A Corpus of Text Data and Gaze Fixations from Autistic and Non-autistic Adults

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Abstract

The paper presents a corpus of text data and its corresponding gaze fixations obtained from autistic and non-autistic readers. The data was elicited through reading comprehension testing combined with eye-tracking recording. The corpus consists of 1034 content words tagged with their POS, syntactic role and three gaze-based measures corresponding to the autistic and control participants. The reading skills of the participants were measured through multiple-choice questions and, based on the answers given, they were divided into groups of skillful and less-skillful readers. This division of the groups informs researchers on whether particular fixations were elicited from skillful or less-skillful readers and allows a fair between-group comparison for two levels of reading ability. In addition to describing the process of data collection and corpus development, we present a study on the effect that word length has on reading in autism. The corpus is intended as a resource for investigating the particular linguistic constructions which pose reading difficulties for people with autism and hopefully, as a way to inform future text simplification research intended for this population.

Keywords: autism, eye tracking, reading, gaze fixations, corpus

1. Introduction

People with Autism Spectrum Disorder (ASD) struggle to comprehend various aspects of spoken and written language such as long words and sentences, abstract concepts, figurative language, irony and sarcasm, etc. (Happe, 1997; MacKay and Shaw, 2004; O'Connor and Klein, 2004). Deficits in reading comprehension have been defined as one of the main reasons for the high rate of school dropout in autistic students, later on affecting their social inclusion and employability prospects (Brugha et al., 2012). In order to address these issues a number of language technology tools have been developed, ranging from Picture Exchange Communications Systems (PECS), which allow users to combine pictures with text in order to convey meaning, to mobile applications such as *Stories About Me*[1] or *VAST-Autism*[2] app, which aim to assist key areas of language development in autistic users. Other software, such as the *OpenBook*[3] tool, performs semi-automatic text simplification specifically targeted at autistic readers by reducing syntactic complexity and disambiguating meaning.

The main issue with the language assistance tools mentioned above is that they need to rely on robust research into the reading difficulties people with autism face and the specific linguistic components which need to be simplified. So far, the only way reading deficits in autism have been investigated is through psychological testing which casts light on the impairment of underlying cognitive mechanisms involved in language processing (Frith and Snowling, 1983; Happe, 1997) rather than the complexity of various linguistic features.

At the same time, a useful and reliable way of detecting linguistic constructions which increase text complexity has been the use of eye-tracking technology (Demberg and Keller, 2008). For instance, this method has been successfully applied to automatic text simplification for people with dyslexia (Rello et al., 2013). The assumption behind eye tracking is that the longer the eye gaze fixation on a certain word is, the more difficult it is for cognitive processing (Just et al., 1996). However, until now, eye tracking has not been used to investigate reading in autism, possibly due to the number of procedural difficulties related to this kind of research with autistic participants (Section 3), and thus there is no reliable information about the particular types of phrases which need simplification for readers with autism.

We bridge this gap by introducing work in progress towards the first corpus of texts with corresponding eye fixations elicited from autistic participants reading 9 text passages (1034 content words in total). Three different gaze-based measures are computed for each word, namely the average time it has been viewed, the average number of fixations and the average number of revisits for it (Section 4). To enable investigation of the particular difficulties of readers with autism and how they differentiate from those of non-autistic people, we have featured the paired gaze fixations of a control group of non-autistic participants, matched to the autistic participants on the basis of reading ability. The corpus also features the Part of Speech (POS) and syntactic role of each word, as well as anaphoric links between words.

The rest of this paper is organised as follows: Section 2 presents related work from the fields of autism research and eye-tracking for reading, while Section 3 presents the design of the reading comprehension experiments and the procedure for eye-tracking data collection. Post-processing of the eye-tracking data is discussed in Section 4, and Section 5 describes preliminary experiments with the corpus, as well as their results. Finally, Section 6 discusses corpus limitations and Section 7 summarises conclusions and future work.

[1] https://itunes.apple.com/us/app/stories-aboutme/id531603747?mt=8, last accessed May 2015.

[2] https://itunes.apple.com/us/app/vast-autism-1-core/id426041133?mt=8, last accessed May 2015.

[3] http://openbooktool.net, last accessed May 2015.

2. Related Work

In this section we first present the main reading-related characteristics of autism and then we discuss previous work in using eye tracking as a method for identifying areas of difficulty in text processing.

