The Effect of Text Simplification on Reading Fluency and Reading Comprehension in L1 English Speakers

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Abstract

Text simplification is a common practice for making texts easier to read and easier to understand. To which extent does it achieve these goals, and which participant and text characteristics drive simplification benefits? In this work, we use eye tracking to address these questions for the first time for the population of adult native (L1) English speakers. We find that 42% of the readers exhibit reading facilitation effects, while only 2% improve reading comprehension accuracy. We further observe that reading fluency benefits are larger for slower and less experienced readers, while comprehension benefits are more substantial in lower comprehension readers, but not vice versa. Finally, we find that high-complexity original texts are key for enhancing reading fluency, while large complexity reduction is more pertinent to improving comprehension. Our study highlights the potential of cognitive measures in the evaluation of text simplification and distills empirically driven principles for enhancing simplification effectiveness.[1]

Keywords: text simplification; reading; eye movements

Introduction

Text simplification is a widespread practice in education, language learning, newswire editing and other domains, which aims at making texts easier to read and easier to understand. Through simplification, texts can be adjusted to the needs and requirements of specific individuals and target groups, such as second language (L2) readers at different language proficiency levels, pupils in different grades, readers with cognitive and language impairments, the elderly and others. Many such readers benefit from, and in some cases even depend on text simplification for accessing and understanding information, learning language and developing their reading skills. Text simplification is also common in editing of newswire material for stylistic reasons and for purposes of increasing the efficiency of information consumption in the general population. The wide range of uses for text simplification has led to the development of many Natural Language Processing (NLP) tools for automated simplification, including simplification functions in user-facing language models such as ChatGPT.

Despite its societal importance, relatively little is known about the effect of simplification on text comprehension, and even less so on reading fluency. Establishing these effects and understanding what drives them is paramount for forming scientific foundations for effective text simplification practices and tools. Furthermore, text simplification provides a naturalistic minimal-pair setting for studying the relations between language complexity and online language processing and comprehension. It is a powerful setting that is yet to be widely exploited in psycholinguistics and the psychology of reading.

In the current work, we provide a general methodological framework for studying text simplification effects. We apply this framework to the population of *adult L1 speakers* of English. While this population is often not considered to be a target group of text simplification, adult L1 speakers vary in reading proficiency, and it is currently unknown to which extent they too can benefit from simplification. Furthermore, this population constitutes an essential reference for studying the effects of simplification in additional populations with lower language proficiency or reading skills.

We measure the overall effects of text simplification on reading fluency and on reading comprehension outcomes in adult L1 speakers using a large-scale eye tracking dataset over a parallel corpus of newswire texts and their simplified versions. We further characterize the variability in simplification effects across participants and texts, and identify key factors that account for it. Our primary results are the following:

- In L1, simplification has a more substantial effect on reading fluency than on reading comprehension. While 42% of the participants exhibit more fluent reading of simplified language, only 2% improve comprehension.

- Slower and less experienced readers benefit most in reading fluency, while lower comprehension readers benefit most in comprehension accuracy, but not the other way around.

- Both the initial complexity of the text and the reduction in complexity as a result of simplification affect simplification benefits, with the former being more pertinent for enhancing reading fluency and the latter for improving comprehension.

These results provide, to our knowledge, the first empirical characterization of the effects of simplification on reading in adult L1 speakers. The outcomes of our analyses advance the scientific understanding of the effects of text complexity on reading and language processing. They can further inform simplification guidelines and decision making on when, for whom, and how to perform simplification in real-world scenarios.

[1]Code is available at: https://github.com/lacclab/text-simplification-effects-eye-movements

In D. Barner, N.R. Bramley, A. Ruggeri and C.M. Walker (Eds.), *Proceedings of the 47th Annual Conference of the Cognitive Science Society*

Experimental Design and Data

Our study is enabled by OneStop Eye Movements (henceforth OneStop) (Berzak et al., 2025), a large-scale dataset of reading comprehension responses and eye movements collected with an EyeLink 1000 Plus eye tracker at a sampling rate of 1000Hz. The textual materials are based on OneStopQA (Berzak et al., 2020), a parallel corpus of texts in their original and simplified forms, with accompanying reading comprehension questions.

