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Melissa Oberembt
University of Northern Iowa

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The effects of text-to-speech on students with reading disabilities

Abstract

Text-to-speech (TTS) is becoming a common accommodation/support for students with reading disabilities to improve reading skills. This review examines the effects TTS has on reading comprehension, reading rate, written language, as well as the social validity of students with reading disabilities and other print disabilities. Twenty-eight peer-reviewed studies published between 2002 and 2019 were selected for analysis in this review. The reviewed research indicates that reading rate increased, while reading comprehension had mixed results, and writing skills did not significantly improve when TTS was used. Research also confirmed the social validity of TTS. Future research into the effects of TTS was recommended.

The Effects of Text-to-Speech on Students with Reading Disabilities

A Graduate Review

Submitted to the

Division of Instructional Technology

Department of Curriculum and Instruction

In Partial Fulfillment

Of the Requirements for the Degree

Master of Arts

UNIVERSITY OF NORTHERN IOWA

by

Melissa Oberembt

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EFFECTS OF TEXT-TO-SPEECH ON STUDENTS

This Review by: Melissa Oberembt

Titled: The Effects of Text-to-Speech on Students with Reading Disabilities

has been approved as meeting the research requirement for the
Degree of Master of Arts.

7/30/2019
Date Approved

Dr. Leigh Zeitz
Graduate Faculty Reader

7/30/2019
Date Approved

Dr. Deborah Tidwell
Graduate Faculty Reader

7/30/2019
Date Approved

Dr. Robin Dada
Head, Department of Curriculum and Instruction

EFFECTS OF TEXT-TO-SPEECH ON STUDENTS

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Text-to-speech (TTS) is becoming a common accommodation/support for students with reading disabilities to improve reading skills. This review examines the effects TTS has on reading comprehension, reading rate, written language, as well as the social validity of students with reading disabilities and other print disabilities. Twenty-eight peer-reviewed studies published between 2002 and 2019 were selected for analysis in this review. The reviewed research indicates that reading rate increased, while reading comprehension had mixed results, and writing skills did not significantly improve when TTS was used. Research also confirmed the social validity of TTS. Future research into the effects of TTS was recommended.

Keywords: *text-to-speech, students with disabilities, reading comprehension, reading rate, writing skills, social validity*

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Introduction

Walk into a secondary language arts classroom where students have just been handed an article they are expected to read, annotate, and then discuss the information presented. Now imagine being one of the 10-20% of students in that classroom who Lyon (1999) described as struggling with reading (as cited in Lange, McPhillips, Mulhern, & Wylie, 2006, p. 13). Increasingly, a common support the teacher can leverage is to provide the student with a text-to-speech (TTS) or a speech synthesis tool. Text-to-speech tools are programs that allow individuals to listen to printed material, read aloud by a synthesized voice or human recorded voice while the passage is highlighted on the screen to allow the reader to follow along. According to Lange et al. (2006), “speech synthesis is a tool that reads aloud computer-based text using digitized or synthesized speech” (p. 14). However, does this tool really help the student? The purpose of this literature review is to examine the research related to the effects TTS tools can have on students with reading disabilities and other print disabilities. For the purpose of this literature review, the terms speech synthesis or text-to-speech are used interchangeably.

According to the National Center for Educational Statistics, approximately 34% of students served under the Individuals with Disabilities Education Act (IDEA) during the 2015-2016 school year has a “specific learning disability” (SLD). Of those with a specific learning disability, it is estimated by Shaywitz (2003) that 80% are students with a reading disability. The reauthorization of the Individuals with Disabilities Education Act in 2004

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states that schools must provide accessible instructional materials in specialized formats such as audio, braille, digital, and large print to students with a print disability. This federal requirement has led to the development of a variety of technologies including TTS software to assist schools in providing these accommodations to students with reading and print disabilities.

A reading disability can be defined as difficulty in reading ability (Forgrave, 2002; Shaywitz, 2003). This could mean laborious or errorful decoding or lack of comprehension (Forgrave, 2002). As Shaywitz (2003) says in her book, *Overcoming Dyslexia*, dyslexia and reading ability or disability are much like other disorders. They are on a continuum where the cut-off for dyslexia is “based on an artificial cutoff point.” (p. 28) such as a certain score on a standardized assessment. This means that many students may struggle with reading or have a reading disability, but may not meet the diagnostic criteria for dyslexia. Many other disorders impact one’s ability to read as well (Shaywitz, 2003). The controversy surrounding the term disability in the literature often focuses on the conflict between the medical model of disability as physical or mental impairment and the social model that argues against the isolation or labeling of physical and mental differences within a social context resulting in intentional segregation that limits participation by those labeled as disabled (Altman, 2001). In addition to the broader term of disability related to reading, the more focused term of dyslexia is debated in the literature as well. The International Literacy Association (ILA) published a research advisory in 2016 that provides some cautions regarding overgeneralizing dyslexia. They argue that research evidence rebuts the notion of a large percentage of young readers with reading difficulties, suggesting that effective and appropriate early literacy instruction results in a small percentage of students continuing with

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difficulty in later grades (Vellutino, Scanlon, & Lyon, 2000). In addition, ILA (2016) states that “the nature and causes of dyslexia, and even the utility of the concept, are still under investigation” (p. 2). They cite the work of Mathes et al. (2005) on examining the effectiveness of specific approaches to instruction for students labeled as dyslexic, with a caution that no one method for teaching children has been found to be most effective. Despite the controversy over the terms dyslexia and reading disability, the literature on technology that is designed to enhance and support those labeled with such difficulties provides insights into possible support for these students. For the purpose of this literature review, reading disability, dyslexia, and reading difficulty were all examined.

The reviewed research related that the effects of TTS support on students with reading difficulties vary in a number of ways based upon age, primary qualifying factors of participants, type of research, and TTS tool used. The research spans elementary (third grade) through adult learners. All the literature included students who struggled in reading or had a diagnosed reading disability, but some researchers looked at other qualifying factors such as attention deficit hyperactivity disorder (ADHD), diagnosed with a specific learning disability (SLD), or qualified for special education services through their IEP. Much of the research involved intervention procedures and treatment designs, but some literature also included a mixed-methods design where students were interviewed about their perceptions of the TTS tool and support, as well as single case withdrawal design.

With many schools implementing technology initiatives such as 1:1 computing, it is imperative to examine the effects that instructional supports such as TTS may have on students with disabilities in order to provide them with the best possible support to facilitate their learning. The results from this review can be used to guide special education teachers,

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general education teachers, parents, and accessibility coaches/strategists in determining if TTS support would be beneficial for their students. In examining the literature, four themes became most prevalent: 1) the effects of TTS on reading comprehension, 2) the effects of TTS on reading fluency or reading rate, 3) the effects of TTS on written language skills, and 4) the social validity of TTS use by students.

