Effects of Text Simplification on Reading Behavior of Older and Younger Users

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Abstract. Research shows that simplifying short textual passages to lower reading levels (e.g., lower than 10th grade reading level) can improve the viewing behavior of younger users. However, little work has been done to examine the viewing behavior of younger users for simplified text that are longer in length and are more difficult than specific reading levels such as 10th grade reading level. Similarly, little work has been done to examine whether and how older and younger users differ in viewing such long and complex textual content. In this study, we used eye-tracking to examine older and younger users' viewing behavior for two relatively long and complex text passages with the same content but varying reading difficulty. Our results supported previous research that suggests age-related cognitive difficulties are likely to be mitigated by task experience. Our results also supported previous research that shows text simplification can improve users' viewing behavior. Our results extended the previous research by showing that the positive effects of text simplification continue to hold even when the simplified text is relatively long and still considered to be hard to read.

Keywords: Reading behavior · Eye tracking · Text simplification · User experience · Older and younger users

1 Introduction

The proliferation of sophisticated information technology (IT) products and services make it increasingly possible for people to access vital information online. For example, many decision support systems provide complex information online for making life-changing decisions [1]. Hence, paying close attention to effective communication of online content is both relevant and important to human-computer interaction (HCI) research. Because online information is typically provided through visual displays, many studies have focused on examining the impact of the format and arrangement of visual elements on communication effectiveness [2]. However, little work has focused on textual content, which is an essential part of communication effectiveness [3].

One possible way to improve communication effectiveness and efficiency of textual content is through text simplification [4]. Text simplification refers to modifying readable text passages, i.e., by simplifying their structure, in a way to improve their ease of

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processing without changing the meaning of the provided content [5]. Text simplification has been shown to help younger users to read and understand textual information that is lower than 10th grade reading levels in shorter glances [4]. While there has been little research on the effect of text simplification on older users, it is likely that text simplification can also improve communication effectiveness for older users. This improvement can be justified by the cognitive theory of aging which implies that older users tend to take longer time than younger users to process information [6].

In this study we examined whether and how simplifying long and complex passages to a level that still requires advanced reading skills can impact viewing behavior. Based on the above-mentioned studies, we expected to see improved reading experience for both older and younger users. To test this expectation, we used a validated operationalized text simplification methodology [4] to modify a long and complex text passage (18th grade reading level) to a relatively less complex yet advanced reading level (12th grade reading level). We then examined older and younger users' viewing behavior to investigate possible differences in how they process the provided information when reading the two different versions of the same text. Recent technological advances make it possible for researchers to continuously study information processing behavior and unobtrusively by capturing and analyzing users' eye movement data [7–9]. As such, eye tracking can provide insights beyond what users themselves report [10]. In this study, which is part of a larger project examining possible differences in processing complex information between younger and older users, we used eye-tracking to examine whether and how eye movements of older and younger users differ when they read complex text passages.

2 Background

A number of studies suggest that older and younger users are likely to process textual information differently. For example, research indicates that when presented with online information, older users compared to young users, experience more cognitive activity, which in turn can lead to greater attention to the content [11]. Cognitive processing tends to get slower with age, which may be the underlying reason for observed changes in older users' viewing behavior [6], resulting in changes in attention to content, navigation patterns, and/or recall of information, to name a few [11]. Grounded in the cognitive theory of aging [12], studies show that when it comes to website usage, older users tend to take more time to process the same amount of information as compared to younger users [13]. "Website stickiness," or the duration of website visit [13], tend to be shorter for younger users because they process information quicker than their older counterparts. This pattern of behavior is partly because the eyes of younger users move faster, and partly because they tend to use websites more frequently as sources of information. When it comes to reading textual information, younger users do not read the text carefully, or ignore them completely. Djamasbi et al. [3] and Varzgani et al. [14] argued that attention to textual content could be improved by simplifying textual information. In one study, Djamasbi et al. [3] modified relatively short text passages at 10th grade level to examine the impact of text simplification on younger users' task performance. They discovered that participants in the simplified text conditions performed significantly better when it came to answering questions about the text [3]. In another study, Varzgani et al.

