World Knowledge During On-line Comprehension in Adults with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders.* Doi: 10.1037/xlm0000289

Huemer, S. V., & Mann, V. (2010). A Comprehensive Profile of Decoding and Comprehension in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *40*(4), 485–493. http://doi.org/10.1007/s10803-009-0892-3

Hughes, C., & Russell, J. (1993). Autistic childrens difficulty with mental disengagement from an object - its implications for theories of autism. *Developmental Psychology, 29*(3), 498-510. doi: 10.1037/0012-1649.29.3.498

Hughes, C., Russell, J., & Robbins, T. W. (1994). Evidence for executive dysfunction in autism. *Neuropsychologia, 32*(4), 477-492. doi: 10.1016/0028-3932(94)90092-2

Hyönä, J., Lorch Jr, R. F., & Kaakinen, J. K. (2002). Individual differences in reading to summarize expository text: Evidence from eye fixation patterns. *Journal of Educational Psychology, 94*(1), 44-55. DOI: 10.1037//0022-0663.94.1.44

Inhoff, A. W., & Liu, W. M. (1998). The perceptual span and oculomotor activity during the reading of Chinese sentences. *Journal of Experimental Psychology-Human Perception and Performance, 24*(1), 20-34. doi: 10.1037/0096-1523.24.1.20

Inhoff, A. W., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics*, *40*(6), 431-439. Doi: 10.3758/BF03208203

Iwanaga, R., Kawasaki, C., & Tsuchida, R. (2000). Brief report: Comparison of sensory-motor and cognitive function between autism and Asperger syndrome in preschool children. *Journal of Autism and Developmental Disorders*, *30*(2), 169-174. Doi: 10.1023/A:1005467807937

Jeffreys, H. (1961). Theory of probability (3rd ed.). New York: Oxford University Press.

Jolliffe, T., & Baron-Cohen, S. (1999). A test of central coherence theory: linguistic processing in high-functioning adults with autism or Asperger syndrome: is local coherence impaired? *Cognition, 71*(2), 149-185. doi: 10.1016/s0010-0277(99)00022-0

Jolliffe, T., & Baron-Cohen, S. (2000). Linguistic processing in high-functioning adults with autism or Asperger's syndrome. Is global coherence impaired? *Psychological Medicine, 30*(5), 1169-1187. doi: 10.1017/s003329179900241x

Jones, C. R. G., Happé, F., Golden, H., Marsden, A. J. S., Tregay, J., Simonoff, E., . . . Charman, T. (2009). Reading and Arithmetic in Adolescents With Autism Spectrum Disorders: Peaks and Dips in Attainment. *Neuropsychology, 23*(6), 718-728. doi: 10.1037/a0016360

Joseph, H. S. S. L., & Liversedge, S. P. (2013). Children’s and adults’ on-line processing of syntactically ambiguous sentences during reading. *PloS one*, *8*(1), e54141.

Joseph, H. S. S. L., Liversedge, S. P., Blythe, H. I., White, S. J., Gathercole, S. E., & Rayner, K. (2008). Children's and adults' processing of anomaly and implausibility during reading: Evidence from eye movements. *Quarterly Journal of Experimental Psychology, 61*(5), 708-723. doi: 10.1080/17470210701400657

Juhasz, B. J., & Rayner, K. (2006). The role of age of acquisition and word frequency in reading: Evidence from eye fixation durations. *Visual Cognition, 13*(7-8), 846-863. doi: 10.1080/13506280544000075

Just, M. A., Cherkassky, V. L., Keller, T. A., & Minshew, N. J. (2004). Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity. *Brain, 127*, 1811-1821. doi: 10.1093/brain/awh199

Just, M. A., Cherkassky, V. L., Keller, T. A., Kana, R. K., & Minshew, N. J. (2007). Functional and anatomical cortical underconnectivity in autism: Evidence from an fMRI study of an executive function task and corpus callosum morphometry. *Cerebral Cortex, 17*(4), 951-961. doi: 10.1093/cercor/bhl006

Kaland, N., Mortensen, E. L., & Smith, L. (2007). Disembedding performance in children and adolescents with Asperger syndrome or high-functioning autism. *Autism, 11*(1), 81-92. doi: 10.1177/1362361307070988

Kamio, Y., & Toichi, M. (2000). Dual access to semantics in autism: Is pictorial access superior to verbal access?. *Journal of Child Psychology and Psychiatry*, *41*(07), 859-867. doi:http://dx.doi.org/

Kamio, Y., Robins, D., Kelley, E., Swainson, B., & Fein, D. (2007). Atypical lexical/semantic processing in high-functioning autism spectrum disorders without early language delay. *Journal of Autism and Developmental Disorders, 37*(6), 1116-1122. doi: 10.1007/s10803-006-0254-3

Kanner, L. (1973). *Childhood psychosis: Initial studies and new insights*. VH Winston & Sons.