Methodology

Research for this literature review began by searching the ERIC and Ebsco databases through access provided by the University of Northern Iowa's (UNI) Rod Library. ERIC and Ebsco were used because they provided me with the ability to search education-related articles and limit the results to scholarly, peer-reviewed journals and research reports. I also used Google Scholar to ensure that I had found as many relevant articles as possible.

Search terms used included: *reading disabilities, dyslexia, reading difficulties, text-to-speech, assistive technology, effects, reading comprehension, reading fluency, read-aloud accommodation, reading rate, writing skills, and speech synthesis*. In addition to using these terms alone, I applied Boolean search qualifiers such as OR and AND to help find as many relevant articles as possible. When I found an article that met my broad filter criteria, I used ERIC to download full-text versions, (if available). Many articles had to be obtained through an inter-library loan. After conducting an initial database search, I used the *backward snowball method* of looking through the references cited in related articles to find more possible relevant articles. This allowed me to find other research reports cited in the references of selected articles that were related to the effects of text-to-speech and its use with students with reading disabilities. This method proved useful in finding approximately 15 additional relevant articles.

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To select the sources that would be analyzed for this literature review, I used various criteria. First, the articles needed to be related to the topic of text-to-speech and its use with students with disabilities, be peer-reviewed and be primary source research. To determine if the articles fit these broad filters, I read through the abstract of each article and quickly scanned through the rest of the text. Articles that did not fit these criteria were excluded from this review.

After this initial examination, I decided to refine my inclusion criteria and further evaluate the articles. An additional criterion that was used was to give preference to the most recent research articles due to the fast pace that technology continues to evolve and improve. The articles for this review were published between 2002-2018. Another criterion used was to examine articles that were written by authors who were widely referenced by other authors in the field of assistive technology and other relevant articles. The final criterion that I used to refine my search was to examine articles published in journals that were related to special education, assistive technology, and literacy.

Analysis and Discussion

As teachers around the world work to make their classrooms more inclusive and universally-designed places to learn, text-to-speech is one way that they are attempting to accomplish this goal. This causes one to wonder what effect does text-to-speech have on students with reading difficulties. Does it improve a student's reading comprehension? Does it increase a student's reading rate? How does text-to-speech affect a student's writing? Is it a socially valid tool? This review will explore the effects of text-to-speech on reading comprehension, effects on reading rate or fluency, effects of text-to-speech on writing skills, and its social validity.

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Effects of Text-to-Speech on Reading Comprehension

Merriam-Webster defines comprehension as “the act or action of grasping with the intellect” or “the capacity to understand fully” (Comprehension, n.d.). As such, reading comprehension would be the act of, or ability to grasp or fully understand information communicated through text. Reading comprehension skills are typically measured by answering a set of literal or inferential questions about a passage, or through a retelling of what the person read. The research considered in this review examines the effects of text-to-speech on reading comprehension using both post reading comprehension questions and post reading retelling to determine whether students showed an improvement in reading comprehension after using text-to-speech tools. These studies showed a variety of results. Some studies showed that students using TTS saw an improvement in their reading comprehension measures (Coleman, Kildare, Bell, & Carter, 2014; Izzo, Yurick, & McArrell, 2009; Lange et al., 2006; Moorman, Boon, Keller-Bell, Stagliano, & Jeffs, 2010; Park, Takahashi, Roberts, & Dellse, 2017; Schneps, et al., 2019; Young, Courtad, Douglas, & Chung, 2018), some showed no improvement in reading comprehension after using TTS (Harvey, Hux, & Snell, 2013; Hecker, Burns, Katz, Elkind, & Elkind, 2002; Meyer & Bouck, 2017; Schmitt, Hale, McCallum & Mauck, 2011; Sorrell, Bell, & McCallum, 2007; Tanners, McDougall, Skouge, & Narkon, 2012), and a few other studies showed mixed results of improvement in reading comprehension measures (Camardese, Morelli, Peled, & Kirkpatrick, 2012; Dolan, Hall, Banerjee, Chun, & Strangman, 2005; Floyd & Judge, 2012; Gonzalez, 2014; Grunèr, Östberg, & Hedenius, 2018; Higgins & Raskind, 2004; Keelor, Creaghead, Silbert, Breit-Smith, & Horowitz-Kraus, 2018; Schmitt, McCallum, Hennessey, Lovelace, & Hawkins, 2012; Stodden, Roberts, Takahashi, Park, & Stodden, 2012).

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Improvement. Though the research measured reading comprehension in a variety of ways, seven studies (Coleman et al., 2014; Izzo, et al., 2009; Lange et al., 2006; Moorman, et al., 2010; Park, et al., 2017; Schneps, et al., 2019; and Young, et al., 2018) concluded that students who used TTS tools showed improvement in the area of reading comprehension. These studies showed much variety in the number of participants, their ages, as well as the tool used to measure the participants' reading comprehension.

Moorman et al. (2010) conducted a single-subject ABAB withdrawal research study with two high school-aged students diagnosed with a specific learning disability in the area of reading. Within this study, participants were asked to read a passage and answer 20 comprehension questions about what they had read. Data collected while not using TTS served as a baseline to which researchers compared TTS-utilizing treatments in order to measure its effect on reading comprehension. Moorman et al. (2010) found that the using TTS increased each participant's comprehension accuracy 5.87-7.0 percentage points, a group average of 6.43 percentage points, or 9% overall. While this was not statistically significant, each participant did show improvement in reading comprehension.

In a slightly larger study, Coleman et al. (2014) examined the effect of TTS support on four college-aged students' reading comprehension, measured by answering literal and inferential questions when the TTS support was used to read a passage at speeds faster than the students read independently. The researchers used an alternating treatment design, where participants read college-level passages under three different conditions: no TTS support, TTS support where text was read at a speed 25% faster than each student read independently during baseline data collections, and TTS support where text was read at a speed 75% faster than each student read independently. Conditions were selected by random assignment and

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varied between sessions. Participants were then asked to answer literal and inferential questions about the passages. This study showed that all participants saw an improvement in reading comprehension when they listened to a computer model read a passage 75% faster, but three of the four participants were able to answer more literal and inferential questions correctly when they listened to a computer model reading the passage 25% faster. The most significant improvements in students' reading comprehension scores were seen with the 25% faster TTS than independently or when they listened to the passage read 75% faster. These are interesting results, but there were only four participants.