Textual Materials OneStop has 30 Guardian news articles with 4-7 paragraphs (162 paragraphs in total), from the News Lessons section of the English language-learning portal onestopenglish.com by Macmillan Education. Each article was simplified by a professional staff member of onestopenglish.com from its original "Advanced" version to a simplified "Elementary" version. The simplification is based primarily on the widely practiced "intuitive" approach (Simensen, 1987; Young, 1999). This approach does not use means such as explicit guidelines and readability formulas but rather relies on experience and subjective judgment regarding the required text complexity and the ways of obtaining it (see further details specific to OneStop in Allen, 2009). Each paragraph has three multiple-choice reading comprehension questions composed by Berzak et al. (2020). The questions and answers are identical for both difficulty levels of each paragraph. Table 1 presents summary statistics of the two text levels. Figure A1 in the Supplemental Material[2] (SM) further presents the distribution of reading comprehension accuracy and question answering time for both text levels.

	Original	Simplified	p value
Number of paragraphs	162	162	-
Number of questions	486	486	-
Words per paragraph	119.9 ± 4.33	97.1 ± 3.66	***
Sentences per paragraph	5.78 ± 0.31	5.75 ± 0.27	ns
Sentence length (words)	20.8 ± 0.66	16.9 ± 0.51	***
Mean word length (characters)	4.8 ± 0.04	4.6 ± 0.04	***
Mean word frequency (Wordfreq)	11.28 ± 0.11	10.99 ± 0.11	***
Mean word surprisal (Pythia-70m)	5.01 ± 0.06	4.77 ± 0.06	***

Table 1: Descriptive statistics for the original and simplified versions of OneStop texts. Each row presents the mean and 95% confidence interval for each version, and the p-value of a t-test comparing the means. ns ($p \geq 0.05$), *** ($p < 0.001$). Frequency is $-\log_2(p(word))$, using counts from Wordfreq (Speer et al., 2018). Surprisal is $-\log_2(p(word|context))$, where *context* are the previous paragraph words, derived from the Pythia-70m language model (Biderman et al., 2023).

Participants OneStop has 180 L1 English participants who read texts for general comprehension. The dataset does not include participants with dyslexia and language impairments, with the exception of one participant with mild dyslexia and one participant with mild reading and writing impairment. The mean participant age is 23.4 and the mean age of English acquisition (AoA) is 0.5. 76.7% of the participants are university students. Prior to the eyetracking experiment, participants filled out a demographic questionnaire, which included reading habits questions based on Section 1 of the reading habits self-report of Acheson et al. (2008). In these questions, participants were asked to report the number of hours per week spent reading different text genres.

Eye Movement Data and Procedure Each participant is assigned to one of three 10-article batches (54 paragraphs). The texts are presented paragraph by paragraph. After each paragraph, the participant has to answer one of the three questions for the paragraph on a new screen, without the ability to return to the paragraph. Each paragraph in a given article is presented to the participant randomly either in the original or the simplified version. This ensures that while a given participant reads each paragraph only in one of its two difficulty levels, they read paragraphs from the same article (i.e. on the same topic) in each of the two difficulty levels. The data is counterbalanced such that each participant reads 27 original and 27 simplified paragraphs overall and approximately the same number of original and simplified paragraphs within each article. Each paragraph is read by 60 participants, 30 in the original level and 30 in the simplified level.

Overall Effects

We first examine the overall effect of simplification on comprehension and eye movement measures of reading fluency.

Reading Comprehension

We examine both reading comprehension accuracy, and the mean time (in seconds) it takes participants to answer the reading comprehension questions. Figure 1 presents the results, where we find a small but significant positive effect of simplification on reading comprehension accuracy (2.3%, $p < 0.01$) and no effect on question answering time. The former result replicates analyses in Berzak et al. (2020), which found a similar effect for the OneStopQA dataset in online (Prolific) and in-lab experiments without eye tracking.

Reading Fluency

Reading Speed Perhaps the most intuitive and simple way to quantify reading fluency is via reading speed. Reading speed is an *offline* measure; if the text is known, obtaining it requires only the overall reading time of the text. Here, we measure reading speed in number of words read per second.

Eye Movement Measures The eyetracking data of OneStop allows further examining *online* eye movement measures that reflect reading fluency in real-time. Eye movements in reading are saccadic; they consist of fixations, prolonged periods of time in which the gaze is stable at a specific location, and saccades, which are rapid transitions between fixations. In this work, we focus on three primary measures from the psycholinguistic literature that capture reading fluency.