Kass, R. E., & Raftery, A. E. (1995). Bayes factors. *Journal of the American Statistical Association, 90*(430), 773-795.

Kintsch, W. (1988). The role of knowledge in discourse comprehension - a construction integration model. *Psychological Review, 95*(2), 163-182. doi: 10.1037/0033-295x.95.2.163

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. Cambridge university press.

Kintsch, W., & Van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological review*, *85*(5), 363. Doi: 10.1037/0033-295X.85.5.363

Kjelgaard, M. M., & Tager-Flusberg, H. (2001). An investigation of language impairment in autism: Implications for genetic subgroups. *Language and cognitive processes*, *16*(2-3), 287-308. Doi: 10.1080/01690960042000058

Klin, A., Volkmar, F. R., Sparrow, S. S., Cicchetti, D. V., & Rourke, B. P. (1995). Validity and neuropsychological characterization of Asperger syndrome: Convergence with nonverbal learning disabilities syndrome. *Journal of Child*

Psychology and Psychiatry, *36*(7), 1127-1140. Doi: 10.1111/j.1469-7610.1995.tb01361.x

Koolen, S., Vissers, C. T. W., Hendriks, A. W., Egger, J. I., & Verhoeven, L. (2012). The interplay between attentional strategies and language processing in high-functioning adults with autism spectrum disorder. *Journal of autism and developmental disorders*, *42*(5), 805-814. Doi: doi:10.1007/s10803-011-1310-1

Koolen, S., Vissers, C., Egger, J. I. M., & Verhoeven, L. (2013). Can monitoring in language comprehension in Autism Spectrum Disorder be modulated? Evidence from event-related potentials. *Biological Psychology, 94*(2), 354-368. doi: 10.1016/j.biopsycho.2013.07.008

Koolen, S., Vissers, C., Egger, J. I. M., & Verhoeven, L. (2014). Monitoring in language perception in high-functioning adults with autism spectrum disorder: Evidence from event-related potentials. *Clinical Neurophysiology, 125*(1), 108-123. doi: 10.1016/j.clinph.2013.06.021

Kreiner, H., Sturt, P., & Garrod, S. (2008). Processing definitional and stereotypical gender in reference resolution: Evidence from eye-movements. *Journal of Memory and Language, 58*(2), 239-261. doi: 10.1016/j.jml.2007.09.003

Kuznetsova, A., Brockhoff, A. B., & Christensen, R. H. B. (2016). lmerTest: Tests in Linear Mixed Effects Models. R package version 2.0-30. https://CRAN.R-project.org/package=lmerTest

Lindgren, K. A., Folstein, S. E., Tomblin, J. B., & Tager-Flusberg, H. (2009). Language and reading abilities of children with autism spectrum disorders and specific language impairment and their first-degree relatives. *Autism Research*, *2*(1), 22-38. Doi: 10.1002/aur.63

Liversedge, S. P., & Findlay, J. M. (2000). Saccadic eye movements and cognition. *Trends in Cognitive Sciences, 4*(1), 6-14. doi: 10.1016/s1364-6613(99)01418-7

Liversedge, S. P., Paterson, K. B., & Pickering, M. J. (1998). Eye movements and measures of reading time. *Eye guidance in reading and scene perception*, 55-75.

López , B., & Leekam, S. R. (2003). Do children with autism fail to process information in context? *Journal of Child Psychology and Psychiatry and Allied Disciplines, 44*(2), 285-300. doi: 10.1111/1469-7610.00121

Lord C., Rutter M., DiLavore P. C., Risi S., Gotham K., Bishop S. (2012). Autism diagnostic observation schedule, second edition. Torrance, CA: Western Psychological Services.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: a revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of autism and developmental disorders*, *24*(5), 659-685. Doi: doi:10.1007/BF02172145

Lord, C., Rutter, M., DiLavore, P. C., Risi, S. (2001). Autism Diagnostic Observation Schedule. Los Angeles: Western Psychological Services.

