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Text-to-Speech Technology: Enhancing Reading Comprehension for Students with Reading Difficulty

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Abstract

The aim of this study was to investigate the impact of text-to-speech (TTS) without highlighting, with highlighting, and with increased highlighting rate, on the reading comprehension of children with reading difficulties. Participants read six expository passages under the following conditions: (a) Silent Reading, (b) Reading Aloud, (c) Listening Only, (d) reading with the use of TTS with No Highlighting, (e) reading with the use of TTS with Highlighting and (f) reading with the use of TTS at a Rapid Rate with Highlighting. They answered comprehension questions following each condition. Data were analyzed using a two-tailed paired t-test and a one-way ANOVA. Reading comprehension was significantly higher for the TTS versus No TTS condition. There was no difference in the presentational features. Comprehension scores for TTS with No Highlighting positively correlated with processing speed; Listen Only negatively correlated with read aloud speed. TTS is a useful compensatory reading aid for improving comprehension.

Keywords: assistive technology, text-to-speech, reading comprehension, dyslexia

Introduction

In the recent decades of educational reform, America's public schools have rallied to address reading skills, given the expectations of initiatives such as the No Child Left Behind Act of 2001. This type of initiative has forced students to contend with increasing literacy demands and accelerated instruction in the classroom. Those with learning disabilities and specifically with dyslexia are especially vulnerable in this high-risk environment (Frase-Blunt, 2000). Dyslexia is characterized by difficulties with fluent word recognition, reduced decoding ability, and slow reading rate despite remedial intervention, exposure to written language, and intact intelligence (IDA, 2002). The incidence of developmental dyslexia is determined to be between approximately 10 to 15% of the population in most languages and countries (Fletcher, Lyon, Fuchs, & Barnes, 2007; Youman & Mather, 2012). While students with dyslexia struggle with decoding, this is not necessarily indicative of their comprehension level. However, failure to treat decoding deficits may adversely affect a student's comprehension and ultimately academic success (Flynn, Zheng, & Swanson, 2012). While a Structured Literacy approach (IDA, 2017; Spear-Swerling, 2019) can improve both decoding and comprehension skills, some students will continue to struggle with reading. Therefore, it is imperative that reading aids be comprehensive for students with dyslexia to mitigate the effects of poor literacy skills on academic achievement, self-efficacy, and future success (Undheim, Wichstrom, & Sund, 2011).

While various aspects of reading have been examined in relationship to the challenges that students with dyslexia face, comprehension is the goal of reading and is imperative for school success. Reading comprehension involves constructing and extracting meaning from the text (Snow, 2010). Text comprehension draws upon oral language skills such as vocabulary, grammar, discourse and metalinguistic aptitude, which are necessary for both listening and reading comprehension (Cutting & Scarborough, 2006; Ukrainetz, 2015). Recent literature has also highlighted the importance of intact executive functions for reading comprehension (Sesma, Mahone, Levine, Eason, & Cutting, 2009).
Executive function is a broad term that involves higher-level cognitive abilities that are necessary for independent goal-directed behaviors such as holding and manipulating information in working memory, as well as planning and organizing complex tasks (Denckla, 1989). Increased working memory capacity is linked to improved reading comprehension because of sufficient cognitive resources to simultaneously decode and extract the meaning of words, while recalling previously read information (Sesma et al., 2009). Additionally, Cutting, Materek, Cole, Levine and Mahone (2009) found that participants with specific reading comprehension deficits showed significant weakness in executive function.

Reading fluency, which includes word recognition and decoding, is a fundamental bridge to reading comprehension (Breznitz, 2006; Pikulski & Chard, 2005). Speed in word recognition is one factor that facilitates extracting meaning from text (Torgesen, Rashotte, & Alexander, 2001). Variations in processing speed often determine differences in a student's word recognition (Breznitz, 2006). Literature suggests that efficient processing of orthographic, phonological, and semantic information promotes automatic word recognition and ultimately comprehension (Bowers & Wolf, 1993; Goswami, 1999). Thus, reducing the burden of decoding through instructional aids may be useful in supporting comprehension.