A recent, similar but smaller study by Young et al. (2018) demonstrated that TTS had a moderate effect on three of four ninth-grade participants of the study. All participants in this study were diagnosed with a specific learning disability, with one participant also diagnosed with having Attention Deficit Hyperactivity Disorder (ADHD) and another diagnosed with autism. Students were asked to read with and without TTS in a single-case ABAB withdrawal design. Through this design, students would read a passage without TTS as a baseline, then with TTS. Researchers collected comprehension data when they withdrew the treatment support and then conducted a second treatment (with TTS) phase. Maintenance sessions were also conducted once a week for four weeks to see if the results continued past the end of the study. As a result of this study, all participants showed improvement ($p = .01$) and the lowest readers made the most gains.

Izzo et al. (2009) conducted a slightly larger reversal design study with 7 high school students who received special education services in the area of reading to determine the functional effect of TTS on the participants' progress in a classroom curriculum. Students were asked to complete 10 units of a transition curriculum, alternating the use of TTS with

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the non-use of TTS for each unit. In the middle and at the end of each unit, students were given a 10-question quiz to assess their comprehension of classroom materials. Also at the end of each unit, the students were asked to read a separate passage and answer a five-item reading comprehension assessment related to the unit content. The data indicated that on the unit quizzes, most participants saw improvement on units when they used TTS (effect size 0.88). On the reading comprehension assessments, all participants showed improvement with the use of TTS. (effect size = 1.3) These large effect sizes show that using TTS had a large positive effect on the students' reading comprehension.

Schneps et al. (2019) examined the effect of TTS on the reading comprehension of 43 college-aged students, with and without disabilities, in an experimental design. In this study, students were asked to read a passage using four modalities (paper, visual, audio, and combined) and to answer four multiple-choice questions related to the passage. The speed at which the TTS read was determined in pre-reading assessments, where the student chose the speed they were confident they would comprehend the information at 95% or better. The researchers found that if the speed of the TTS was kept the same at 290 wpm throughout modalities, then visual presentation produced the best comprehension results. The researchers also found that students who were identified as dyslexic performed better on comprehension assessments in the visual modalities than those students identified as typical.

In a larger study, Lange et al. (2006) showed that speech synthesis support could improve students' reading comprehension. In this study, these participants used advanced tools (spellchecker and thesaurus) within Microsoft Word in addition to the TTS. The control group used no extra supports and showed no significant improvement. The researchers used a two-factor mixed design with 93 secondary level students from Ireland,

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where students were given a pretest, trained on specified tools, and given a post-test to monitor the effects of the support. Researchers in this study also concluded that students with below-average to average IQs benefited most from the accessibility software and TTS tools.

While the study completed by Lange et al. (2006) showed significant improvement using assistive technology software and speech synthesis in a larger study, Park et al. (2017) have more recently, and with a larger population, replicated similar results. In this experimental design study, 164 ninth-grade students who received special education services, and who read significantly below their grade level peers, used TTS support through a program called Kurzweil 3000 (Park et al., 2017). Through the statistical analysis, TTS seemed to show a significant effect on reading comprehension. One unique aspect of this study is that TTS support was not provided during the pre-test or post-test, but instead while the students were being asked to read course material as a part of this study. This means the improvement in reading comprehension scores seen in this study shows that the use of TTS during reading can improve a student's ability to comprehend when they are asked to read unassisted.

No Improvement. As with research in almost any topic, six studies have also concluded that text-to-speech showed no significant improvement in students' reading comprehension (Harvey, et al., 2013; Hecker, et al., 2002; Meyer & Bouck, 2017; Schmitt, et al., 2011; Sorrell, et al., 2007, Tanners, et al., 2012). All of the studies were relatively small

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in regards to the number of participants, ranging from one to 20. However, they varied greatly in the age of the participants, including participants from elementary age to adults.

One such study was conducted by Tanners et al. (2012). This study brings an interesting perspective to the knowledge base because the first author is the only participant in this single case study of a doctoral student with a learning disability. During the alternating treatment design, the participant would read a chapter of the required reading and then take a comprehension quiz related to the material he had read. He alternated reading one chapter with TTS audio support and another similar chapter reading alone without support. Through this model, he found that comprehension was slightly higher in the read alone condition ($M_{RA} = 7.33$ correct responses versus $M_{RL} = 5.50$ correct responses). The effect size was 1.02, which shows that this participant's comprehension was better when he read the material without the use of TTS.

Harvey et al. (2013) also explored a single participant case study where they examined the effects of TTS on reading comprehension for an adult with cognitive impairment and aphasia. The authors looked at three conditions: no TTS, TTS at a listening rate similar to that of neurotypical peers, and slow TTS where the TTS read the material at a rate comparable to that of the silent reading speed of the individual. The data in this study indicated a slight increase in the individual's comprehension accuracy with the use of TTS, but the differences between conditions showed no statistically significant due to the small sample size [$F(2, 35) = 0.9, p = .387$].

In a slightly larger study, Sorrell et al. (2007) examined the use of TTS with 12 elementary-aged students who had been identified as reading below grade level using Accelerated Reader (AR) passages and quizzes. The authors found that there was no

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significant difference in comprehension between readers who read independently and those who used computer-assisted TTS using multivariate F method [$F(1,10) = 2.41; p = .15$]. Interestingly, the faster readers' performance on comprehension measures decreased when they used the TTS support, while slower readers yielded similar results under both TTS conditions as well as reading independently.

Another such study by Meyer and Bouck (2017) used a single case alternating treatment method with four seventh-grade students, identified as having learning disabilities in reading, to examine the effects of text-to-speech on students' reading comprehension. This study found that there was a lack of effect or only a small questionable effect on students' reading comprehension when students used TTS. The authors also found that there was little to no benefit of TTS when using synthesized speech versus text read by human audio.

A larger study by Schmitt et al. (2011) looked at the effect of text-to-speech on 25 sixth- to eighth--grade students who were enrolled in a general education remedial reading class. All participants independently read significantly below grade level but were not necessarily diagnosed with a reading disability. Students in this study completed similar tasks to those in Coleman et al.'s (2014) study, where they were asked to read three passages and answer 10 questions (five inferential and five literal) about each passage. During one of the sessions, the students would listen to the passages being read aloud while they followed along on the screen, and during the other session, they were asked to read the 3 passages silently. This study concluded that there was no significant difference in the performance between students who listened while they read versus when they read the passages silently. The authors of the study claim that just accommodating poor decoding skills with text-to-speech alone is not enough to improve a students' reading comprehension.