2.1. Reading Comprehension and Word Decoding in Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a developmental condition of neural origin characterised by impairments in communication and social interaction (American Psychiatric Association, 2013). An early sign of atypical development in autism is language delay, with some autistic children learning to speak as late as the age of five, while others may remain non-verbal throughout all their lives (excluding cases of children later diagnosed with a specific subtype of autism called Asperger's syndrome where no language delay has been observed) (Frith, 2003). Language delay results in atypical language processing later on in life, which includes atypical language production such as speaking of self in third person or phrase repetition, a phenomenon known as *echolalia* (Tek et al., 2014; Boucher, 2003). In echolalia the autistic child is likely to echo immediate questions which they do not understand or have no response for (Tager-Flusberg et al., 2005), which also relates to the problem of language comprehension.

Language comprehension difficulties in autism include both listening and reading comprehension and cover phenomena such as difficulties in syntax processing of long sentences (Whyte et al., 2014), resolving ambiguity in meaning (Happé and Frith, 2006; Happe, 1997; Frith and Snowling, 1983; O'Connor and Klein, 2004; Martos et al., 2013), and identifying pronoun referents (O'Connor and Klein, 2004), as well as having difficulties in figurative language comprehension (MacKay and Shaw, 2004) and making pragmatic inferences (Norbury, 2014). One example of the impaired ability of some autistic people to use context in order to process ambiguity and polysemy is an experiment by (Happe, 1997), where children with autism were shown to have a decreased ability to disambiguate homographs in context, as in sentences a) and b) below:

a) *"She had a tear in her eye"*
b) *"She had a tear in her dress"*

(Happe, 1997)

In terms of word decoding, autistic readers have not been shown to have deficits, as they were found to use successfully both lexical strategies for reading familiar words (look-and-say) and phonological strategies for unfamiliar words, based on grapheme-to-phoneme conversion (Frith and Snowling, 1983). In fact, many autistic readers have been shown to have exceptionally good word decoding skills, a phenomenon known as *hyperlexia* (Nation et al., 2006). Readers with a hyperlexic profile exhibit exceptionally good word and non-word decoding skills but there are significant deficits in their comprehension of the text being read. In the case of autism, hyperlexia may be due to preoccupation with word decoding as an activity and ignoring the overall purpose of reading as means to extract information.

The lack of word-decoding deficits within autism supports the theory that long eye fixation durations for certain linguistic constructions within the text are not due to decoding difficulties, such as within dyslexia. Instead, in the case of autism, as well as in the general population where deficits in word decoding are not usually present, longer fixation durations and higher number of revisits to previously read phrases are signs of higher cognitive effort required for accessing semantic meaning and integrating the syntactic structure of the particular linguistic units being read. The next section presents related work in the field of eye-tracking during reading tasks.

2.2. Eye-fixations during Reading

Eye tracking is a process where an eye-tracking device measures the point of gaze of one's eye (gaze fixation) or the motion of an eye (saccade) relative to the head and a computer screen. Fixations are eye movements which stabilise the retina over a stationary object of interest (Duchowski, 2009), which, in the case of reading research, is the written text and its units (letters, words, phrases, etc). Gaze fixations and revisits (go-back fixations to a previously fixated object) have been widely used as measures of text processing difficulty by taking into account their durations and the places in text in which longer fixations occur (Duchowski, 2009).

The idea that the durations of gaze fixations could be used as a proxy for measuring cognitive load dates back to the *strong eye-mind hypothesis* by Just and Carpenter (1980), according to which, "there is no appreciable lag between what is fixated and what is processed" (Just and Carpenter, 1980). That is, when a subject looks at something, he/she also processes it cognitively. The hypothesis also states that the amount of time the subject spends on processing the particular object is equal to the amount of time his/her gaze stays fixated on this object.

A series of studies on eye tracking during reading were conducted by Rayner et al. and summarised in (Rayner, 1975; Rayner, 1998; Rayner et al., 2012). The effects of different linguistic constructions investigated included word frequency, verb complexity and lexical ambiguity (Rayner and Duffy, 1986), as well as contextual effects on word perception (Ehrlich and Rayner, 1981) and the way eye movements reflect attention while reading (Rayner, 2009). These findings are integrated into a model of eye movement control during reading called the E-Z model (Reichle et al., 1999), which provides a theoretical framework for understanding "how word identification, visual processing, attention, and oculomotor control jointly determine when and where the eyes move during reading" (Reichle et al., 2003).