As schools explore ways to boost academic achievement, exploiting assistive technology (AT) to access text is a key approach (Anderson-Inman & Horney, 2007). However, addressing the academic needs of children with disabilities by using AT is not an innovative idea, but rather a federally mandated requirement in the Individuals with Disabilities Education Improvement Act of 2004. This piece of legislation endorsed the benefits of AT by emphasizing that Individual Education Plan teams should consider the use of AT within the child's academic environment (Madlowitz, 2006). Text-to-Speech (TTS) is considered a high-tech AT reading aid (Bouck, 2017). TTS provides readers with audio input as digital text is read aloud with synthetic speech (Anderson-Inman, & Horney, 2007). The aim of this study was to investigate the effective use of TTS features in supporting comprehension in struggling readers.

The potential value of compensatory strategies such as TTS for individuals with reading difficulties is based on learning theories such as Cognitive Load Theory (Pollock, Chandler & Sweller, 2002) and Automaticity Theory (LaBerge & Samuels, 1974). The Cognitive Load Theory purports that learning is best facilitated when information is presented in a way that is efficiently processed in working memory (Chandler & Sweller, 1991). This is especially pertinent to reading because it is a complex task with heavy demands on working memory (Swanson & Siegel, 2001). When word recognition is not automatic, the reading process is slow, placing heavy demands on memory (LaBerge & Samuels, 1974). Slow and labored reading diminishes the ability to address the higher-order processes necessary for comprehending text (Samuels, 1997).

TTS may help reduce cognitive load and increase automaticity for struggling readers. Students using TTS have demonstrated gains in volume of text read while decreasing fatigue and stress (Hecker, Burns, Elkind, Elkind, & Katz, 2002; Hodapp & Rachow, 2010); slower readers have increased reading rate (Elkind, 1998; Sorrell, Bell, & McCallum, 2007); students with learning disabilities have bolstered their reading comprehension (Elkind, Cohen, & Murray, 1993). A longitudinal study of middle school special education students showed a significant positive relationship between use of TTS, reading rate, and comprehension scores (Hodapp & Rachow, 2010). In contrast, Schmitt, Hale, McCallum and Mauck (2010) found no difference between the ability of 25 middle school remedial readers (ages 11 to 15 years) to correctly answer factual and inferential comprehension questions with and without TTS. Despite the lack of information regarding the specific populations who benefit from TTS (Alper & Raharinirina, 2006), Strangman and Dalton (2005) suggest that students with weak word recognition and stronger comprehension skills may benefit more from TTS than students who are weak in both decoding and comprehension.

TTS has several available features such as synchronized highlighting and adjusting the rate of the synchronized voice. Although the previously mentioned TTS studies have typically included TTS with highlighting, (Elkind et al., 1993; Horney et al., 2009; Meyer & Bouck, 2014) and the option to adjust rate to the participant's preference (Elkind et al., 1993; Horney et al., 2009; Izzo, Yurick, & McArrell, 2009; Meyer & Bouck, 2014), the researchers did not examine outcomes related to differences in presentation. In contrast, Sorrell et al. (2007) presented the TTS at a reduced and rapid rate but found no meaningful differences in comprehension when varying the presentation rate. Similarly, Lionetti and Cole (2004) found no differences in fourth and fifth grade poor readers' comprehension related to rate of presentation during listening while reading. More information regarding the executive function abilities related to the beneficial use of TTS presentational features that best support reading comprehension for a specific type of disability is needed (Alper & Raharinirina, 2006; Wood, Moxley, Tighe, & Wagner, 2017). The current study deals with this question.

The aim of this study was to characterize the reading comprehension of children with reading difficulties while using TTS. Specifically, we aimed to determine: 1) if there is a significant difference between reading comprehension scores when reading a passage with TTS compared to without TTS; 2) if there is a significant difference in reading comprehension scores under different TTS conditions (TTS with No Highlighting, TTS with Highlighting, and TTS at a Rapid Rate with Highlighting); and 3) the relationship between reading comprehension scores and executive function abilities when using TTS.