[14] examined the impact of text simplification for more complex text passages (18th grade level) on viewing behavior. They showed significantly different cognitive activity (measured as pupillary responses) when participants viewed simplified text compared to when they viewed the original text. They also showed increased attention to the last paragraph in the simplified passage. This behavior is important because attention typically attenuates from top to bottom [15] and because in text passages, the last paragraph often contains important information such as the summary or conclusion of the provided material.

While the studies mentioned above examined the impact of text simplification on performance and viewing behavior, they did not investigate how older and younger users may differ in reaction to text simplification, particularly when the simplified text is still considered to be difficult to read. Because we are interested in communication effectiveness for cognitively complex tasks, in this study, we focus on examining viewing behavior for text passages that even after simplification, still may require higher levels of reading skills (e.g., medical or legal information). In particular, we examine whether and how text simplification for such passages may affect older and younger users' viewing behavior differently.

3 Methodology

We used an eye-tracking experiment to conduct our study. Because we wanted to examine the viewing behavior of older and younger users for passages that required advance reading skills, we recruited participants for our study from a pool of graduate students and employees (faculty and staff) at a university in United States. We chose a text passage at 18th grade level from GRE, a test for graduate admission in US universities. Using a validated set of plain language standards, we then simplified this passage to 12th grade reading level [4, 16], which is still not considered an easy-to-read passage for average readers [17]. From this point on in this current paper, we will refer to the original passage, as OP, and its simplified version as SP.

3.1 Areas of Interest (AOIs)

Areas of Interest (AOI) are used in eye tracking to delineate specific regions of displayed stimulus for gaze analysis [2]. Hence, we used AOIs to investigate whether and how text simplification can impact the behavior of younger and older users differently. To investigate overall differences, the entire passage was considered as one single AOI. Additionally, we divided both passages into three corresponding AOIs. The reason for this delineation was that OP contained three paragraphs; hence, one AOI was designated for each paragraph in OP. The text simplification procedure, however, converted the first paragraph in OP into two paragraphs in SP. Hence, the first AOIs in OP and SP had a different number of paragraphs. The rest of the AOIs in these passages contain the same number of paragraphs [14] (Fig. 1).