- **Total Fixation Duration (TF)** The sum of all fixations durations on a word, for words that were fixated.
- **Skip Probability (SP)** The fraction of words that were not fixated.

[2] https://osf.io/mgk69

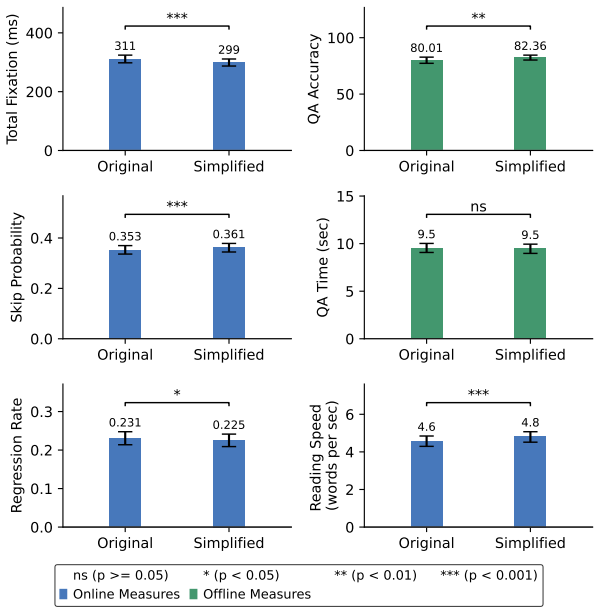

Figure 1: The mean effect of text simplification on reading fluency and reading comprehension. Differences between the original and simplified text levels are tested using mixed effects models of the form: $measure \sim level + (level|participant) + (level|paragraph)$, where *level* is original or simplified. Error bars indicate 95% confidence intervals.

- **Regression Rate (RR)** The number of saccades per word that go backward.

Greater reading fluency in the simplified texts should be manifested in higher reading speed, shorter per-word TF, higher SP and lower RR. Figure 1 shows that this is indeed the case for all four measures ($p < 0.001$ for reading speed, TF and SP, $p < 0.05$ for RR). Figure A2 in the SM presents this analysis with additional measures: Gaze Duration (GD), First Pass GD, First Fixation (FF), First Pass FF, Higher Pass Fixation Duration, Fixation Count, First Pass SP, and First Pass RR (see SM for measure definitions). These measures yield similar results ($p < 0.001$ in all cases), with the exception of First Pass SP (significantly higher in the simplified texts, $p < 0.05$) and First Pass RR (not significant).

Response to Linguistic Word Properties One of the hallmark characteristics of eye movements in reading is the sensitivity of reading times to the linguistic properties of the text, and in particular to the "big three" properties of lexical processing (Kliegl et al., 2006; Rayner & Liversedge, 2011): word length, frequency and predictability (Kliegl et al., 2004; Rayner et al., 2004, among others). Here, we ask whether word property effects are reduced as a result of text simplification. We extract word properties in the following manner:

- **Length** in characters, excluding punctuation.
- **Frequency** $-\log_2(p(word))$ based on frequency counts from Wordfreq (Speer et al., 2018).

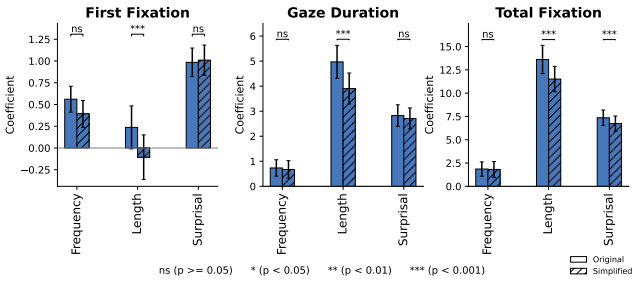

Figure 2: The effect of word length, frequency and surprisal on reading time measures for fixated words. Depicted are the current word coefficients from models of the form $measure \sim len + freq + surp + len_{prev} + freq_{prev} + surp_{prev} + (len + freq + surp|participant) + (len + freq + surp|paragraph)$, fitted separately for the original and simplified paragraphs, where *prev* is the previous word to account for spillover. Error bars denote 95% confidence intervals. Significance of statistical test results is presented for the current word interaction terms in $measure \sim level * len + level * freq + level * surp + level * len_{prev} + level * freq_{prev} + level * surp_{prev} + (level + len + freq + surp|participant) + (level + len + freq + surp|paragraph)$.