Methods

Participants

Ten 8 to 11-year-old children with reading difficulties (M = 9.36 years, SD = 1.07) participated (8 females, 2 males). The following were inclusion criteria: (a) reading difficulty as measured by scores at or below the 25th percentile on a total of two subtests taken from the following measures: Test of Word Reading Efficiency (TOWRE), (Subtests-Sight Word Efficiency, Phonemic Decoding Efficiency), (Torgesen, Wagner, & Rashotte, 2012); Comprehensive Test of Phonological Processing-Second Edition (CTOPP-2), (Subtest-Elision), (Wagner, Torgesen, Rashotte, & Pearson, 2013); Woodcock Johnson Tests of Achievement-Third Edition (WJ III), (Subtests-Word Identification, Word Attack and Passage Comprehension), (Woodcock, McGrew, & Mather, 2001); Test of Silent Reading Efficiency and Comprehension (TOSREC), (Wagner, Torgesen, & Roshette, 2010); (b) intelligence quotient >85 as measured by the Test of Non-Verbal Intelligence-4th Edition (TONI-4), (Brown, Sherbenou, & Johnsen, 2010); (c) school reported full scale IQ >80 as measured by the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV), (Wechsler, 2003); (d) school reported normal hearing and vision; (e) native speakers of American English; (f) absence of neurological or psychiatric condition. All participants were recruited via flyers during a remedial summer session in a local private school for children with learning disabilities. These participants were recruited as part of a larger study which also investigated reading, eye-tracking, and executive function in children with and without reading difficulties. A neuro-imaging component was included.

Procedure

Behavioral measures. Each participant completed a testing battery that included reading, language, cognitive, and executive function tasks. The following list of testing measures is a comprehensive list that includes the inclusion/exclusion measures as well as additional tests and subtests to further understand the reading profile of each student.

Measures for assessing reading and language. TOWRE (Subtests-Sight Word Efficiency, Decoding

Efficiency), CTOPP-2 (Subtest-Elision), WJ III (Subtests-Word Identification, Word Attack, Passage Comprehension), TOSREC, Peabody Picture Vocabulary Test-Fourth Edition (PPVT-4), (Dunn & Dunn, 2007).

Measures for assessing cognitive ability and executive functions. TONI-4; Wechsler Intelligence Scale for Children-Fourth Edition (WISC-4), (Wechsler, 2003) (Subtests-Processing Speed Index: Digit Span, Coding & Symbol Search); Comprehensive Test of Phonological Processing-Second Edition (CTOPP-2) (Subtests-Rapid Digit Naming, Rapid Letter Naming); Conners 3rd Edition-Parent Survey and Child Self Report Survey (Conners, 2009); Behavior Rating Inventory of Executive Function (BRIEF) Parent Form (Gioia, Isquith, Guy & Kenworthy, 2000).

The test battery was administered to each child individually in a quiet room. The total testing battery lasted approximately two hours (see Table 1 for participant testing results). Students took a 15-minute break after the first hour. The Conners and BRIEF parent surveys were completed at home and returned at the time of the experimental session.

Text-to-Speech Design

This study employed a repeated measures design wherein each subject read the same six passages which were randomized across six conditions: (a) Silent Reading, (b) Reading Aloud, (c) Listening Only with digitized speech and no text, (d) reading with the use of TTS with No Highlighting, (e) reading with the use of TTS with Highlighting and (f) reading with the use of TTS at a Rapid Rate with Highlighting. The independent variable was the six experimental conditions. The dependent variable was the number of accurately answered comprehension questions following each passage.

TTS reading materials. The students read six expository passages derived from the Level 2 Reading Comprehension Cards, (Lingui-Systems, 2007). The mean Flesch-Kincaid Readability Level for the six passages was 4.8 with a range of 4.5 to 5.3 (see Appendix A). All six passages contained 7 to 8 lines of text with a mean of 110 words and a range of 102 to 127 words per passage. Passage length was limited to accommodate the visual field appropriate for collecting eye-tracking data for the larger study. A linguist experienced in child language development reviewed and made modifications to the passages for consistency of total length, sentence complexity, word frequency and cohesion.

TTS software. The six passages were downloaded into TTS software (e.g. Kurzweil 3000TM) on a laptop computer. The Listen Only, TTS with No Highlighting, and TTS with Highlighting conditions were presented at a reading rate set at 150 words per minute (Hasbrouck & Tindal, 2006). The rate for the TTS at a Rapid Rate with Highlighting was set at 225 words per minute, with a 50% increase in rate, as determined to be most comfortable without distorting the synthesized voice. All passages were visually displayed on the computer screen for each condition, except for the Listen Only condition. During this condition, the participant was shown an X on the computer screen while listening to the passage read with a digitized voice.