In terms of corpora containing data from eye fixations, there are only a few relatively large corpora containing eye-tracking data obtained during a reading task. The Dundee corpus (Kennedy et al., 2003; Kennedy et al., 2013) was developed as participants read newspaper articles from The Independent or Le Monde newspapers, so the corpus includes whole texts and the languages included are English and French. The Potsdam Sentence Corpus (Kliegl et al., 2004; Kliegl et al., 2006) is another corpus of eye-tracking data obtained through reading but it focuses on sentence reading only. It comprises records of eye movements from 222 participants reading 144 German sentences. Both these corpora contain eye movement records from people of average reading ability. To the best of our knowledge, currently there are no corpora available containing eye fixations obtained from people with autism or other disabilities relating to reading. The next section presents related work on eye tracking during reading involving clinical populations.

2.3. Eye Tracking during Reading for People with Autism and Dyslexia

The E-Z model and the majority of eye-tracking research on reading has been conducted on, and is relevant to, the general population of non-impaired readers but has also been applied to clinical populations such as readers with dyslexia (Rayner, 1998; Eden et al., 1994) and autism (Sansosti et al., 2013; Brock et al., 2008). Eye-tracking studies involving dyslexic subjects have also been conducted to aid the development of text simplification systems (Rello et al., 2013), as well as to train machine learning models to distinguish between dyslexic and non-dyslexic readers on the basis of eye-tracking data (Rello and Ballesteros, 2015).

So far, eye tracking has been applied relatively scarcely to investigating reading in autism; however, there have been studies investigating whether people with autism process words in context (Brock et al., 2008), where the participants are asked to look at images relevant or irrelevant to a target word while hearing it in a sentence. Another study investigated the effects of images in texts concluding that in text and image pairs, participants with autism spent longer proportions of time focusing on the image compared to control participants (Yaneva et al., 2015). A study by (Sansosti et al., 2013) investigated the ability of autistic adolescents to make bridging inferences by recording eye-tracking data while they were reading pairs of sentences. The data revealed that there was a significant difference between the total fixation durations, number of fixations and number of regressions between the autistic and non-autistic participants (Sansosti et al., 2013). In Section 5 of this paper we present similar results from an experiment we conducted examining the effects of word length on these three measures for our sample of adult autistic readers. Before that, in Section 3, we describe the data collection process for the development of our corpus.

3. Reading Comprehension Experiments and Eye-tracking Data Collection

20 adults with a confirmed diagnosis of autism and 20 non-autistic adults were asked to read 9 texts and answer 3 multiple choice questions (MCQs) per text. While reading, the eye movements of the participants were recorded with an eye-tracking device.

3.1. Materials

One of the biggest challenges in the design of this study was to decide on such a number of texts to be assessed by each participant that would not cause fatigue in them and thus be in bridge with ethical requirements. The reason behind this consideration is that compared to non-autistic people, individuals with autism are much more prone to experiencing issues with concentration and attention which may result in fatigue, sensory overload or even meltdowns (Happé and Frith, 2006; Lai et al., 2014). Thus for the initial stage of this study a total of 9 texts were assessed by the participants. The texts varied in difficulty, as shown by the Flesch (Flesch, 1948) and Flesch-Kincaid (Kincaid et al., 1975) readability formulae, and were obtained from miscellaneous domains in order to avoid genre bias. Table 1 summarises some of the characteristics of the texts included in this study.

Title	Genre	Words	FKGL[4]	Flesch[5]
Playing Safe	Informational	163	4.93	79.548
Coral Reefs	Educational	178	4.671	80.22
Conditioning	Educational	206	7.577	65.437
Evolution	Educational	189	9.276	56.758
Juan Carlos	Newspaper	226	11.98	40.658
Football	Newspaper	160	8.866	59.82
Power Station	Informational	163	8.765	66.657
Cover Art	Informational	185	14.68	45.34
Western	Newspaper	188	9.823	58.298

Table 1: Characteristics of the 9 texts included in the initial stage of the study.

Each text was assessed by each participant through answering three literal or inferential multiple-choice questions (MCQs) with four possible answers each.