Lucas, R., & Norbury, C. F. (2014). Levels of text compehension in children with autism spectrum disorders (ASD): The influence of language phenotype. *Journal of Auitsm and Developmental Disorders, 44,* 2756-2768. doi:10.1007/s10803-014-2133-7

Lucas, R., & Norbury, C. F. (2015). Making inferences from text: it's vocabulary that matters. *Journal of Speech, Language, and Hearing Research*, *58*(4), 1224-1232. Doi:10.1044/2015_JSLHR-L-14-0330

MacDonald, M.C., Pearlmutter, N.J., & Seidenberg, M.S. (1994). The lexical nature of syntactic ambiguity resolution*. Psychological Review*, 101, 676-703. Doi: doi.org/10.1037/0033-295X.101.4.676

Matsuki, K.. Chow, T., Hare, M., Elman, J. L., Scheepers, C., & McRae, K. (2011). Event-Based plausibility immediately influences on-line language comprehension. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 37*(4), 913-934. DOI: 10.1037/a0022964.

Mayes, S. D., & Calhoun, S. L. (2006). Frequency of reading, math, and writing disabilities in children with clinical disorders. *Learning and Individual Differences, 16*(2), 145-157. doi: 10.1016/j.lindif.2005.07.004

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception .1. An account of basic findings. *Psychological Review, 88*(5), 375-407. doi: 10.1037//0033-295x.88.5.375

McConkie, G. W., & Rayner, K. (1975). Span of effective stimulus during a fixation in reading. *Perception & Psychophysics, 17*(6), 578-586. doi: 10.3758/bf03203972

McKoon, G., & Ratcliff, R. (1992). Inference during reading. *Psychological Review, 99*(3), 440-466. doi: 10.1037//0033-295x.99.3.440

McRae, K., Spivey-Knowlton, M. J., & Tanenhaus, M. K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language*, *38*(3), 283-312. Doi: doi.org/10.1006/jmla.1997.2543

Micai, M., Joseph, H., Vulchanova, M., & Saldaña, D. (2016). Strategies of readers with autism when responding to inferential questions: An eye-movement study. *Autism Research*. Doi: 10.1002/aur.1731

Minshew, N. J., & Goldstein, G. (1998). Autism as a disorder of complex information processing. *Mental Retardation and Developmental Disabilities Research Reviews, 4*(2), 129-136. Doi: 10.1002/1098-2779-X

Minshew, N. J., Goldstein, G., & Siegel, D. J. (1995). Speech and language in high-functioning autistic individuals. *Neuropsychology, 9*(2), 255-261. doi: 10.1037//0894-4105.9.2.255

Minshew, N. J., Goldstein, G., & Siegel, D. J. (1997). Neuropsychologic functioning in autism: profile of a complex information processing disorder. *Journal of the International Neuropsychological Society : JINS, 3*(4), 303-316.

Minshew, N. J., Williams, D. L., & McFadden, K. (2008). Information Processing, Neural Connectivity, and Neuronal Organization. In A. W. Zimmerman (Ed.), *Autism: Current Theories and Evidence* (pp. 381-405).

Morey, R. D. & Rouder, J. N. (2015). BayesFactor: Computation of Bayes Factors for Common Designs. R package version 0.9.12-2. https://CRAN.R-project.org/package=BayesFactor

Morrison, C. M., & Ellis, A. W. (2000). Real age of acquisition effects in word naming and lexical decision. *British Journal of Psychology, 91*, 167-180. doi: 10.1348/000712600161763

Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In Burack, J. A., Charman, T., Yirmiya, N., & Zelazo P. R (Eds.). *The Development of Autism: Perspectives from Theory and Research* (131-148). Mahwah: United States.