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The largest study to show that TTS provides no statistically significant improvement was conducted by Hecker et al. (2002). This study used 20 college-aged students with a formal diagnosis of ADHD in an experimental design. Five of the participants also had a diagnosed reading disability or had documentation supporting a reading disability. The procedure for this study had multiple components. First, students took a self-assessment about their reading habits, then they participated in the independent reading component in the places they typically study, both with and without TTS. Nelson-Denny Reading Comprehension Tests were administered between the assisted and unassisted independent reading sessions. The students then participated in extended, observed reading sessions, with and without TTS, finishing with a student questionnaire. The average comprehension score between unassisted Nelson-Denny Reading Comprehension Test and the TTS assisted Nelson-Denny Reading Comprehension Test was unchanged. Also, while 65% of participants thought the TTS improved their comprehension, only 40% of participants actually saw an improvement in their comprehension.

Mixed Results. While some studies (Coleman et al., 2014; Izzo et al., 2009; Lange et al., 2006; Moorman et al., 2010; Park et al., 2017; Schneps et al., 2019; and Young et al., 2018) showed that TTS improves students' performance in the area of reading comprehension, yet others (Harvey et al., 2013; Hecker et al., 2002; Meyer & Bouck, 2017; Tanners et al., 2012; Schmitt et al., 2011; Sorrell et al., 2007) concluded that TTS did not improve students' reading comprehension. Still a third group of nine studies showed that TTS improved reading comprehension for some specific students, while it did not improve other specific students' reading comprehension (Camardese, et al., 2012; Dolan, et al., 2005;

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Floyd & Judge, 2012; Gonzalez, 2014; Grunèr, et al., 2018; Higgins & Raskind, 2004; Keelor, et al., 2018; Schmitt, et al., 2012; Stodden, et al., 2012).

In a small alternating treatment experimental design study, Schmitt et al. (2012) examined the use of TTS in the form of a reading pen, on three college-level students with reading disabilities. Participating students were asked to read college-level passages silently, as well as read the passages using the reading pen to decode the passage and decode and define unknown words. Students use a reading pen by scanning the text they would like to hear read aloud. The pen uses optical character resolution to read the selected text aloud. While one participant saw an essentially large effect size, the other two participants showed a negligible effect of the TTS support provided by the reading pen. The results also showed that for two of the participants, the use of the reading pen slowed their reading down and did not improve their reading comprehension. The authors also noted that the participant who saw the largest growth in comprehension was also the student with the greatest disability.

In a slightly larger, ‘multiple baseline across participants design-mixed methods’ (Floyd & Judge, 2012, p. 53) study involving six college-level students identified with a specific learning disability, Floyd and Judge (2012) found that when using percent of non-overlapping data points to analyze, two-thirds of students showed a moderate effect, while one-third of the students showed marginal to no effect on reading comprehension. This means that for two-thirds of the students, a majority of their reading comprehension scores fell above the highest baseline score. The percent of non-overlapping data points scores above 85% were considered to be highly effective, and scores between 65% and 85% percent were considered moderately effective (p. 56). However, when the authors analyzed the data using the improvement rate differences, only one-third showed improvement rates of 50% or

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had a moderate effect on reading comprehension, meaning that only one-third of students in this study had reading comprehension scores above their baseline 50% of the time. Two-thirds of the participants showed only slight to limited differences in improvement.

Conversely, Dolan et al. (2005) examined the use of TTS with 15 eleventh and twelfth graders on standardized assessments, yet yielded similarly mixed results. The authors of this study found that participants performed better overall using the TTS feature than on the paper version of the assessment. When they compared performance on longer passages and shorter passages, they found that students performed better using the TTS on longer passages (effect size =0.6), but subsequently performed worse using the TTS on shorter passages (effect size =0.29). They also noted that all students who were considered “low average” (p. 17) readers performed better using the TTS on the assessment.

A slightly larger study by Gonzalez (2014), involving 17 third and fourth-grade students with IEPs and receiving reading instruction, measured both how well the students could retell the stories and how they did on a post reading multiple choice quiz about the story. Participants were presented text in three formats: eBooks with full TTS support; eBooks with vocabulary definitions and single word TTS; and traditional print books. It was found that when students used full TTS support, the eBook students had higher retelling scores than when students used single word TTS support. The authors also noted that there was a significant difference in oral retelling scores across formats. However, when the same TTS supports were used, there was not a statistically significant improvement when students were asked to answer multiple-choice questions about the eBook they had read.

Keelor et al. (2018) examined the effects of TTS on 29 school-aged (aged 8-12 years old) students with disabilities in a correlational design study. Participants were assessed and

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evaluated based on their reading and language skills, as well as executive functioning skills. They were then asked to read passages under five conditions: silent reading, reading aloud, listening to TTS with no highlighting, listening to TTS with no text presented, and listening to TTS while viewing highlighted text. Keelor and his colleagues concluded that those students with better reading and language skills had better comprehension when TTS was used, while those with fewer reading and language skills, did not benefit from the use of TTS. Those with higher executive functioning skills performed better when listening with no text, or reading text only, thus demonstrating that TTS may not be beneficial for these students.

Comparable to results achieved in Schmitt et al.'s (2012) study, Higgins and Raskind (2004) explored the use of TTS features in a reading pen on reading comprehension assessments, with 30 school-aged students with reading disabilities, and also achieved mixed results. Through analysis, the researchers found that the conditions were statistically significant ($p < .0001$) and that students performed better on the assessments when using the reading pen versus when they did not use the reading pen. While overall the reading pen showed benefit to students, there was also a significant inverse correlation between scores obtained from silent reading and the amount of improvement in scores with TTS. Those with low unassisted scores showed the most growth using TTS, while those with high silent reading scores showed no growth, or poorer scores while using TTS.

In a slightly larger pilot study of 35 students and an even larger second pilot study of 69 participants, Stodden et al. (2012) examined the effects of TTS on high school students' reading comprehension in a mixed-method study. In both pilot studies, students were administered the Nelson-Denny reading comprehension test prior to use of the TTS software,

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and after they had used the TTS to complete in-class readings. In the pilot, researchers found that unaided reading comprehension did not significantly change. However, in the full study, researchers found significant improvements in students' reading comprehension over time $t(9) = 3.481; p = .007$.