3.2. Participants

Participants in the study were 20 adults (7 female, 13 male) with a confirmed diagnosis of autism and 20 non-autistic adults (11 female and 9 male). None of the 40 participants had comorbid conditions affecting reading (e.g. dyslexia, learning difficulties, aphasia etc.). Mean age (m) for the ASD group was m = 30.75, with standard deviation SD = 8.23, while for the control group it was m = 30.81, SD = 4.8. Years spent in education, as a factor influencing reading skills, for the ASD group were m = 15.31, SD = 2.9, and for the control group, m = 17.25, SD = 2.15. All participants were native speakers of English and had normal or corrected vision.

3.3. Apparatus and Procedure

The eye tracker used was a Gazepoint GP3 video-based eye tracker [6] with a 60Hz sampling rate and a 19” LCD monitor. A 9-point calibration procedure was used to calibrate the device individually for each participant and the distance between each participant and the eye tracker was controlled by using a software-integrated sensor and was roughly 85 cm. The documents and the MCQs pertaining to each document were presented on screen in a randomised order and

[5]The higher the Flesch-Kincaid Grade Level (Kincaid et al., 1975) is, the harder the text is.

[5]The higher the Flesch score (Flesch, 1948) is, the easier the text is.

[6]http://www.gazept.com/

participants could take as long as they needed to read them. Participants had the chance to refer to the texts while answering the MCQs as the relevant text was displayed under each question, which was done to avoid potential memory deficits as a confounding variable to comprehension.

3.4. Ensuring Data Quality

After the completion of the data collection all gaze data was manually corrected for vertical systematic error by adjusting the coordinates according to "anchors" inserted on the screen (Figures 1 and 2). These "anchors" were navigation buttons, which participants had to look at in order to press them and thus they served as reference points to possible dispositioning of the gaze path (e.g. reading above the line). In order to ensure the robustness of the data a threshold of 80% was set, where if the good quality data (data without unfixable inaccuracies) obtained from a participant was less than 80%, all the data from that participant was discarded. Data inaccuracies usually result from poor calibration or system imprecisions typical of all eye trackers (Duchowski, 2009). However, in the case of autistic participants, inaccuracies also resulted from too many head movements and reduced ability to follow instruction (Sasson and Elison, 2012). Due to this added procedural difficulty the final number of participants from whom the data was retained was 9 participants, who were carefully matched for reading ability with non-autistic participants from the control group (Section 3.5) in order to allow fair comparison between the two populations.

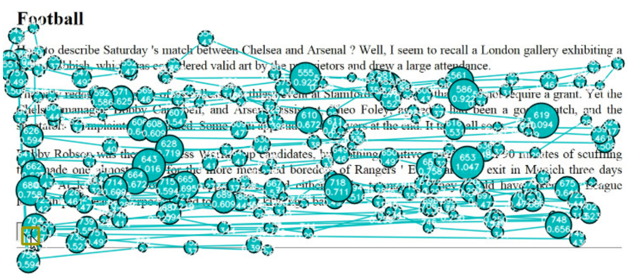

Figure 1: Gaze path before correction of vertical inaccuracy

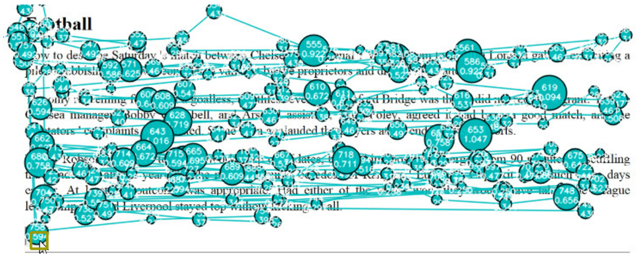

Figure 2: Gaze path after correction of vertical inaccuracy

3.5. Participant Matching

The importance of participant matching is high when comparing clinical groups to the general population because of the heterogeneity and varying levels of linguistic ability of participants in both groups (Jarrold and Brock, 2004). Thus, we wanted to be sure that if there were differences between the durations of gaze fixations between the two groups, these were not caused by differences in text comprehension but rather by differences in the way participants from both groups reached a similar level of comprehension of a given text.