Mottron, L., Burack, J. A., Iarocci, G., Belleville, S., & Enns, J. T. (2003). Locally oriented perception with intact global processing among adolescents with high-functioning autism: evidence from multiple paradigms. *Journal of Child Psychology and Psychiatry*, *44*(6), 904-913. Doi: 10.1111/1469-7610.00174

Mottron, L., Dawson, M., Soulieres, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: an update, and eight principles of autistic perception. *Journal of autism and developmental disorders*, *36*(1), 27-43. Doi: 0.1007/s10803-005-0040-7

Myers, J. L., Cook, A. E., Kambe, G., Mason, R. A., & O'Brien, E. J. (2000). Semantic and episodic effects on bridging inferences. *Discourse Processes*, *29*(3), 179-199. Doi: 10.1207/S15326950dp2903_1

Nation, K., Clarke, P., Wright, B., & Williams, C. (2006). Patterns of reading ability in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 36*(7), 911-919. doi:10.1007/s10803-006-0130-1

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive psychology*, *9*(3), 353-383. Doi: 10.1016/0010-0285(77)90012-3

Newman, T. M., Macomber, D., Naples, A. J., Babitz, T., Volkmar, F., & Grigorenko, E. L. (2007). Hyperlexia in children with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders, 37*(4), 760-774. doi: 10.1007/s10803-006-0206-y

Norbury, C. F. (2004). Factors supporting idiom comprehension in children with communication disorders. *Journal of Speech Language and Hearing Research, 47*(5), 1179-1193. doi: 10.1044/1092-4388(2004/87)

Norbury, C. F. (2005a). The relationship between theory of mind and metaphor: Evidence from children with language impairment and autistic spectrum disorder. *British Journal of Developmental Psychology*, *23*(3), 383-399. Doi: 10.1348/026151005X26732

Norbury, C. F. (2005b). Barking up the wrong tree? Lexical ambiguity resolution in children with language impairments and autistic spectrum disorders. *Journal of Experimental Child Psychology, 90*(2), 142-171. doi: 10.1016/j.jecp.2004.11.003

Norbury, C. F., & Bishop, D. V. M. (2002). Inferential processing and story recall in children with communication problems: a comparison of specific language impairment, pragmatic language impairment and high-functioning autism. *International Journal of Language & Communication Disorders, 37*(3), 227-251. doi: 10.1080/13682820210136269

Norbury, C., & Nation, K. (2011). Understanding Variability in Reading Comprehension in Adolescents With Autism Spectrum Disorders: Interactions With Language Status and Decoding Skill. *Scientific Studies of Reading, 15*(3), 191-210. doi: 10.1080/10888431003623553

O'Connor, I. M., & Klein, P. D. (2004). Exploration of strategies for facilitating the reading comprehension of high-functioning students with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 34*(2), 115-127. doi: 10.1023/B:JADD.0000022603.44077.6b

O'Connor, N., & Hermelin, B. (1994). Two autistic savant readers. *Journal of Autism and Developmental Disorders*, *24*(4), 501-515. Doi: 10.1007/BF02172131

O'Riordan, M. A., Plaisted, K. C., Driver, J., & Baron-Cohen, S. (2001). Superior visual search in autism. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(3), 719. Doi: 10.1037/0096-1523.27.3.719

O'Brien, E. J., Shank, D. M., Myers, J. L., & Rayner, K. (1988). Elaborative inferences during reading - do they occur on-line. *Journal of Experimental Psychology-Learning Memory and Cognition, 14*(3), 410-420. doi: 10.1037/0278-7393.14.3.410

O'Riordan, M. A. (2004). Superior visual search in adults with autism. *Autism*, *8*(3), 229-248. Doi: doi.org/10.1177/1362361304045219

Ozonoff, S. (1995). Reliability and validity of the wisconsin card sorting test in studies of autism. *Neuropsychology, 9*(4), 491-500. doi: 10.1037//0894-4105.9.4.491

Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of autism and developmental disorders*, *29*(2), 171-177. doi:10.1023/A:1023052913110

Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of child Psychology and Psychiatry*, *32*(7), 1081-1105. Doi: 10.1111/j.1469-7610.1991.tb00351.x

Ozonoff, S., South, M., & Miller, J. N. (2000). DSM-IV-defined Asperger syndrome: Cognitive, behavioral and early history differentiation from high-functioning autism. *Autism*, *4*(1), 29-46. Doi: doi.org/10.1177/1362361300041003

Paterson, K. B., Liversedge, S. P., & Underwood, G. (1999). The influence of focus operators on syntactic processing of short relative clause sentences. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology, 52*(3), 717-737. doi: 10.1080/027249899391025