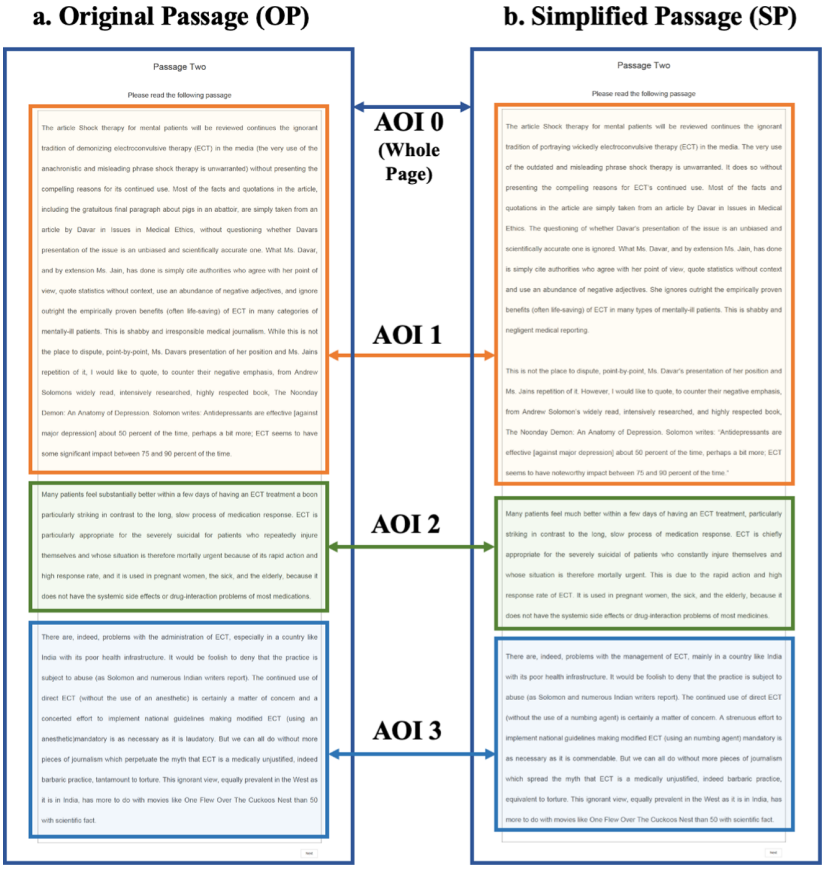

Fig. 1. Areas of Interest (AOIs) in OP and SP

3.2 Participants and Design

We recruited 65 participants from a university located in the northeastern part of the United States. The participants included students, faculty, and university staff, with an age range of 18–70 years. We conducted a between-subject study where the participants were randomly assigned to read one of the two versions of the same passage, either OP or SP. After reading the passage, participants were asked to complete a survey to capture their perceived difficulty of the passage they read.

3.3 Data Collection and Preparation

During the time that participants were viewing the passage, we collected their gaze data using the Tobii TX300 eye-tracking device. This device uses infrared waves to track eye movements and collects gaze data unobtrusively. We used the IVT filter in the Tobii Studio software (version 3.4.8) to process the raw gaze data. As in prior research, we

set the IVT saccade identification threshold to 30°/s and fixation duration threshold to 100 ms [18].

We controlled for age by categorizing participants between the ages of 18 and 46 as younger users [19]. We then considered participants above the age of 46 as older users. We used the relative terms "younger" and "older" for user groups to highlight the comparative nature of age categorization in our study.

In order to prepare for data analysis, we removed gaze data sets with less than 80% sampling rate [20]. Sampling rate refers to eye-trackers' success in detecting users' gaze; hence, 80% sampling rate indicates that the eye tracker was able to detect a user's gaze 80% percent of the time the user was engaged in completing the task. Five participants in our study had less than 80% gaze sampling percentage; hence the dataset for these five participants was removed from data analysis. Two of the remaining participants did not provide information about their age, so we removed the data for those participants as well. Therefore, for the analysis, our study comprised of 21 older users (Age $>$ 47 years) and 37 younger users (18 years $=$ $<$Age $<=$ 46 years).

4 Data Analysis

4.1 Perceived Difficulty

To verify that the text passages used in our study were complex, we measured their perceived difficulty via the Subjective Mental Effort Questionnaire (SMEQ) [21], which ranges from '0' representing the lowest possible level of difficulty to '150' representing the highest possible level of difficulty. The SMEQ scores supported that both OP and SP (18th and 12th grade levels, respectively) were not an easy read. Younger and older participants in our study found reading OP to be "rather hard to do" and "fairly hard to do," respectively. Both user groups found reading SP to be "fairly hard to do." As we expected, these results verified that both text passages used in our study were perceived as harder than average reading material.

The analysis of perceived difficulty provided additional insight. While both user groups rated the perceived difficulty of SP in a similar range ("fairly hard to do," SMEQ-older users $=$ 35.56, SMEQ-younger users $=$ 39.77), they exhibited almost significant differences (p-value $=$ 0.052) in rating the perceived difficulty of OP (SMEQ-older users $=$ 40.00, SMEQ-younger users $=$ 60.33). Additionally, younger users rated SP to be significantly less difficult than OP ($p = 0.046$) (Table 1). These results indicate that younger users had a more nuanced reaction to text simplification than older users. One possible explanation for these differences in response to text simplification between the two user groups is that older people in our study were recruited from the pool of professionals in a university; hence, they had more exposure to and experience with reading text at the college level. This explanation is consistent with the argument that experience can help people to improve their performance regardless of their age [10, 22, 23]. Another explanation is that younger users tend to exhibit "impatient" viewing behavior; hence, text simplification can help them read text passages more efficiently [3]. We examine the impact of text simplification on viewing behavior in the following sections.