- **Predictability** is measured with surprisal (Hale, 2001; Levy, 2008) $-\log_2(p(word|context))$, where *context* are the preceding paragraph words, using the Pythia-70m language model (Biderman et al., 2023).

We measure the effect of these word properties on TF, and two earlier fixation measures:

- **Gaze Duration (GD)** The time from first entering a word to first leaving it.
- **First Fixation (FF)** The duration of the first fixation on a word.

Figure 2 presents a comparison between the response to linguistic word properties in the original and simplified text levels. Depicted are the coefficients from linear mixed-effects models that predict First Fixation, Gaze Duration and Total Fixation Duration from word length, frequency and surprisal. We find that word property effects are smaller in the simplified version in TF for length ($p < 0.001$) and surprisal ($p < 0.001$), in GD and FF for length ($p < 0.001$). Figure A3 in the SM presents analyses for: First Pass FF, First Pass GD, SP and RR, where we find largely similar results. Figure A4 and Figure A5 in the SM further shows that the results hold after reading speed normalization.

Variability Across Readers and Texts

How do simplification effects vary across participants and textual items? Figure 3 presents the effects of simplification on individual participants and individual paragraphs. In the by-participant breakdown, we find that 42% (76 out of 180) of

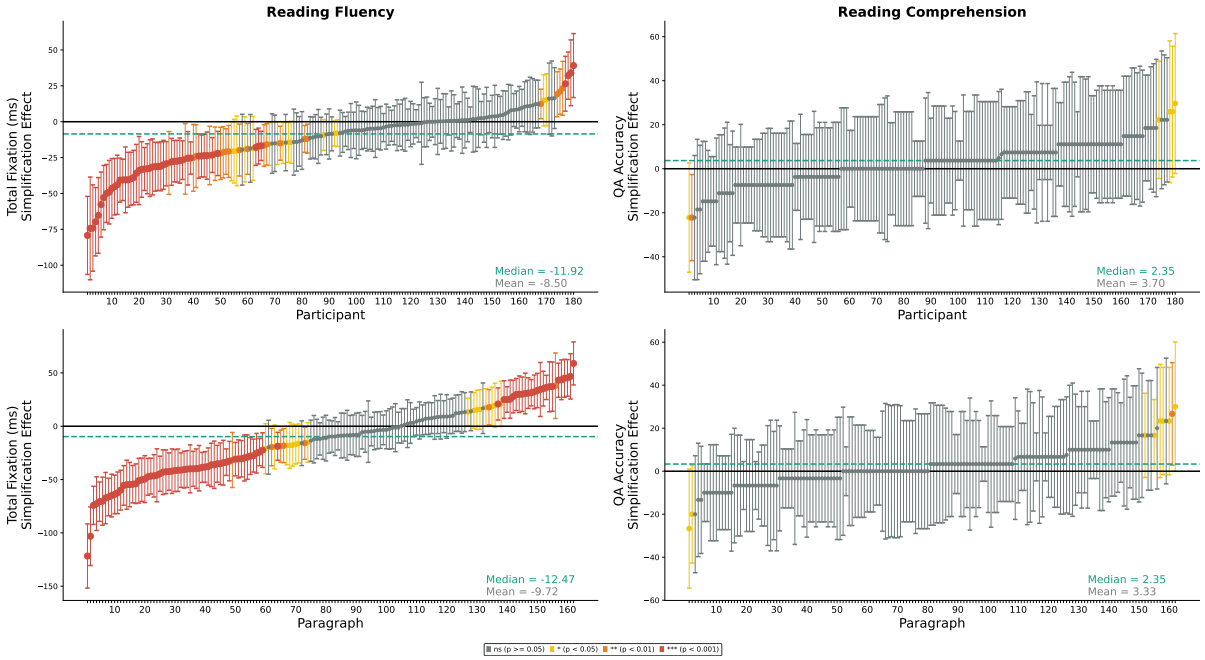

Figure 3: Simplification effects on per word Total Fixation Duration (left) and reading comprehension accuracy (right) per *participant* (top) and per *paragraph* (bottom). The simplification effect is the measured difference between the simplified and the original text levels. Each participant reads 27 original and 27 simplified paragraphs. Each paragraph is read by 30 participants in its original level and by 30 participants in its simplified level. Error bars represent 95% confidence intervals.