Patson, N. D., & Warren, T. (2010). Eye movements when reading implausible sentences: Investigating potential structural influences on semantic integration. *Quarterly Journal of Experimental Psychology, 63*(8), 1516-1532. doi: 10.1080/17470210903380822

Pellicano, E., & Burr, D. (2012). When the world becomes 'too real': a Bayesian explanation of autistic perception. *Trends in cognitive sciences*, *16*(10), 504-510. Doi: 10.1016/j.tics.2012.08.009

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37*(1), 51-87. doi: 10.1111/j.1469-7610.1996.tb01380.x

Perea, M., & Pollatsek, A. (1998). The effects of neighborhood frequency in reading and lexical decision. *Journal of Experimental Psychology-Human Perception and Performance, 24*(3), 767-779. doi: 10.1037/0096-1523.24.3.767

Pérez, A., Joseph, H. S., Bajo, T., & Nation, K. (2016). Evaluation and revision of inferential comprehension in narrative texts: an eye movement study. *Language, Cognition and Neuroscience*, *31*(4), 549-566. Doi: 10.1080/23273798.2015.1115883

Perfetti, C. A., Landi, N., & Oakhill, J. (2005). *The Acquisition of Reading Comprehension Skill*.

Pinheiro, J. C., & Bates, D. M. (2000). *Mixed-Effects Models in S and S-PLUS*. Springer; New York.

Pollatsek, A., Bolozky, S., Well, A. D., & Rayner, K. (1981). Asymmetries in the perceptual span for israeli readers. *Brain and Language, 14*(1), 174-180. doi: 10.1016/0093-934x(81)90073-0

Pollatsek, A., Bolozky, S., Well, A. D., & Rayner, K. (1981). Asymmetries in the perceptual span for Israeli readers. *Brain and language*, *14*(1), 174-180. Doi: 10.1016/0093-934X(81)90073-0

Poynor, D. V., & Morris, R. K. (2003). Inferred goals in narratives: Evidence from self-paced reading, recall, and eye movements. *Journal of Experimental Psychology-Learning Memory and Cognition, 29*(1), 3-9. doi: 10.1037/0278-7393.29.1.3

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

R Core Team. (2016). R: language and environment for statistical computing. R Foundation for Statistical Computing, 2005; Vienna, Austria

Rapin, I., & Dunn, M. (2003). Update on the language disorders of individuals on the autistic spectrum. *Brain and Development*, *25*(3), 166-172. Doi: 10.1016/S0387-7604(02)00191-2

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of experimental child psychology*, *41*(2), 211-236. Doi: 10.1016/0022-0965(86)90037-8

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*(3), 372. doi: org/10.1037/0033-2909.124.3.372.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology, 62*(8), 1457-1506. doi:10.1080/17470210902816461

Rayner, K., & Duffy, S. A. (1986). Lexical complexity and fixation rimes in reading – Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition, 14* (3), 191-201. doi:10.3758/bf03197692

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior*, 22, 358-374. Doi: 10.1016/S0022-5371(83)90236-0

Rayner, K., Castelhano, M. S., & Yang, J. (2009). Eye Movements and the Perceptual Span in Older and Younger Readers. *Psychology and Aging, 24*(3), 755-760. doi: 10.1037/a0014300

Rayner, K., Kambe, G., & Duffy, S. A. (2000). The effect of clause wrap-up on eye movements during reading. *The Quarterly Journal of Experimental Psychology: Section A*, *53*(4), 1061-1080. Doi: 10.1080/713755934

Rayner, K., Liversedge, S. P., White, S. J., & Vergilino-Perez, D. (2003). Reading disappearing text: Cognitive control of eye movements. *Psychological Science, 14*(4), 385-388. doi: 10.1111/1467-9280.24483

Rayner, K., Liversedge, S. P., White, S. J., & Vergilino-Perez, D. (2003). Reading disappearing text: Cognitive control of eye movements. *Psychological science*, *14*(4), 385-388. Doi: 10.1111/1467-9280.24483

Rayner, K., Pacht, J. M., & Duffy, S. A. (1994). Effects of prior encounter and global discourse bias on the processing of lexically ambiguous words - evidence from eye fixations. *Journal of Memory and Language, 33*(4), 527-544. doi: 10.1006/jmla.1994.1025