In order to match the levels of ability of participants from both groups, we took their answers to the MCQs, where each correct answer was given a score of 1 and each incorrect answer a score of 0. We then assessed the answers of the 9 participants from the ASD group whose gaze data was retained and divided them into two groups of "skillful" readers with ASD (Group A) and another group of "less skillful" readers with ASD (Group B), with statistically significant difference between the two groups according to a non-parametric Mann-Whitney U test, as our data was shown to be non-normally distributed according to a Shapiro-Wilk test conducted previously ($U = 5568$, $N1 = 5$, $N2 = 4$, $p < 0.001$, two-tailed). We then matched the two groups to participants from the pool of the control group who also passed the 80% threshold of good quality gaze data and had a similar level of text comprehension. The selected 9 control participants were also divided into two significantly different groups of "skillful" and "less skillful" readers ($U = 5724$, $N1 = 5$, $N2 = 4$, $p < 0.001$, two-tailed) (Table 2). Thus we had Group A readers including 4 autistic and 4 non-autistic "skillful" readers, which did not differ significantly in terms of answering scores ($U = 5512$, $N1 = N2 = 4$, $p = 0.129$, two-tailed) and a Group B readers consisting of 5 autistic and 5 non-autistic "less skilful" readers with no statistically significant difference in their answers ($U = 8244$, $N1 = N2 = 5$, $p = 0.193$, two-tailed), as shown in Table 2.

	Skillful	Less-skillful
ASD	4 participants	5 participants
Control	4 participants	5 participants

Table 2: Participant matching based on reading ability

4. Post-processing of the Eye-Tracking Data

Each content word from the texts was defined as an Area of Interest (AOI) in the eye tracking analysis software and for each AOI three gaze-based measures were computed:

Average Time Viewed (ATV): The average time an AOI was viewed by all participants measured in seconds.

Average Number of Fixations (AF): The average number of gaze fixations from all participants in a given AOI.

Average Number of Revisits (AR): The average number of times participants have gone back to a previously viewed AOI. This measure is particularly relevant to measuring heavy cognitive load posed by particular text constructions and is informative about the process of information integration in the readers.

Item	AOI name	POS	Coref	ASD ATV	ASD AF	ASD AR	Con ATV	Con AF	Con AR
13	$< /s >< s >$								
14	Your	prp$	set 11	0.225	2.229	2.618	0.221	2.234	2.505
15	team	nn		0.22	2.219	2.447	0.213	2.075	2.076
16	is	vbz		0.112	1.704	1.959	0.108	1.859	2.024
17	losing	vbg		0.255	2.155	2.438	0.297	2.4	72.89
18	by	in							
19	just	rb		0.198	1.833	2.094	0.194	1.788	2.067
20	one	cd		0.159	1.945	1.945	0.149	1.762	2.051
21	goal	nn		0.188	1.903	1.852	0.184	1.966	2.789
22	.	.							
23	$< /s >< s >$								

Table 3: Example of the corpus data obtained from skilled autistic (ASD) and non-autistic control (Con) readers.

All texts were processed using the Stanford parser[7] (Klein and Manning, 2003). The resulting corpus is a csv file containing all eye-tracking data from both groups, POS tags for each word, and anaphoric links within the texts, as shown in Table 3.

5. The Corpus in Use: Are Long Words Truly More Difficult for Readers with Autism?

In this section we test the assumption that readers with autism struggle with comprehending long and complex words (Martos et al., 2013). We do this in order to give an example for a possible way in which our corpus could be used in identifying particular areas of reading difficulty for people with autism and thus to inform future text simplification research.

5.1. Experimental design

To test the above assumption we first compared all data obtained from readers with and without autism for all the 1034 content words (all-word condition), in order to see whether there are any between-group differences for all words in our corpus. The formal hypotheses for this part of the experiment are:

H1(a): There are no between-group differences in the **Average Time Viewed** measure for all 1034 areas of interest.

H1(b): There are no between-group differences in the **Average Number of Fixations** measure for all 1034 areas of interest.

H1(c): There are no between-group differences in the **Average Number of Revisits** measure for all 1034 areas of interest.

We then sorted all words in the corpus based on their length, removed any repeating words and selected a subsection of the 100 longest words, the majority of which had more than 3 syllables (long-word condition). Compound words were not discarded, as they are usually perceived as whole entities. Examples of words selected randomly from the 100-word sample are: *narcissistic, smart-alecky, conditioning, decapitated, iconoclasm, scuffling, insensitivity, ruritarian, republican, salivating, self-respecting, etc*. We compare the gaze data for these words obtained from participants with and without autism:

H2(a): There are no between-group differences in the **Average Time Viewed** measure for the 100 longest words in the corpus.