TTS presentation. The participants completed one experimental session. During the experimental session, the participants read six expository passages under each of the six conditions. Each child was tested individually. The principal investigator (PI) provided scripted verbal instructions to the participant before each experimental condition. The student was instructed to read the passage silently for all conditions except the Read Aloud and the Listen Only conditions. During the Listen Only condition, the child was told to watch the X on the screen as the computer read the passage with the synthesized voice. Each passage was read only once. The text disappeared immediately from the computer screen after the last word was read.

Following the reading of each passage, the participants responded to three comprehension questions in a multiple-choice format (three choices per question) to test their comprehension of each passage in each condition. The test items were read to the children by the PI, and the child had a copy of the written questions and answers. The child gave a verbal response of the answer.

Data Analysis

Behavioral measures data analysis. Group descriptive statistics, including mean and standard deviation, were gathered for all reading, language, cognitive, and executive function measures.

Text-to-speech data analysis. To explore the first research question, the investigators employed a two-tailed paired t-test comparing the comprehension scores as a total of the three NO TTS treatment conditions with the total of the three TTS conditions. For the second question, a single factor analysis of variance (ANOVA) was performed to determine if there was a significant difference among the comprehension scores on the three TTS conditions.

Correlation of behavioral and TTS measures. A Pearson correlation was performed to establish the relationship between participant scores on the behavioral measures and the number of correct comprehension responses under the six experimental conditions.

Results

Behavioral Measures

The mean scores for the participants on each behavioral measure are shown in Table 1.

Reading measures. Children with reading difficulties showed impaired sight word recognition (TOWRE-SWE) and nonsense word decoding (TOWRE-PDE) in a timed condition. They also had difficulty with elision on a phonological processing task. Sentence level comprehension and passage level comprehension were also below average for these children.

Cognitive and executive function measures. The average standard non-verbal intelligence score fell within the average range, while the average processing speed fell within a relatively low range. Executive functions scores were elevated for the probability of attention issues and mildly clinically elevated for working memory. However, the global executive composite score for executive functioning fell within the normal range for these participants.

Table 1: Participant Scores on Behavioral Measures

Behavioral Tests	*M*	*SD*	*Range*
Reading/Language			
CTOPP-2 Elision	7.7	3.12	5-14
PPVT	98.8	8.40	80-112
TOSREC	83.1	12.41	55-99
TOWRE-2 SWE	83.5	12.96	61-95
TOWRE-2 PDE	80.3	10.68	63-95
WJ III SWE	86.9	10.13	62-98
WJ III PDE	89.9	8.06	74-97
WJ III Pass Comp	81.4	14.08	50-101
Cognitive/Executive Function			
CTOPP-2 RLN	6.4	3.34	1-11
WISC-IV PSI	88.4	22.31	50-121
BRIEF-2 GEC	58.0	9.60	41-71
Conner's 3	46.6	2.88	46.99

Note: [1]The following subsets used scaled scores (7-13 average range): Comprehensive Test of Phonological Processing-Second Edition (CTOPP-2) Elision, Rapid Digit Naming (RDN), Rapid Letter Naming (RLN).
[2]The following tests used standard scores (mean of 100): Test of Silent Efficiency & Comprehension (TOSREC); Test of Word Reading Efficiency (TOWRE-2)-Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE) lists; Woodcock Johnson (WJ-III)-Sight Word Efficiency (SWE), Phonemic Decoding Efficiency, Passage Comprehension; Peabody Picture Vocabulary (PPVT); Test of Non-Verbal Intelligence (TONI-4); Weschler Intelligence Scale for Children (WISC-IV)-Processing Speed Index (PSI).
[3]The following tests used Tscores (< 60 average range): Behavior Rating Inventory of Executive Function (BRIEF-2)-Global Executive Composite (GEC); Conner's 3.

Reading Conditions

Comparison of No TTS and TTS conditions. A two-tailed paired t-test was used to compare the comprehension scores as a total of the three No TTS conditions with the total of the three TTS conditions. The independent variable was the six experimental conditions grouped by the three No TTS conditions (Silent Read, Read Aloud, and Listen Only) and the three TTS conditions (TTS with No Highlighting, TTS with Highlighting, and TTS at a Rapid Rate with Highlighting). The dependent variable was the total number of comprehension questions answered correctly after the three passages in the No TTS and TTS conditions. The mean number of comprehension questions answered correctly after each of the six passage conditions and the means for the combined No TTS & TTS conditions are presented in Table 2.