Grunèr, et al. (2018) also found mixed results when they examined the effect of TTS on 49 third through ninth-grade students with reading and attention disabilities. This study presented a randomized crossover design where students were divided into two age groups, and then two experimental groups and provided one of the treatment conditions (either TTS or no TTS), tested, and then given the opposite treatment condition and tested again. The majority of students (71%) in this study showed an increase in reading comprehension with TTS support. Students in the older age group, who had more severe attention deficit hyperactivity disorder (ADHD), showed more improvement over those with less severe ADHD symptoms. In the younger group, students with less severe ADHD saw more improvement over those with more severe ADHD symptoms. A larger increase in reading comprehension was seen overall in the younger grades, and older grade students had a non-significant increase overall. While most saw an improvement, 29% of students saw a decrease in reading comprehension when they used TTS support. The authors noted that these students had significantly higher reading comprehension scores, to begin with. It was also noted that of the younger students that saw a decrease in their reading comprehension scores, they scored higher on the ADHD symptom assessment, whereas older students who saw a decrease in reading comprehension had lower ADHD scores.

In a slightly larger study, Camardese et al. (2012), looked at the use of Kindle e-readers in the classroom in 3rd to 7th-grade students, specifically looking at key features,

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such as the ability to change the font, text-to-speech feature, and a dictionary feature.

Students were asked to read on Kindles for 30 minutes, 3 times a week for 12 weeks. They kept a journal about their use of the tools and the Kindles in general. Noted in their journals and based on teacher observations, researchers drew the conclusion that TTS and dictionary tools were the most frequently used. Students mentioned how they enjoyed having the Kindle read to them, however, some became bored with the monotone sounding voice. In the end, the results showed that younger students in 5th to 6th grade saw improvement in their reading comprehension. However, students in 7th and 8th grades did not show a significant improvement.

Understanding and grasping what one reads is an important skill that is needed in many aspects of daily life. When students struggle with these skills, one-way teachers tend to assist is to provide text-to-speech, but the research shows a mixed effect on students with reading disabilities. Depending on a variety of factors, text-to-speech has shown to be effective for some students identified with reading disabilities, while not as effective for other students identified with disabilities.

Effects of Text-to-Speech on Reading Rate

Appropriate reading rate is a key to reading competence and success. (Fuchs, Fuchs, Douglas, Hosp, & Jenkins, 2001) Reading rate is the speed of reading, usually documented in words per minute, in which a reader completes a reading passage. The reading rate can be assessed in a variety of ways. It could be measured by how many words or correct words are read in a specified time. It could also be assessed by how much time it takes to read a passage and possibly calculate a rate from that observation. Research examining the effects of text-to-speech on reading rate used all of these methods to determine the effects on a students'

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reading rate after or while using text-to-speech. The results from these studies also showed a variety of results. Most studies showed that students using TTS saw an improvement in their reading rate, and a few other studies showed mixed results of improvement in reading rate.

Improvement. Improvement in the area of reading rate can take many forms. It may mean that it took the student less time to complete the reading assignment (Grunér et al., 2018; Tanners et al., 2012; Staels & Van den Broeck, 2013; and Stodden et al., 2012). It may also mean that the student read more words or correct words per minute (Coleman et al., 2014; Harvey et al., 2013; Moorman et al., 2010; Young et al., 2018).

Along with examining the effects of TTS on the reading comprehension of a doctoral student, Tanners et al. (2012) also examined the amount of time it took the student to complete his reading assignments in relation to the time it took him to read similar chapters alone. The authors found that when the student read with the assistance of TTS, it took him half as long to complete his reading assignment, about 29.5 minutes on average, as it did when he read alone, about 57 minutes on average. This means that the student was able to complete his assignments almost twice as fast when he used the TTS compared to when he did not.

In a similarly small study, Harvey et al. (2013) found that when their single adult participant with cognitive impairments and aphasia used TTS, there was a significant difference in the reading rate across all conditions. When they compared TTS to slow TTS, they found $t(1,11) = -11.480, p = .000$ and when they compared TTS to no TTS they found $t(1,11) = 6.281, p = .000$. Harvey et al. concluded that the use of TTS may make reading more efficient (spending less time reading a greater amount of text) due to the increase in reading rate as long as comprehension can be preserved.

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In a slightly larger study, Moorman et. al (2010) also examined the effects of TTS on the reading rate in terms of words read per minute of 2 high school students. In this study, participants' reading rate was assessed at the beginning of the study as a baseline, while they were using TTS when the TTS was removed, and again while they were using the TTS again (an ABAB withdrawal design). One participant of this study began the study reading 93.75 words per minute (wpm), and was able to achieve 149.64 average wpm while using TTS. This is a 65% increase in the number of words she could read in one minute. The other participant began with a reading rate of 96.3 wpm and achieved 149.64 wpm with the use of TTS. This is a 50% increase. While the increase in reading rate is not statistically significant, the implications of these students being able to read faster and more efficiently could show a functionally significant improvement.

Coleman et al. (2014) asked participants to read aloud a 400-word passage under 3 conditions: independently, while the TTS support read the passage to them at 25% faster than they had read in their baseline, and while TTS read the passage 75% faster than their baseline speed. Researchers then recorded how many words they were able to read correctly in each reading. All participants in this study saw an improvement in the number of words correct per minute (WCPM), read with fewer errors, and increase their overall reading rate. Three-fourths of participants read faster after reading with the 25% faster TTS, while one of the participants read fastest after reading with the 75% faster model.

Replicating the results found in the Moorman et al. (2010) ABAB withdrawal design study, Young et al. (2018) found that three-fourths of the participants made progress in their reading rate as measured by words per minute. The authors in this study, however, evaluated the effectiveness of TTS as it relates to Hasbrouck and Tindal's 2005 norm-referenced

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suggested growth rate. Two of the 3 participants who finished the study made more progress than the suggested growth rate, with one nearly making twice as much progress as was suggested. The other participant, even though he made progress using TTS, however, did not make as much progress as suggested by the norms chart.

In a much larger pilot study, Stodden et al. (2012) investigated the use of TTS on 69 high school students who read independently at a level significantly below their peers. Through this investigation, the participants showed significant improvements in unaided reading rates. $t(9) = 3.108$; $p = .013$. While initial TTS speeds were set for the students, they were encouraged to increase the speed as they felt comfortable. Every participant was able to raise the rate to at least 120 wpm. The authors concluded that continued use of TTS software would mean students would continue to make gains in reading rate.

When Grunér et al. (2018) examined the effects of TTS on 49 students with a reading disability and demonstrated a higher level of ADHD symptoms, researchers found that TTS had a strong positive effect on all participants reading rates. All participants increased their reading rate regardless of the severity of their ADHD symptoms. This study also compared students based on their age. In regards to reading rate, however, both younger and older students showed an increase in their reading rate ($p < .001$).