Table 1. Results of SMEQ ratings (Mean, Std. Dev)

	Text passage		
User	OP	SP	OP vs SP
Older	40.00 (18.03)	35.56 (24.85)	t Stat = 0.449, df = 14, P = 0.661
Younger	60.33 (32.10)	39.77 (24.31)	t Stat = 2.103, df = 25, **P = 0.046**
Older vs Younger	t Stat = −2.052, df = 23, P = 0.052	t Stat = −0.432 df = 15, P = 0.672	

4.2 Viewing Behavior

In this section, we report the viewing behavior of older and younger users when they were reading the original or the simplified text passage. We compared user attention to content via three different metrics: average fixation duration, adjusted total fixation duration, and fixation-to-visit duration ratio. Average fixation duration reveals the average lengths of glances with which a stimulus is processed, while total fixation duration reveals the total amount of attention spent on a stimulus. When comparing text passages with different lengths, it is customary to adjust total fixation duration for text length (total-fixation-duration/word-count) [24]. Because simplification typically changes the length of textual passages, we used adjusted fixation duration to examine the viewing behavior of older and younger users for OP and SP.

Visit duration provides information about both fixations and saccades during the time an AOI is processed. Fixation refers to relatively stable gazes that take foveal snapshots of objects that capture our attention. Saccade refers to fast eye movements that change the focus of attention from one fixation to another. Hence visit duration in our study encompasses the total amount of time that is spent to read a passage and to search or change focus during reading. The fixation-to-visit duration ratio reveals the ratio of the AOI visit that was dedicated to reading [1].

Average Fixation Duration. Our analysis showed that older users read both OP and SP with similar average glances (0.219 s for both text passages). The average glance duration for younger users was longer in OP than in SP (0.237 vs. 0.225) but the difference was not significant. On average, younger participants used significantly longer glances when reading OP than their older counterparts ($p = 0.041$). The differences in average glances between younger and older users were not significant when reading SP (Table 2). Consistent with prior research [3] these results show that younger users processed the simplified passage (SP) with shorter glances. These results also confirm the SMEQ ratings for OP and SP that show younger users found SP significantly easier to read than OP while older users did not.

Adjusted Total Fixation Duration. While our analysis showed lower adjusted values when reading SP (compared to when reading OP) for both younger and older users, these differences between OP and SP were not significant (see OP vs. SP in Table 5).

Table 2. Results of average fixation duration (Mean, Std. Dev) for the entire passage

	Text passage		
User	OP	SP	OP vs SP
Older	0.219 (0.022)	0.219 (0.022)	t Stat = 0.029, df = 17, P = 0.977
Younger	0.237 (0.022)	0.225 (0.021)	t Stat = 1.723, df = 29, P = 0.096
Older vs. Younger	t Stat = −2.164, df = 24, **P = 0.041**	t Stat = −0.713, df = 14, P = 0.487	

Our analysis, however, showed that younger users had significantly higher adjusted fixation duration compared to older users when reading OP (p-value = 0.013). When reading SP, the difference in adjusted fixation duration of both the participant groups was not significant, but close (p-value = 0.066, see Older vs. Younger in Table 3).

Table 3. Results of adjusted total fixation duration (Mean, Std. Dev) for the entire passage

	Text passage		
User	OP	SP	OP vs SP
Older	0.250 (0.051)	0.244 (0.086)	t Stat = 0.161, df = 12, P = 0.875
Younger	0.359 (0.143)	0.330 (0.161)	t Stat = 0.568, df = 33, P = 0.574
Older vs. Younger	t Stat = −2.747, df = 18, **P = 0.013**	t Stat = −1.913, df = 27, P = 0.066	

These results are consistent with younger users' higher perceived reading difficulty for OP captured by SMEQ. It is natural to find a higher cognitive activity (e.g., increased fixation intensity) when a task (in this case, reading OP) is perceived as more difficult to do.

We then refined our analysis by examining the attention that was spent to process each AOI. Our analysis did not show significant differences in attention intensity between corresponding AOIs in OP and SP for younger or older users (see OP vs. SP in Table 4). However, when comparing older and younger users' attention to AOIs, our analysis showed that younger users had significantly longer adjusted fixation duration in all 3 AOIs when reading OP (p-values = AOI1: 0.007, AOI2: 0.039, AOI3: 0.027). When viewing the simplified passage (SP), younger users still had longer adjusted fixation duration than older users; but the difference in adjusted fixation duration between the two user groups was only significant for AOI2 (p-value = 0.043). These results suggest that text simplification had a more pronounced impact on younger users. Younger users viewing behavior become more similar to older user behavior in SP (they differed

significantly only in one AOI). Because older users exhibited a more efficient viewing behavior than younger users regardless of which AOI they read, these results indicate that text simplification made younger users' viewing behavior to become more efficient.