the participants exhibit a significant negative effect of simplification on TF. In the SM Figure A6 and Figure A7 we further find that 22% have a significant effect for reading speed, 20% for First Pass GD, 37% for GD, 37% for Higher Pass Fixation Duration, 13% for SP, 13% for RR. Differently from this outcome, only 2% (4 out of 180) of the participants exhibit significant gains in reading comprehension accuracy. Thus, more participants experience more fluent reading than improved reading comprehension as a result of simplification.

The by-paragraph breakdown of reading fluency effects shows that in 44% (72 out of 162) of the items, simplification significantly reduces the item's mean TF. Interestingly, in 21% (34 out of 162) of the items, opposite than intended, simplification leads to significant increases in TF. In the SM Figure A6 and Figure A7 we obtain similar results with reading speed, First Pass GD, GD, Higher Pass Fixation Duration, SP, and RR. Similarly to the pattern in the by-participant analysis, simplification significantly improves reading comprehension only in a small fraction of 4% (7 out of 162) of the paragraphs. Overall, we find that across both participants and textual items, simplification has a more prevalent impact on reading fluency than on reading comprehension accuracy. We note however that comprehension accuracy depends on specific reading comprehension questions, and each paragraph has only one such question. As reflected in the large confidence intervals for reading comprehension, the inherent challenges of measuring comprehension and the limited data may render the resulting estimates to be less reliable than reading fluency estimates.

Who Benefits Most from Simplification?

The analysis above has shown considerable variability in simplification effects across participants. Which participants benefit most from simplification? To study this question, we examine several key participant characteristics that could be related to the magnitude of the resulting simplification effects:

- **Reading Speed** Measured on the original paragraphs.
- **Reading Practice** Self-reported total number of reading hours per week across all text genres.
- **Reading Comprehension Accuracy** Measured on the original paragraphs.

We hypothesize that slower readers will benefit more from simplification. This hypothesis stems from the assumption that longer reading times capture, at least in part, difficulty in processing the text which could potentially be alleviated through simplification. It is further based on a previously observed interaction between reading speed and reading facilitation in repeated reading (e.g. Hyönä & Niemi, 1990; Meiri & Berzak, 2024). In a similar vein, we expect participants who read less in their daily lives to have larger simplification effects. Finally, we hypothesize that participants with lower reading comprehension performance will exhibit larger reading facilitation as a result of simplification.

Figure 4 shows the individual-participant simplification effects as a function of each of the three participant characteristics. We find that the participants' reading speed

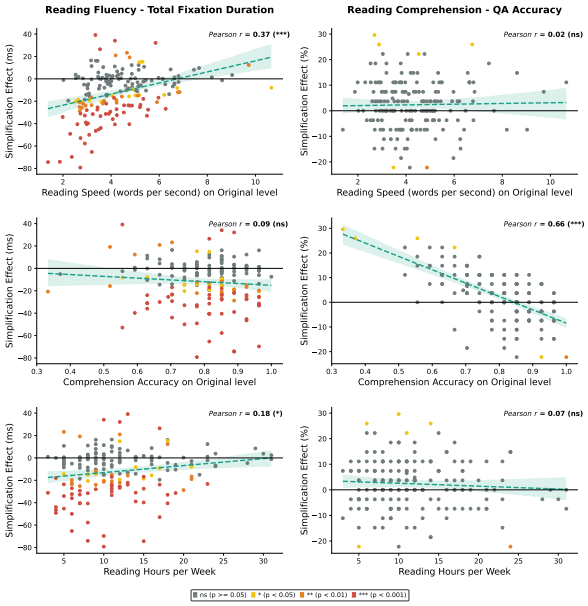

Figure 4: The effect of simplification on reading fluency for Total Fixation Duration (left) and on comprehension accuracy (right) as a function of three participant characteristics: reading speed (words per second) on the original paragraphs, comprehension accuracy on the original paragraphs, and reading experience (number of hours spent reading per week). Each circle represents a single participant.