In a larger study, Staels and Van den Boreck (2013) used an experimental design to study the effects to TTS on 4th and 5th-grade disabled readers in Belgium's orthographic skills. To do this, the participants were asked to read 8 stories containing pseudowords with and without TTS support, and then answer 3 questions about what they had read. Three to seven days after reading the passages, students were assessed using three measures of orthographic learning: identify the target spelling, read or name the target spelling, and spell

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the target word. When students had used TTS to read a passage, they were able to name the target spelling of a pseudoword significantly faster than the homophone spelling of the target word. When the authors analyzed the differences in naming times between the target word and the homophone pseudoword, they did not find a significant interaction effect.

Mixed Results. While the majority of studies in this review showed an improvement in students' reading rates, three studies found mixed results (Hecker et al., 2002; Schneps et al., 2018; Sorrell et al., 2007) such as reading rate improved for some students but did not improve for other students. Like those studies that indicated improvement in the area of reading rate, these studies measured the reading rate in a variety of measures.

Sorrell et al. (2007) examined the use of TTS with 12 elementary students while they read AR passages and books, and then took quizzes related to what they had read. Researchers found that 75% of students read faster after using TTS to read. Through this study, researchers were able to observe that those who had a baseline below the average, saw a larger increase in their reading rate with the use of TTS, whereas those whose baseline was above the average saw a decrease in their reading rate when using TTS. The reverse was also noticed. If students baseline was below the beginning average, their rate decreased when they read without TTS, while those whose baseline was above the beginning average saw an increase in their reading rate when they did not use TTS.

Attention and focus are two key factors that Hecker et al. (2002) argue can also play a role in what a student's reading rate is or how long it takes students to complete a reading assignment. Researchers measured the reading rate of 20 students diagnosed with an attention disorder as well as a reading disability. Like Sorrell et al. (2007), researchers noticed that students whose unassisted reading baselines were lower than 187 wpm, they

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were more likely to see an increase in reading rate, whereas those whose unassisted baseline reading rates were more than 187 wpm, they were more likely to see a decrease in reading rates when using TTS. Overall, students' unassisted reading rates increased 13% throughout the study, but this was not statistically significant. The time spent students spent reading passages on the Nelson-Denny reading comprehension test (baseline and end of study assessment) decreased by 29% on average. This finding was significant ($p = .01$).

In a slightly larger study, Schneps et al. (2018) examined how participants' reading rates changed when reading a passage under four different conditions: on paper, when the passage was presented visually and disappeared from the screen at a set rate, listening to a passage with no visual text, and when audio and visual were combined (TTS). Researchers found that the speed a student was able to read and maintain comprehension was higher under both the audio and combined conditions when compared to visual condition speed, but these were not statistically significant. A major contribution of this study to the topic knowledge base, however, was that when the group labeled as impaired readers read with audio and visual condition combined (TTS) the average speed was equal to the average speed at which the group labeled as normal readers read on paper.

While the research examining the effects of text-to-speech on reading rate was measured both through correct words read in a specified time, or how much time it took to read a reading assignment to determine the effects on a students' reading rate after or while using text-to-speech. The results from these studies also showed a variety of results. The use of TTS has shown in a majority of studies to improve a students' reading rate, with a few studies showing mixed results of both improvement or no improvement.

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Effects of Text-to-Speech on Students' Writing Skills

While the effects of text-to-speech have been primarily investigated in the area of reading skills such as reading comprehension and reading rate, the effect on written language skills is an emerging theme in the literature. Researchers have examined the effects on TTS while students are producing their initial writing (Cullen, Richards & Frank, 2008; Silió & Barbeta, 2010), as well as while revising previously written work (Conard-Salvo & Spratz, 2012; Garrison, 2009). Another study investigated how TTS can affect a student's ability to spell pseudowords correctly (Staels & Van den Broeck, 2013).

Initial writing. Due to its objective nature of reading what is written, TTS has been explored as a way to read writing aloud to find errors that the author may not find while they read and revise their own work.

Cullen, et al. (2008) examined the effects of TTS on the initial writing skills of seven elementary students with learning disabilities using a modified multiple-baseline design study. During the study, students wrote unassisted as a baseline. This was followed by having them write using WriteOutloud, a TTS support program with spell check which read the words aloud to the students as they typed. They then wrote using Co-Writer, which included word prediction support. For the purpose of this review, results from the first treatment phase (WriteOutloud) were explored. The researchers found that 5 out of 7 students increased the number of words written with the use of the TTS only. They also decreased the number of misspellings. As a group, the students increased their overall spelling accuracy of 87.07% to 95.11% and saw a slight increase in their score when their writing was evaluated using a writing rubric.

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In a similar study, Silió and Barbetta (2010) examined the effects of TTS on initial narrative writing of six Hispanic boys with specific learning disabilities, who had previously received ELL services as well. In this study, students were provided a writing prompt and asked to write for 15 minutes. After the baseline was collected, three treatments were used with their narrative writing. First, word prediction software which tried to predict the words while writing so the writer could select the correct word when it appeared on the screen. Secondly, the TTS tool where the tool would read the words as the writer created them. Thirdly, word prediction software used in conjunction with the TTS tool. Cohort A used word prediction software alone first and then word prediction software with TTS for the second trial. Cohort B used TTS software alone first and then TTS with word prediction. For the purpose of this review, Cohort B's results were examined. When the students used TTS, their writing fluency and syntax did not change or was worse than when they had written unassisted. Spelling was also unchanged, except for one participant who increased by 4.3%. The organization of writing showed the most varied effect of TTS; one student increased minimally, one student remained the same, and one decreased minimally. The authors concluded that when word prediction was used alone, or with TTS, there were positive results; however if TTS was used alone, there was little to no improvement in student's writing abilities.

Revision of Writing. Revising ones' own writing is a written language skill that students often learn as they become proficient writers.

Conard-Salvo and Spratz (2012) bring an interesting perspective to the field of TTS in the area of writing. In their study, they conducted a focus group and survey to examine the effects of TTS in a college writing center serving both students with and without disabilities.

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Conard-Salvo and Spratz examined the findings of a “failed” (p. 40) study where they realized they couldn’t support their hypothesis due to factors they had not considered prior to the start of the study. In the study, they had trained writing center tutors to teach those needing writing assistance to use TTS to revise a previously written essay. The researchers saw more improvements in higher-order revisions but felt they needed to teach students and tutors more on how to use the tools of the TTS program in future implementations.