There were no outliers in the comprehension score data set and the assumption of homogeneity of variance was met. A two-tailed paired t-test was performed. There was a significant difference between the mean score for the No TTS (M = 5.7, SD = 2.01) and the mean score for the TTS (M = 7.2, SD = 1.08) conditions; $t(9)$ = 2.26, p = 0.04, showing a medium effect size. Thus, the students showed increased comprehension of the expository passages when utilizing TTS versus when not using TTS.

Table 2: Comprehension Scores for Each Experimental Condition

Condition	*M (out of 3)*	*SD*	*% Correct*
SR	1.6	0.70	53%
RA	2.2	0.63	73%

Condition	*M (out of 3)*	*SD*	*% Correct*
LO	1.9	0.74	63%
Total No TTS (SR + RA + LO)	5.7	1.42	63%
TTS-NH	2.4	0.70	80%
TTS-H	2.4	0.70	80%
TTS-RR	2.4	0.70	80%
Total TTS (TTS-NH + TTS-H + TTS-RR)	7.2	1.03	80%

Note: SR = Silent Read; RA = Read Aloud; LO = Listen Only; TTS-NH = Text-to-Speech with No Highlighting; TTS-H = Text-to-Speech with Highlighting; TTS-HRR = Text-to-Speech with Highlighting at a Rapid Rate

Comparison of TTS conditions. The scores under the three TTS conditions were examined to determine if there was a significant difference in the performance of the students when using specific TTS presentational features.

Table 3: t-Test Results between Comprehension Scores and Experimental Conditions

Conditions	*t*	*p*	*d*
SR & RA	-2.71	0.02	-0.783
SR & LO	-1.00	0.34	0.289
SR & TTS-NH	-2.23	0.05	-0.645
SR & TTS-H	-2.45	0.04	-0.708
SR & TTS-HRR	-3.21	0.01	-0.928
RA & LO	1.00	0.34	0.289
RA & TTS-NH	0.51	0.62	0.147
RA & TTS-H	-0.56	0.59	-0.162
RA & TTS-HRR	-0.80	0.44	-0.231
LO & TTS-NH	-1.86	0.10	-0.538
LO & TTS-H	-1.46	0.18	-0.422
LO & TTS-HRR	1.34	0.21	-0.387
TTS-NH & TTS-H	0.00	1.0	0.000
TTS-NH & TTS-HRR	0.00	1.0	0.000
TTS-H & TTS-HRR	0.00	1.0	0.000

Note: SR = Silent Read; RA = Read Aloud; LO = Listen Only; TTS-NH = Text-to-Speech with No Highlighting; TTS-H = Text-to-Speech with Highlighting; TTS-HRR = Text-to-Speech with Highlighting at a Rapid Rate

The independent variables included the three TTS conditions: TTS with No Highlighting, TTS with Highlighting, TTS at a Rapid Rate with Highlighting. The dependent variable was the number of correctly answered comprehension questions for each passage. A single-factor ANOVA was performed. There was no significant difference among the comprehension scores (M = 2.4, SD = 0.48) resulting from the three TTS conditions; $F(2, 27)$, < 1, p >.05. The mean of the comprehension scores was identical in each of the TTS conditions. Because silent reading is standard practice for gaining information and demonstrating knowledge in school, the Silent Read condition was compared to all other conditions. T-tests revealed a significant difference between Silent Read and all three TTS conditions with better scores under all TTS conditions with medium to large effective sizes. See Table 3.

Correlation between behavioral measures and TTS performance. Participant scores on the behavioral testing were correlated with number of correct comprehension responses under each of the six conditions. Higher comprehension scores were positively correlated with processing speed (WISC-IV, $p < .03$) and negatively correlated with Read Aloud time ($p < .02$). The following correlations were significant: (a) TTS with No Highlighting was positively and strongly correlated $r(8) = .687$, $p < .05$ with processing speed as measured by the WISC-IV. Participants with faster processing speed had increased comprehension using TTS with No Highlighting. (b) Listen Only was negatively and strongly correlated $r(8) = -.736$, $p < .05$ with total Read Aloud time. Faster readers had better auditory comprehension. The remainder of the correlations were not significant. The results are shown in Table 4.