Rayner, K., Warren, T., Juhasz, B. J., & Liversedge, S. P. (2004). The effect of plausibility on eye movements in reading. *Journal of Experimental Psychology-Learning Memory and Cognition, 30*(6), 1290-1301. doi: 10.1037/0278-7393.30.6.1290

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z Reader model of eye-movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences, 26*(4), 445-+. doi: 10.1017/s0140525x03000104

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The EZ Reader model of eye-movement control in reading: Comparisons to other models. *Behavioral and brain* *sciences*, *26*(4), 445. Doi: 10.1017/S0140525X03000104

Riches, N. G., Loucas, T., Baird, G., Charman, T., & Simonoff, E. (2015). Elephants in Pyjamas: Testing the Weak Central Coherence Account of Autism Spectrum Disorders Using a Syntactic Disambiguation Task. *Journal of Autism and Developmental Disorders*, 1-9. doi:10. 1007/ s10803-015-2560-0

Ricketts, J., Jones, C. R., Happé, F., & Charman, T. (2013). Reading comprehension in autism spectrum disorders: The role of oral language and social functioning. *Journal of Autism and Developmental Disorders*, *43*(4), 807-816. Doi: doi:10.1007/s10803-012-1619-4

Ring, H., Sharma, S., Wheelwright, S., & Barrett, G. (2007). An electrophysiological investigation of semantic incongruity processing by people with Asperger's syndrome. *Journal of Autism and Developmental Disorders, 37*(2), 281-290. doi: 10.1007/s10803-006-0167-1

Rouder, J. N., Morey, R. D., Speckman, P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology, 56,* 365-374. doi:10.1016/j.jmp.2012.08.001

Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: II. The contextual enhancement effect and some tests and extensions of the model. *Psychological review*, *89*(1), 60. Doi: 10.1037/0033-295X.89.1.60

Rumsey, J. M., & Hamburger, S. D. (1988). Neuropsychological findings in high-functioning men with infantile autism, residual state. *Journal of Clinical and experimental Neuropsychology*, *10*(2), 201-221. Doi: 10.1080/01688638808408236

Rumsey, J. M., & Hamburger, S. D. (1990). Neuropsychological divergence of high-level autism and severe dyslexia. *Journal of autism and developmental disorders*, *20*(2), 155-168. Doi: doi:10.1007/BF02284715

Saldaña, D., & Frith, U. (2007). Do readers with autism make briging inferences from world knowledge? *Journal of Experimental Child Psychology, 96*, 310-319. doi:10.1016/j.jecp.2006.11.002.

Saldaña, D., Carreiras, M., & Frith, U. (2009). Orthographic and Phonological Pathways in Hyperlexic Readers With Autism Spectrum Disorders. *Developmental Neuropsychology, 34*(3), 240-253. doi:10.1080/87565640902805701

Sanford, A. J., & Garrod, S. C. (1998). The role of scenario mapping in text comprehension. *Discourse Processes, 26*(2-3), 159-190. Doi: doi.org/10.1080/01638539809545043

Sansosti, F. J., Was, C., Rawson, K. A., & Remaklus, B. L. (2013). Eye movements during processing of text requiring bridging inferences in adolescents with higher functioning autism spectrum disorders: A preliminary investigation. *Research in Autism Spectrum Disorders, 7*(12), 1535-1542. doi:10.1016/j.rasd.2013.09.001

Schoonbaert, S., & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes, 19*(3), 333-367. doi: 10.1080/01690960344000198

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*(4), 523. Doi: 10.1037/0033-295X.96.4.523

Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical evaluation of language fundamentals*, fourth edition (CELF-4). Toronto, Canada: The Psychological Corporation/A Harcourt Assessment Company.

Shah, A., & Frith, U. (1983). An islet of ability in autistic-children - a research note. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 24*(4), 613-620. doi: 10.1111/j.1469-7610.1983.tb00137.x

Silberberg, N. E., & Silberberg, M. C. (1967). Hyperplexia: specific word recognition skills in young children. *Exceptional Children*.