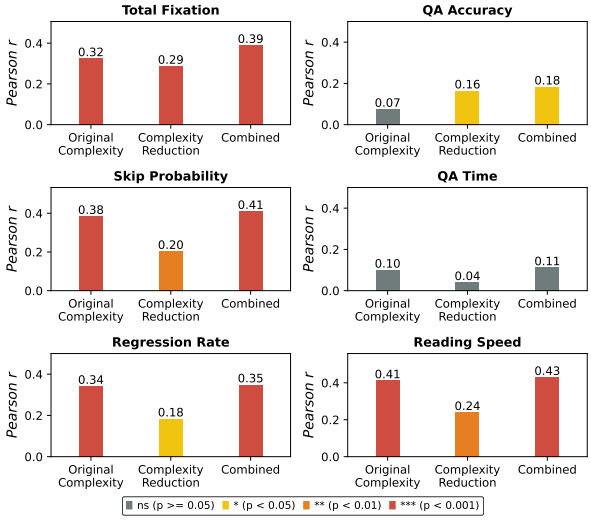

Figure 5: The effect of simplification on reading fluency and on reading comprehension as a function of textual paragraph properties (1) Original Complexity: the average word length, frequency and surprisal of the original text $Measure_{diff} \sim len_{orig} + freq_{orig} + surp_{orig}$, (2) Complexity Reduction: the difference in the average length, frequency and surprisal between the original and simplified text verions $Measure_{diff} \sim len_{diff} + freq_{diff} + surp_{diff}$ and (3) the combination of both feature sets. Depicted are Pearson r correlation coefficients for these models for each of the simplification effect measures.

on the original paragraphs correlates with reduction in TF ($r = 0.37, p < 0.001$), but does not correlate with changes in reading comprehension accuracy as a result of simplification. The opposite pattern is observed with participants' initial reading comprehension accuracy on the original paragraphs, which correlates negatively with the benefit in reading comprehension accuracy ($r = 0.66, p < 0.001$), but does not correlate with reading speed differences as a result of simplification. We further observe a significant negative correlation of daily time spent reading with a reduction in TF ($r = 0.18, p < 0.05$), but not with changes in comprehension accuracy. Figure A8 and Figure A9 in the SM show that the results for TF hold for SP and RR. Figure A10 shows that there is no significant interaction between the simplification effect size on TF and other participant characteristics: age, number of education years and student status. Overall, we find that simplification leads to more fluent reading in slower and less experienced readers, and to reading comprehension benefits in lower comprehension participants, but not the other way around: slower and less experienced readers do not improve comprehension, and lower comprehension readers do not read more fluently as a result of simplification.

In Which Textual Items is the Simplification Most Effective?

As observed above, simplification effects vary considerably not only across participants but also across textual items. Our final analysis takes a first step in characterizing the item properties that account for this variability. We hypothesize that the effectiveness of simplification depends on two key item factors: the complexity of the original item (more gains for more complex items) and the complexity reduction in the simplified item relative to this reference (more gains for better simplification edits). We quantify text complexity via per-word averaged word properties: word length, frequency and surprisal. The differences in the values of each of these properties in the simplified item relative to the original item further capture the quality of the simplification edits.

Figure 5 presents the Pearson r correlations of models that regress these predictors against reading fluency and comprehension accuracy differences between the original and simplified paragraphs. Figure A11 in SM further includes the correlations for univariate models. We find that across all the measures, both the initial complexity of the paragraph and the reduction in complexity as a result of simplification are correlated with gains in reading fluency. The combination of the two yields the highest correlations, suggesting that they provide, to some extent, complementary information. Interestingly, for reading fluency measures, the initial complexity of the text plays a more important role than the quality of the simplification. Differently from these results, comprehension accuracy effects depend more on the reduction in complexity than on the complexity of the original text.

These outcomes not only characterize item properties that are related to simplification effectiveness, but also lead to two practical strategies for simplification in L1. Selecting the most complex items is key when the goal is to enhance reading fluency, while thorough simplification should be the focus if the goal is improved comprehension. These principles can guide both human and machine text simplification.

Related Work

Empirical work on simplification effects in reading is relatively scarce. Most prior studies have primarily examined reading comprehension effects in L2 (Long & Ross, 1993; Yano et al., 1994; Tweissi, 1998; Oh, 2001; Crossley et al., 2014; Rets & Rogaten, 2021). These studies generally found that in L2, simplification leads to improved comprehension outcomes. Our work suggests that simplification can also lead to comprehension benefits in L1, especially for readers with lower reading comprehension performance.