H2(b): There are no between-group differences in the **Average Number of Fixations** measure for the 100 longest words in the corpus.

H2(c): There are no between-group differences in the **Average Number of Revisits** measure for the 100 longest words in the corpus.

We can conclude that long words are an area of particular difficulty for people with autism, only if the results show that there are statistically significant differences between groups in the long-word condition (the 100 longest words), which were not present in the between-group comparison for the all-word condition (all words in the corpus).

5.2. Results

A Shapiro-Wilk test showed that the data in the all-word condition was non-normally distributed, which is why the non-parametric Mann-Whitney U test was applied to compare Average Time Viewed, Average Fixations and Average Revisits for all areas of interest. The results show that there is no overall between-group difference in the average time participants spent looking at each area ($U = 489951$; $p = 0.08$) confirming H1(a). However, there are differences in the overall amount of fixations per area they make ($U = 485773$; $p = 0.039$) and even more so in the number of revisits ($U = 470398$; $p = 0.001$), refuting hypotheses H1(b) and H1(c). This suggests that the autistic participants tend to move their eyes more abruptly compared to the control group participants and to skim through the text more often. This result is consistent with previous eye-tracking research involving autistic adolescent readers, where it is found that

[7] Available at: http://nlp.stanford.edu/software/lex-parser.shtml

they "spent more time fixating on text, made more fixations overall, and made more regressions (i.e. moving backward within the text) while reading than did controls" (Sansosti et al., 2013). Further psycholinguistic research is required to establish whether this reading behaviour and shift of attention between different words in the text may be the reason for the lower comprehension of readers with autism.

For the long-word condition the data was also non-normally distributed, which is why the areas of interest were again compared using the Mann-Whitney U test. This time the results show a statistically significant difference for the Average Time Viewed measure (U = 4062, p = 0.022), refuting H2(a). This difference was not present in the all-word condition H1(a), confirming that long words do pose more difficulty to readers with autism compared to the general population. The other two measures also resulted in statistically significant difference (Average fixations: U = 3938, p = 0.009; Average Revisits: U = 3881, p = 0.006), a result which is similar to the one in the all-word condition (all H1(b), H1(c), H2(b) and H2(c) were refuted).

6. Discussion and Corpus Limitations

In the previous section we show that long words evoke significantly longer fixations from the autistic participants compared to the non-autistic ones, a difference in fixation length which is not present when comparing all 1034 areas of interest from the corpus. The fact that there are significant differences in the number of fixations and revisits is consistent with previous research in eye tracking involving autistic readers (Sansosti et al., 2013).

The corpus presented in this paper suffers from several limitations, which need to be taken into account when designing experiments involving this data. The biggest limitation is the low sampling rate of the eye tracker (60Hz), which is lower than the minimal sampling rate of 120Hz generally recommended for reading research. As a result not every word in the corpus if fixated by all participants and even though care was taken to remove vertical systematic error and reference "anchors" were included in the text, it is still possible that some of the fixation locations may not be as accurate as in other eye-tracking corpora of data obtained using faster devices and from non-autistic readers. Thus, while the data is still relevant for distinguishing bigger or more frequent entities in the text such as sentences, long phrases or groups of linguistic phenomena including a large number of data points such as the 100 long words used in this study, the corpus should be applied with caution to linguistic phenomena which is more fine-grained (e.g. very short words) or less frequent within the corpus (e.g. figurative expressions). Another limitation is the small number of participants and texts, which is due to the fact that only the data with highest quality was included in the corpus. All limitations listed above should be accounted for when experiments using this corpus are designed. However, at the present moment this is the only corpus of its kind to allow investigation of autism-specific difficulties related to reading and to inform future text simplification research.

7. Conclusions and Future Work

The corpus presented in this paper consists of 1034 content words tagged with their POS, syntactic role and three gaze-based measures obtained from autistic and non-autistic individuals. The participants were divided into two groups according to their reading skills, and thus it is possible to say whether particular fixations are attributed to skilful or less skilful readers. The paper also presented an experiment where the corpus was used to investigate difficulties in processing long words among readers with autism. Current work involves the collection of more data involving more participants and 11 additional texts, thus expanding the size of the corpus to 20 texts.

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