In another article detailing a college-level pilot study and full-scale experimental study, Garrison (2009) examined the effects of TTS on student’s revisions of an essay previously written for another class. Researchers rated changes made in the areas of mechanics such as spelling and grammar, and local/global changes as either positive, neutral, or negative changes based upon whether the change improved (positive), did not improve (negative), or do nothing (neutral) for the quality of the writing. In the pilot study, researchers noticed that students using TTS to revise their work were more likely to make positive spelling changes and complete the revision task quicker than the control group; however, they were less likely to make neutral changes. In the full study, those in the control group made more positive clarity changes, total positive changes, number of neutral changes, and the total number of changes as compared to peers who used TTS support to revise their writing. These comparisons were statistically significant ($p > .05$). Researchers concluded that while TTS seemed to work for proofreading, it did little better than word processing programs that include spelling and grammar checkers.

Spelling. Orthography is the “art of writing words with proper letters according to standard usage.” (Orthography, n.d) This means it is the knowledge that a writer has to correctly use conventional spellings, as well as other conventions such as punctuation and

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capitalization. Spelling is a key skill for proficient writing, and is often connected to decoding and efficient reading (Share, 1995 as cited in Staels & Van den Broeck, 2013). One study examined the effects of TTS on student's ability to identify and read pseudowords found in a grade-level passage (Staels & Van den Broeck, 2013).

Staels and Van den Broeck (2013) examined the effects of TTS on orthographic learning. In this study, the authors hypothesized that if TTS could accommodate a student's decoding struggles, then the student would be able to encode more effectively and thus improve their orthographic or spelling skills. Results from this study showed that students were more able to identify the target pseudoword and spell the target pseudoword more often than chance.

While TTS is typically thought of and used as a reading support, researchers have also examined its use in the area of writing. Researchers found that the use of TTS assisted students with producing more writing and finding common errors, but did not significantly improve students' writing.

Social Validity and the Effects of Text-to-speech on Student Use

Social validity examines whether the treatment is socially accepted by the students and teachers. In these studies, if teachers or students decide that a treatment such as TTS is unacceptable, they will be less likely to use the intervention in the future. Examining the social validity of TTS could also provide researchers with a starting point when developing new TTS supports and tools. Many of the studies reviewed included some measure of social validity. Many examined whether students preferred or enjoyed using TTS (Camardese et al., 2012; Dolan et al., 2005; Meyer & Bouck, 2017; Moorman et al., 2010; Schmitt et al., 2012; Young et al., 2018). While others examined whether a student would be likely to continue to

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use the TTS as it was provided (Dolan et al., 2005; Floyd & Judge, 2012; Hecker et al., 2002; Schmitt et al., 2012). Still, further, some studies examined the social validity of TTS by looking at other benefits that may be experienced through the use of TTS (Conard-Salvo & Spratz, 2012; Cullen et al., 2008; Floyd & Judge, 2012; Tanners et al., 2012).

Preference/ Enjoyment. Whether a person enjoys a tool or intervention has an influence on their use of it, or if they will continue to use the tool. Enjoyment or preference was measured by the completion of a questionnaire or an interview.

Moorman et al. (2010) had participants complete a questionnaire at the completion of the study to determine the social validity of the ReadPlease TTS software. Both participants in this study agreed that the TTS was easy to use. They also scored a mean of 3.5 on a 5 point Likert Scale when asked about their opinion of the TTS voices, meaning they did not quite like the voices. The researchers concluded that overall the participants accepted the TTS support, and determined it was socially valid.

When Schmitt et al. (2012) examined social validity through an acceptability rating form, they found that most of the participants found the accommodations of read-aloud enjoyable, and one found using the reading pen to be enjoyable. All of the participants found the TTS to be helpful when completing their reading. Researchers in this study concluded that the participants may have enjoyed the idea of the technology more than the TTS support.

Participants in the Young et al. study (2018) were also asked to complete a survey to determine social validity. On average, most students enjoyed the visual and auditory support that the TTS provided but were neutral when it came to the highlighting support and the voice selection. Overall, participants enjoyed the rate of speed and thought they remembered

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more when they used TTS. Researchers concluded that TTS was generally enjoyed by the students in this study.

Unlike the previous studies mentioned, Meyer and Bouck (2017) found through interviews that only one-fourth of their participants enjoyed or preferred TTS, while half of the participants preferred to read to themselves. All of the participants did agree that they would rather use TTS than listen to a person read to them. Also, in the study interviews, the students predicted that TTS would increase their comprehension and help them to read faster. When their teacher was interviewed, she stated that she believed TTS would increase their independence as well. Researchers concluded that it may have been the novelty of the technology that caused the students to enjoy the TTS so much.

Similar to Meyer and Bouck's (2012) social validity results, Dolan et al. (2005) found that participants preferred TTS over human audio. When interviewed, students stated that TTS was easier to use and understand compared to the paper tests. When researchers examined the usage survey data, 40% of students used TTS to read questions aloud, 90% used it to decode passages, and 70% of students said it definitely helped with comprehension.

Camardese et al. (2012) also conducted interviews with the students, teachers, and researchers to determine the preference and enjoyment level of using Kindles in their elementary level classrooms. Most participants enjoyed the use of Kindles. Some of the students thought they read faster and could pronounce more words after using the Kindles for independent reading. They did not like the monotone robot voice but did report that TTS was the most used feature on the Kindles.

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Continued Use. While the previous studies examined the students' enjoyment or preference of use in regards to TTS, the following studies delve deeper into whether students would continue to use TTS support in the future.

When participants completed the treatment rating survey, Schmitt et al. (2012) found that all three students found the TTS helpful. Two-thirds of the students said they would use the reading pen again, while one of the three participants stated they would possibly use the reading pen again. An interesting observation that the researchers found was that the student who benefited the most from the reading pen was the student who rated the technology lower than the other two participants.

Floyd and Judge (2012) examined the social validity of TTS through the use of exit interviews. The interview consisted of five Likert Scale questions about the qualities of the TTS and also three open-ended questions. Five out of the six students in the study stated they would use the ClassMate Reader device in class and thought it aided in their comprehension. Half of the participants submitted a request to use the ClassMate Reader in their future classes.

In a slightly larger study, Hecker et al. (2002), asked students on the End-of-Semester questionnaire whether they would continue to use the ClassMate Reader in their English class, or their other classes. Eleven of the 16 students who completed the questionnaire stated they would continue to use the ClassMate Reader in their English classes where the materials were already scanned and readily available. Half of the students also planned to continue to use the ClassMate Reader in their other classes even though it would require more effort on their part to scan and obtain text materials.

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Other benefits observed. Not only did researchers examine whether students preferred or enjoyed using the TTS, or if students planned to continue to use TTS in the future, but researchers also noted other benefits that students reported in their social validity surveys and interviews.