Table 4: Correlations between Experimental Conditions and Behavioral Tests

Conditions	*Test*	*r*	*p*
LO	RA Time	-0.73	≤ 0.015
TTS-NH	PSI	0.68	≤ 0.028
TTS-H	TOSREC	-0.57	≤ 0.081 NS
TTS-HRR	CTOPP-2	0.51	≤ 0.125 NS
LO	CTOPP-2	-0.44	≤ 0.195 NS

Note: No TTS Conditions: SR = Silent Read, RA = Read Aloud, LO = Listen Only; TTS Conditions: TTS-NH = Text-to-Speech with No Highlighting, TTS-H = Text -to-Speech with Highlighting, TTS-HRR = Text-to-Speech with Highlighting at a Rapid Rate; NS = Not Significant. Significance set at p *= 0.01 and* p *= 0.05.*

Discussion

This study examined the impact of Text-to-Speech (TTS) on the reading comprehension of students with reading difficulties. We found that using TTS was related to higher reading comprehension scores compared to not using TTS, but the specific presentational features of TTS were not related to increased comprehension. The correlation between behavioral testing measures and the six experimental conditions was also examined. Children with faster processing speed showed better comprehension following the use of *TTS with No Highlighting*. Faster readers had better auditory comprehension as evidenced by their performance on *Listen Only.*

Use of TTS

The results show that TTS was beneficial in bolstering the reading comprehension of these struggling readers. Comprehension scores were better than Silent Read under all TTS conditions. These findings corroborate results of previous studies that point to the effectiveness of this compensatory reading strategy (Elkind et al., 1993; Hecker et al., 2002; Hodapp & Rachow, 2010; Izzo et al., 2009; Meyer & Bouck, 2014). The successful use of TTS has been broadly based on cognitive theories such as the Cognitive Load Theory which denotes that information should be delivered in a way that reduces unnecessary load on working memory (Chandler & Sweller, 1991). This is especially important while reading, because struggling readers often have difficulty with working memory (De Jong, 1998; Swanson & Siegel, 2001). It is understood that oral reading fluency is a marker of overall reading competence (Fuchs, Fuchs, Hosp, & Jenkins, 2001). Automaticity Theory states that as the reading of words becomes more automatic, fewer cognitive resources need to be apportioned to this task, so more energy can be designated to comprehension (LaBerge & Samuels, 1974). If using TTS can reduce labored decoding, more cognitive resources can be allocated to comprehending the text.

Presentational Features of TTS

The results demonstrate no differences in the reading comprehension scores related to specific presentational features of TTS. The mean numbers of correct responses in the TTS with No Highlighting, TTS with Highlighting, and TTS at a Rapid Rate with Highlighting conditions were exactly the same. As such it is not possible to determine which features associated with TTS may be most helpful in supporting reading comprehension for students with reading difficulties. Although we could not specify which features were most beneficial, the results of this study demonstrate that there is something valuable about TTS that is helping children read and comprehend more successfully. The one feature in common with all the TTS conditions is that the student had auditory input to supplement the visual text. This suggests that the addition of auditory input may be the key factor in enhancing reading comprehension using TTS.

While the presence of auditory input across all TTS conditions suggests the benefit of that component, the possible role of other features such as highlighting or rapid rate is still not clear. The Modality Principle (Low & Sweller, 2005) suggests that spreading the cognitive load across the auditory and visual aspects of working memory may have contributed to the overall difference between the TTS and No TTS conditions. This inclusion of both auditory and visual modalities may be adequate for reducing cognitive load. The specific visual (no highlighting, highlighting, and highlighting at a rapid rate) and auditory (normal rate and rapid rate) presentations may not add further benefit. However, passage length may be a factor in increasing cognitive load. The passages in this study averaged 110 words in length, which may not have challenged cognitive load sufficiently to delineate how particular features may contribute to assisting with comprehension of larger volumes of text.

TTS at a Rapid Rate with Highlighting was included as a condition because an accelerated reading rate has been found to be beneficial to children with reading difficulty (Breznitz, 1987; Horowitz-Kraus & Breznitz, 2013; Horowitz-Kraus, Cicchino, Amiel, Holland, & Breznitz, 2014). The TTS at a Rapid Rate with Highlighting condition was established to better understand the connection between processing rate and reading success. No differences were found between the performance of participants during the TTS conditions at a typical rate versus TTS at a Rapid Rate with Highlighting. These findings are similar to those of Sorrell et al. (2007), but diverge with those of Breznitz (1987), who found a positive relationship between faster rate and increased comprehension for first graders. The different results may be related to the higher language and content demands of upper elementary text. In contrast to the current study, participants in the Breznitz study were beginning readers and were not identified as students with reading difficulties. The struggling readers in our study may not have the resources to increase comprehension with a faster rate as did the typical first graders. Without further research, the impact of rate of TTS presentation on comprehension is unclear.