Singer, M., & Ritchot, K. F. (1996). The role of working memory capacity and knowledge access in text inference processing. *Memory & Cognition*, *24*(6), 733-743.Singer, M., Andruslak, P., Reisdorf, P., & Black, N. L. (1992). Individual differences in bridging inference processes. *Memory & Cognition*, *20*(5), 539-548. Doi: doi:10.3758/BF03201098

Snowling, M., & Frith, U. (1986). Comprehension in hyperlexic readers. *Journal of Experimental Child Psychology, 42*(3), 392-415. doi: 10.1016/0022-0965(86)90033-0

Snowling, M.J., Stothard, S.E., Clarke, P., Bowyer-Crane, C., Harrington, A., Truelove, E., Nation, K. & Hulme, C. (2010). *York Assessment of Reading for Comprehension: Passage Reading - Secondary Version*. GL Assessment.

Speirs, S., Yelland, G., Rinehart, N., & Tonge, B. (2011). Lexical processing in individuals with high-functioning autism and Asperger's disorder. *Autism, 15*(3), 307-325. doi: 10.1177/1362361310386501

Spiveyknowlton, M. J., Trueswell, J. C., & Tanenhaus, M. K. (1993). Context effects in syntactic ambiguity resolution - discourse and semantic influences in parsing reduced relative clauses. *Canadian Journal of Experimental Psychology, 47*(2), 276-309. doi: 10.1037/h0078826

Staub, A., Rayner, K., Pollatsek, A., Hyona, J., & Majewski, H. (2007). The time course of plausibility effects on eye movements in reading: Evidence from noun-noun compounds. *Journal of Experimental Psychology-Learning Memory and Cognition, 33*(6), 1162-1169. doi: 10.1037/0278-7393.33.6.1162

Staub, A., White, S. J., Drieghe, D., Hollway, E. C., & Rayner, K. (2010). Distributional Effects of Word Frequency on Eye Fixation Durations. *Journal of Experimental Psychology-Human Perception and Performance, 36*(5), 1280-1293. doi: 10.1037/a0016896

Stockbridge, M. D., Happé, F. G. E., & White, S. J. (2014). Impaired comprehension of altering syntactic constructions in autism. *Autism Research, 7*, 314-321. Doi: 10.1002/aur.1348

Sukenik, N., Friedmann, N., & Brock, J. (2014, February). *Individual differences in homograph reading among Hebrew-speaking individuals with autism.* Poster session presented at the 1st Conference on Cognition Research of the Israeli Society for Cognitive Psychology, Akko, Israel.

Tabor, W., Juliano, C., & Tanenhaus, M. K. (1997). Parsing in a dynamical system: An attractor-based account of the interaction of lexical and structural constraints in sentence processing. *Language and Cognitive Processes*, *12*(2-3), 211-271.

Tager-Flusberg, H. (1981). On the nature of linguistic functioning in early infantile-autism. *Journal of Autism and Developmental Disorders, 11*(1), 45-56. doi: 10.1007/bf01531340

Tager-Flusberg, H. (2006). Defining language phenotypes in autism. *Clinical Neuroscience Research, 6*(3-4), 219-224. doi: 10.1016/j.cnr.2006.06.007

Tager-Flusberg, H., Calkins, S., Nolin, T., Baumberger, T., Anderson, M., & Chadwickdias, A. (1990). A longitudinal-study of language-acquisition in autistic and down syndrome children. *Journal of Autism and Developmental Disorders, 20*(1), 1-21. doi: 10.1007/bf02206853

Taraban, R., & McClelland, J. L. (1988). Constituent attachment and thematic role assignment in sentence processing: Influences of content based expectations. *Journal of Memory and Language, 27*(6), 597-632. doi:10.1016/0749-596x(88)90011-3

Tirado, M. J., & Saldaña, D. (2016). Readers with Autism Can Produce Inferences, but they Cannot Answer Inferential Questions. *Journal of autism and developmental disorders*, *46*(3), 1025-1037. doi:10.1007/s10803-015-2648-6

Toichi, M., & Kamio, Y. (2001). Verbal association for simple common words in high-functioning autism. *Journal of Autism and Developmental Disorders, 31*(5), 483-490. doi: 10.1023/a:1012216925216

Traxler, M. J., Pickering, M. J., & Clifton, C. (1998). Adjunct attachment is not a form of lexical ambiguity resolution. *Journal of Memory and Language*, *39*(4), 558-592. Doi: doi.org/10.1006/jmla.1998.2600

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). semantic influences on parsing - use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33*(3), 285-318. doi: 10.1006/jmla.1994.1014