To our knowledge, only two studies have analyzed the effect of simplification on reading fluency. Crossley et al. (2014) examined the effect of simplification on reading times in self-paced reading in L2. Similarly to the current work, they used materials from the News Lessons section of the onestopenglish.com portal. The results of this study are inconclusive. Rets & Rogaten (2021) used eye tracking, and found that in L2 simplification leads to longer first pass GD and shorter higher-pass reading times (the sum of fixations after the first pass), suggesting different effects of simplification on initial processing and reanalysis. We do not find evidence for this differentiation in L1.

In L1, simplification effects have been studied with children and special population adults. Javourey-Drevet et al. (2022) found that in L1 2nd-grade children, simplification leads to improved comprehension and faster reading. They further found that poor readers benefit more from simplification. Our study obtains similar outcomes in adult L1 readers. Reading comprehension and reading speed benefits of text simplification have also been found in L1 children with dyslexia (Gala & Ziegler, 2016; Rello et al., 2013), and comprehension benefits were observed in functionally illiterate adults (Margarido et al., 2008). To the best of our knowledge, the effects of simplification on comprehension and reading times were not previously studied in the general population of adult L1 readers.

Our study adds to prior work on the relation of reading fluency to linguistic knowledge (Cop et al., 2015; Whitford & Titone, 2012, 2017; Mor & Prior, 2022; Berzak & Levy, 2023) and prior interaction with the text (Hyönä & Niemi, 1990; Raney & Rayner, 1995; Meiri & Berzak, 2024), which showed that readers with more linguistic knowledge, and readers who previously interacted with the text, tend to have shorter reading times and smaller word property effects. Our study adds a new dimension to this picture: these effects are also smaller in simplified texts. Together, the results strengthen the interpretation of both standard eye tracking measures and word property effects as measures of reading fluency.

Summary and Discussion

We present the first empirical study of reading comprehension and reading fluency facilitation effects of text simplification in L1 speakers of English. Although L1 speakers are often not the main target group of text simplification, we find that a substantial fraction of them can benefit from text simplification. Given that most of the participants in OneStop have university education, we expect even more prevalent simplification effects in more representative samples of the general population of adult L1 speakers. We further identify key factors that differentially drive reading fluency and reading comprehension benefits across participants and across textual items. These, in turn, lead to cognitively based principles that can guide simplification in accordance with the desired outcomes of the simplification process. Whether these principles apply to other populations beyond L1 is an open question for future research.

More broadly, our results highlight the often overlooked variability in L1 reading patterns in general and simplification outcomes in particular. They further demonstrate the feasibility of characterizing this variability via eye tracking measures and accounting for it by modeling participant and item characteristics. In a complementary vein, real-world simplification provides a test-bed for better understanding and interpretation of standard eye tracking measures and their sensitivity to linguistic word properties, as well as the role of text complexity in online language processing

Perhaps most importantly, our work brings forth a cognitive framework for evaluating simplification, and guiding it based on reading data. This framework validates to some extent the "intuitive" simplification approach, which leads to reading fluency benefits even in L1. However, it also identifies items in which this is not the case. Furthermore, eye tracking measures, and their textual proxies, can provide a cognitive basis for guiding both humans and AI simplification models in choosing which items to simplify, how to simplify them, and for which target groups or even individuals to perform the simplification.

Finally, we note a number of limitations of the current work. First, our study is limited to manual simplification. It does not directly address automated simplifications using AI tools, which are becoming increasingly widespread. Furthermore, within the realm of manual simplification, the used corpus is based on the "intuitive" simplification approach, leaving out "structural" approaches to simplification (Young, 1999; Allen, 2009). Some characteristics of the dataset may also be specific to the individual simplification styles of onestopenglish.com staff members. The dataset is further restricted to the newswire domain. Additional data collection and analyses of different simplification resources, approaches and tools are needed to test the generality of the presented findings in the L1 population. In future work, we plan to further investigate the suitability of reading data for simplification evaluation at different levels of text granularity and for different audiences. To this end, we plan to collect eye tracking data from additional populations, in particular L2 learners and children.

Acknowledgments

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