Table 4. Results of adjusted total fixation duration (Mean, Std. Dev) for each AOI

AOI 1			
User	Text passage		
	OP	SP	OP vs SP
Older	0.261 (0.065)	0.257 (0.112)	t Stat = 0.089, df = 12, P = 0.931
Younger	0.397 (0.159)	0.353 (0.177)	t Stat = 0.784 df = 32, P = 0.439
Older vs. Younger	t Stat = −3.019, df = 19, **P = 0.007**	t Stat = −1.810, df = 23, P = 0.083	
AOI 2			
	OP	SP	OP vs SP
Older	0.214 (0.041)	0.184 (0.058)	t Stat = 1.310, df = 14, P = 0.211
Younger	0.281 (0.107)	0.282 (0.197)	t Stat = −0.035, df = 34, P = 0.972
Older vs. Younger	t Stat = −2.212 df = 19, **P = 0.039**	t Stat = −2.125, df = 28, **P = 0.043**	
AOI 3			
	OP	SP	OP vs SP
Older	0.212 (0.048)	0.222 (0.067)	t Stat = −0.359, df = 14, P = 0.725
Younger	0.313 (0.152)	0.288 (0.140)	t Stat = 0.504, df = 29, P = 0.618
Older vs. Younger	t Stat = −2.435, df = 17, **P = 0.027**	t Stat = −1.780, df = 28, P = 0.086	

Fixation-to-Visit Duration Ratio. First, we calculated the fixation-to-visit duration ratio for the entire passages. While our analysis did not show significant differences in reading OP vs. SP in each of the two user groups (see OP vs. SP in Table 5), it did show that younger users had a significantly higher fixation-to-visit duration ratio compared to older users when reading OP (p-value = 0.003). Younger and older users' fixation-to-visit duration ratio did not differ significantly when reading SP (p-value = 0.340, see Older vs. Younger in Table 5). Again, these results suggest that text simplification improved younger users reading behavior because it made it to become more like the viewing behavior of older users, who exhibited a more effective reading behavior.

Table 5. Results of adjusted fixation-to-visit duration (Mean, Std. Dev) for the entire passage

	Text passage		
User	OP	SP	OP vs SP
Older	0.830 (0.024)	0.842 (0.035)	t Stat = −0.913, df = 13, P = 0.378
Younger	0.859 (0.021)	0.855 (0.025)	t Stat = 0.511, df = 34, P = 0.613
Older vs. Younger	t Stat = −3.321, df = 22, **P = 0.003**	t Stat = 0.999, df = 11, P = 0.340	

Table 6. Results of adjusted fixation-to-visit duration (Mean, Std. Dev) for each AOI

AOI 1			
User	Text passage		
	OP	SP	OP vs SP
Older	0.834 (0.031)	0.846 (0.039)	t Stat = −0.758, df = 15, P = 0.460
Younger	0.862 (0.021)	0.858 (0.023)	t Stat = 0.522, df = 32, P = 0.605
Older vs. Younger	t Stat = −2.667, df = 19, **P = 0.015**	t Stat = −0.852, df = 10, P = 0.414	
AOI 2			
	OP	SP	OP vs SP
Older	0.843 (0.037)	0.837 (0.034)	t Stat = 0.360, df = 18, P = 0.723
Younger	0.869 (0.027)	0.860 (0.032)	t Stat = 0.894, df = 33, P = 0.378
Older vs. Younger	t Stat = −2.008 df = 20, P = 0.058	t Stat = −1.727 df = 14, P = 0.106	
AOI 3			
	OP	SP	OP vs SP
Older	0.831 (0.026	0.852 (0.031)	t Stat = −1.636, df = 15, P = 0.123
Younger	0.860 (0.024)	0.862 (0.026)	t Stat = −0.279, df = 32, P = 0.782
Older vs. Younger	t Stat = −3.024, df = 23, **P = 0.006**	t Stat = −0.921, df = 13, P = 0.374	