Correlations Between Reading Conditions and Behavioral Testing

Additional insight regarding the effect of the presentational features on reading comprehension may be gathered through examining their relationship to other characteristics of the readers such as executive function and processing speed. Processing speed as measured by the WISC-4 Processing Speed Index was not correlated with comprehension scores following reading while using TTS at a Rapid Rate with Highlighting. It would seem logical that the speed at which a student can process information would impact their comprehension of text delivered at a faster rate since it is in line with theories regarding the beneficial effect of fluency on reading comprehension (Breznitz, 2006). The highlighting may have been too fast to be facilitative or may have been distracting to the readers. Further research is needed to understand this relationship. However, students with a faster processing speed as measured by the WISC-IV Processing Speed Index had more success with TTS when it was not combined with the highlighting feature. It seems plausible that they would want to read at their own comfortable rate, which may be faster than the highlighting, which was set at (150 WPM).

The relationship between the *Listen Only* condition and the time required to read one of the expository fourth grade passages used in this study indicates that the faster readers had better auditory language comprehension. This conveys a connection between spoken and written language comprehension, which is broadly supported in the literature (Catts, 1993; Kim, Park, & Park, 2015). Because this study did not include a listening comprehension measure as part of the testing battery, the relationship between ability to process spoken language and decoding speed cannot be explored further. This is an important link to consider. Previous findings report that poorer readers are also poorer listeners and show more diffused brain activation when listening (Horowitz-Kraus, Buck & Dorrman, 2016). Listening comprehension is critical for TTS to be useful.

Limitations and Future Research

This study has several limitations that may reduce the generalizability of the data. Participants included a small number of children who were available through a summer academic support program. The group was lacking in racial and socioeconomic diversity. Due to the small sample size the results can best serve as suggestions for what type of relationships might be obtained with a larger sample size and a more focused design. The statistical analysis employed with this data set was parametric in nature (ANOVA, t-tests). Considering the smaller sample size contained in this study, the use of non-parametric equivalents may be considered a more common approach to the statistical analysis. However, non-parametric statistics could be more problematic with a small sample size, since they often have inferior power when compared to analogous parametric statistics for a given situation.

The stimulus materials included expository passages that were short in length with a small number of comprehension questions (3). Longer passages would more closely represent the volume of text that students are typically expected to read, and thus would provide more realistic challenges to their reading comprehension skills and perhaps allow for the potential benefits of different presentational features to be evidenced. Longer passages would also accommodate more questions per passage to provide a greater range of scores to facilitate statistical analysis and reduce error due to guessing.

Future research could incorporate a measure of spoken language skills, especially listening comprehension, in order to examine the relationship between listening comprehension and reading comprehension scores when using TTS. Students with reading difficulties often have concomitant disabilities such as Attention Deficit Hyperactivity Disorder (ADHD). Future studies could further examine the relationship between attention and reading comprehension. Incorporating eye-tracking data during the reading task may give information regarding the child's attention to the text as well as other reading behaviors.

Outcomes and Benefits of AT

The results of this study substantiate previous research in validating the effectiveness of TTS in augmenting the reading comprehension of children with reading difficulties. This outcome is critically important in advocating the role of assistive technology, specifically TTS, as an effective compensatory reading strategy for struggling readers. Increasing reading comprehension with TTS allows students with reading difficulty to not only access but also comprehend text that is more commensurate with their typical peers. This has positive implications in overall academic success, self-esteem, and self-efficacy. While the results were inconclusive for which presentational features best support the reading process for this population, correlations between specific behavioral measures (i.e., processing speed, reading rate) and comprehension resulting from specific presentational features were found to help guide further research.

Target Audience and Relevance

This study has relevance for educators, special education educators, speech-language pathologists, assistive technology specialists, and faculty in higher education. Discussion of specific TTS features, such as highlighting and reading rate, may also inform future studies and clinical practices for both children with developmental disorders and adults with acquired disorders (e.g., aphasia, traumatic brain injury).

Declarations

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