Van Gompel, R. P. G., Liversedge, S. P., & Pearson, J. (2004). Antecedent typicality effects in the processing of noun phrase anaphora. In M. Carreiras & C. Clifton, Jr. (Eds.), The on-line study of sentence comprehension: Eye Tracking, ERP, and beyond (pp. 119–137). Hove,UK: Psychology Press

Van Gompel, R. P., Pickering, M. J., & Traxler, M. J. (2000). Unrestricted race: A new model of syntactic ambiguity resolution. *Reading as a perceptual process*, 621-648. Doi: 10.1016/B978-008043642-5/50029-2

Van Overschelde, J. P., Rawson, K. A., & Dunlosky, J. (2004). Category norms: An update and expanded version of the Battig and Montague (1969) norms. *Journal of Memory and Language, 50*, 289-335. Doi: doi.org/10.1016/j.jml.2003.10.003

Venables, W. N. & Ripley, B. D. (2002) Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0

Wagenmakers, E. (2007). A practical solution to the pervasive problems of *p* values. *Psychonomic Bulletin & Review, 14*(5), 779-804. Doi: 10.3758/BF03194105

Wahlberg, T., & Magliano, J. P. (2004). The ability of high function individuals with autism to comprehend written discourse. *Discourse Processes*, *38*(1), 119-144. doi:10.1207/s15326950dp3801_5

Warren, T., & McConnell, K. (2007). Investigating effects of selectional restriction violations and plausibility violation severity on eye-movements in reading. *Psychonomic Bulletin & Review*, *14*(4), 770-775. Doi: 10.3758/BF03196835

Warren, T., McConnell, K., & Rayner, K. (2008). Effects of context on eye movements when reading about possible and impossible events. *Journal of Experimental*

Psychology-Learning Memory and Cognition, 34(4), 1001-1010. doi: 10.1037/0278-7393.34.4.1001

Wechsler, D. (1999). Wechsler Abbreviated Scale of Intelligence. The Psychological Corporation: Harcourt Brace & Company. New York, NY.

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development, 72*(3), 655-684. doi: 10.1111/1467-8624.00304

White, S. J. (2013). The Triple I Hypothesis: Taking Another('s) Perspective on Executive Dysfunction in Autism. *Journal of Autism and Developmental Disorders, 43*(1), 114-121. doi: 10.1007/s10803-012-1550-8

White, S., Frith, U., Milne, E., Rosen, S., Swettenham, J., & Ramus, F. (2006). A double dissociation between sensorimotor impairments and reading disability: A comparison of autistic and dyslexic children. *Cognitive Neuropsychology, 23*(5), 748-761. doi: 10.1080/02643290500438607

Whitehouse, A. J., Barry, J. G., & Bishop, D. V. (2007). The broader language phenotype of autism: a comparison with specific language impairment. *Journal of Child Psychology and Psychiatry*, *48*(8), 822-830. Doi: 10.1111/j.1469-7610.2007.01765.x

Whitehouse, A. J., Barry, J. G., & Bishop, D. V. (2008). Further defining the language impairment of autism: is there a specific language impairment subtype? *Journal of communication disorders*, *41*(4), 319-336. Doi: 10.1016/j.jcomdis.2008.01.002

Whitehouse, D., & Harris, J. C. (1984). Hyperlexia in infantile-autism. *Journal of Autism and Developmental Disorders, 14*(3), 281-289. doi: 10.1007/bf02409579

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8*(2), 221-243. doi: 10.3758/bf03196158

Williams, D. L., Goldstein, G., & Minshew, N. J. (2006). Neuropsychologic functioning in children with autism: Further evidence for disordered complex information-processing. *Child Neuropsychology, 12*(4-5), 279-298. doi: 10.1080/09297040600681190

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs - representation and constraining function of wrong beliefs in young childrens understanding of deception. *Cognition, 13*(1), 103-128. doi: 10.1016/0010-0277(83)90004-5

Wing, L., & Gould, J. (1979). Severe impairments of social-interaction and associated abnormalities in children - epidemiology and classification. *Journal of Autism and Developmental Disorders, 9*(1), 11-29. doi: 10.1007/bf01531288

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological bulletin*, *123*(2), 162. Doi: 10.1037/0033-2909.123.2.162

Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The construction of situation models in narrative comprehension - an event-indexing model. *Psychological Science, 6*(5), 292-297. doi: 10.1111/j.1467-9280.1995.tb00513.x