Next, we calculated fixation-to-visit duration ratio for each AOI. We did not find significant differences in fixation-to-visit duration ratio between the two passages' respective AOIs in each user group (see OP vs. SP in Table 6). When comparing fixation-to-visit duration ratio between younger and older users, our analysis showed that younger users had significantly larger fixation-to-visit duration ratios in AOI1 and AOI3 and almost significantly larger ratios in AOI2 when reading OP (p-values = AOI1: 0.015, AOI2: 0.058, AOI3: 0.006). There were no significant differences in reading behavior between the two user groups when they were viewing the simplified passage (SP). These results suggest that text simplification improved younger users' reading behavior by making it more efficient like older users' viewing behavior.

5 Discussion

In this study, we examined older and younger users' viewing behavior when reading text passages that required advanced (college level) reading skills. Hence, we recruited faculty, staff, and students from a university in the United States to participate in our study. We used two text passages that had the same content but were different in grade-level reading. To prepare these text passages for our study, we selected a GRE text passage at 18th grade reading level and simplified it to 12th grade reading level [14]. Our results confirmed that the text passages used in our study were indeed in the difficult reading range for both user groups.

We expected that text simplification would improve the reading experience of both older and younger users in our study. It would improve younger users' viewing behavior because it would help them to read more efficiently. It would improve older users' reading behavior because it would compensate for their age-related cognitive deficits such as slower eye movements [25]. Our results, however, did not show a similar improved reaction to text simplification for both user groups. While younger users found the less complex text passage (SP at the 12th grade reading level) significantly easier to read than the more complex text passage (OP with 18th grade reading level), older users did not perceive SP and OP to be significantly different in reading difficulty. Moreover, younger users perceived the more complex text passage almost significantly harder to read than older users. The differences in reaction to text simplification between younger and older users in our study can be explained by our participants' population. While younger users were recruited from a pool of graduate students, older users were recruited from a pool of faculty and staff, most of whom had masters or doctoral degrees. Hence, the older users in our study were probably more experienced than younger users in reading complex text as part of their daily routine.

Older users' experience in our study can also explain the observed viewing behavior. Our results showed that older users exhibited a more efficient viewing behavior (e.g., shorter average fixation duration, shorter adjusted total fixation duration, shorter fixation-to-visit duration ratio) compared to younger users when reading the more complex passage (OP). When reading the simplified version of the text (SP) viewing behavior of younger users became more like the viewing behavior of older users, more efficient. These results are interesting because they show that compared to younger users, older users have a more efficient reading behavior (read text with shorter glances and spend

more time on reading rather than searching) and that younger users (not both user groups) have a more nuanced reaction to text simplification. These results do not support the cognitive theory of aging [12]. Rather, they support the argument that experience is likely to close age-related cognitive gap, such as differences in information processing speed and reaction time, between younger and older users [10]. In other words, the reason, why older users in our study had lower perceived difficulty scores and showed less intense viewing behavior than their younger counterparts, is experience makes people to get better and more comfortable at tasks. The results together suggest that we are likely to improve viewing behavior for complex text passages for older users through training and for younger users through text simplification.

6 Study Limitations and Future Study

Our study is not without limitations. All participants in our study had at least a college degree. Most of the older participants in our study had advanced higher education degrees, such as masters or doctoral degrees. There is a possibility that a population with lower education levels would exhibit different viewing behavior than the one observed in our study. Our study was limited to participants that were recruited from a technical college campus. Future studies, using a population with a more diverse background and expertise, can help make new discoveries. Similarly, a larger sample size is likely to reveal more nuanced reactions to text simplification.

7 Contribution

Studies show that simplifying textual information can have a significant impact on viewing behavior and, thus, the performance of younger users. However, little work has been done to investigate how older and younger users' viewing behavior may differ in reaction to text simplification for more complex passages. Our results suggest that experience (e.g., through frequent use, education, or training) is likely to minimize age-related cognitive deficiencies that can affect older users' viewing behavior. Our results also show that text simplification is likely to improve younger users' viewing behavior to become more efficient and effective in reading.

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