Tanners et al. (2012), had the participant in their study complete two interviews, one at the beginning of the research and one at the end. In these interviews, as well as his journal, he noted that he preferred using the TTS because he felt it made him a better student and that he understood more of the reading. He also noted that he was able to complete more assignments because it took him less time to complete those reading assignments. On the contrary, he noticed that he had a lot more fear and anxiety about a reading assignment when he read without TTS support. This fear and anxiety caused him to have difficulty concentrating and to take more breaks while completing his reading assignments.

Through the interviews conducted as a part of the Floyd and Judge study (2012), five key concerns emerged about the social validity and continued use of TTS. First, students preferred that the TTS be provided on a device that was portable. Students also thought that the TTS needed to provide them with better use of their time, meaning that the time they invested in using TTS showed a benefit to them. They also enjoyed the ability to proofread their work as they wrote. A fourth benefit that students acknowledged was an increase in their ability to remember what they read because they were not using their working memory so hard to decode the words. They felt as though they had better retention when they used the TTS. The final benefit that students expressed about social validity was that they saw the technology as a benefit because it increased their independence and they could rely on technology, rather than relying on people to read their text aloud.

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At the conclusion of Cullen et al.'s (2008) study, researchers conducted interviews to investigate students' preferences, as well as other benefits, seen through the use of TTS with students writing skills. One student stated they preferred TTS as opposed to the word prediction software because it was faster to use. Researchers also noted that those students who struggled with the act of handwriting for the baseline in this study could now work independently and express themselves in writing due to the use of TTS and word prediction tools. Teachers who participated in the research stated that the use of TTS had improved their students' writing and they saw the audio feedback as beneficial, as well, for their students.

Dolan et al. (2005) investigated social validity through student surveys, interviews, field observations, and usage tracking data. Through this investigation, researchers found that nearly all students would recommend the TTS to other students. Usage patterns suggested that students preferred to read along with the text and that students would use TTS in real-world situations. Researchers concluded that the use of TTS promoted the independence of students.

As a part of the focus group and survey conducted by Conard-Salvo and Spratz (2012), participants stated that the TTS made it easier to pick out errors in their writing, especially sentence-level errors. The students also expressed frustration with the non-human voice, and that it was not convenient because TTS was only available on writing lab computers. Tutors and students also felt that more training would be needed in order for TTS to be more helpful.

Conclusions

Text-to-speech is becoming a common, universally-used support for students in classrooms around the United States, and even in my own district. With all practices in

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education, the use of text-to-speech should be evaluated for its effectiveness and examined for what effect text-to-speech has on students' reading comprehension, reading rate/fluency, written language skills, and focus our attention to reading tasks.

Does text-to-speech improve a student's reading comprehension? The research has shown that the effect of text-to-speech on a student's reading comprehension has mixed results, taking into account the age of the student, other diagnoses or symptoms a student may exhibit, type of text-to-speech tool, as well as what information is being read and how reading comprehension is measured. In my own practice, I feel that before I suggest text-to-speech to a student, I will need to carefully examine these student characteristics in relation to what has proven effective. The research has shown that a student who has the following characteristics: below average to average IQ (Lange et al., 2006), comprehension significantly below grade level reading (Park et al., 2017; Grunér et al., 2018), and older students who also demonstrate more severe ADHD symptoms or younger students who show less severe ADHD symptoms (Grunér et al., 2018) will see more benefit in the use of text to speech than a student who does not have these characteristics. Research conducted by Gonzalez (2014) leads one to believe that TTS may be more beneficial when a student is retelling what was read versus answering questions about what was read. Just as the reviewed studies demonstrated a variety of results, a variety of conclusions can be drawn about the effects of TTS on reading comprehension.

Does it increase a student's reading rate? Overall, the research suggests that TTS does improve a student's reading rate both while the student is using TTS and when the student reads unassisted after using TTS. All studies reviewed showed that at least some student's reading rates improved, while a few studies showed that specific students' rates may not

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increase with the use of TTS (Hecker, et al., 2002; Schneps, et al., 2019; Sorell et al. 2007).

These students tended to be students whose reading rates were already higher than the average reading rates in the study. Another conclusion that can be drawn from a review of this literature is that the time taken to complete a reading assignment can be reduced with the use of TTS (Hecker et al., 2002; Tanners et al., 2012). Due to these conclusions, I would suggest TTS be used with students who have a reading rate lower than that of their peers. This increase in reading rate may also assist students with completing more of their reading assignments and thus increase their motivation to learn.

How does text-to-speech affect a student's writing abilities? The use of TTS in the area of written language has shown to have minimal benefits; however, it may help some students proofread their writing as well as write more and complete tasks quicker. Those studies that examined it as an initial writing tool found that it helped to increase the number of words written, but did not improve the quality of writing produced. Due to this conclusion, I would suggest TTS as writing support for students who struggle with getting started writing, or with producing enough writing. When TTS is used as a revision tool, TTS had a neutral effect on students' writing. It did not cause students to correct more proofreading errors, nor did it cause students to make more global or higher-order changes to their writing.

Is it a socially valid tool? Most students in the reviewed studies showed they enjoyed or preferred to use TTS compared to reading alone or while listening to a human read aloud. They also noted that most planned to continue to use TTS in future reading assignments. One interesting conclusion drawn from these studies about social validity was that the survey and interviews were conducted in a research setting rather than in a general practice setting, such as the general education classroom.

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Recommendations

Because the reviewed research does not provide a clear effect of TTS on a student who has been labeled as struggling with reading comprehension, it is recommended that further research be done on this topic. The majority of the studies reviewed were conducted with students at the middle school level or higher. Future studies should be conducted with students in lower grade levels, such as elementary level students (third through fifth grades), to explore the effects of the introduction of TTS at an earlier age on a student's reading comprehension, reading rate/fluency, or writing skills. Future studies should also be conducted to investigate the effects of TTS as an accommodation or compensatory tool, versus the effects of TTS usage in conjunction with continued remedial reading instruction. While the studies reviewed showed that TTS was a socially acceptable tool in the research setting, it is recommended that future studies be conducted to investigate the social validity of TTS in a general education classroom setting.

Classroom text-to-speech usage has practical classroom applications as well. Due to the variety of results examined in this review, it is recommended that teachers and other education professionals continue to review the effects of TTS on students' reading comprehension, reading rate, and writing skills before choosing TTS as an accommodation or support in a student's IEP or 504. That said, due to the possible improvement seen by some students, it may prove beneficial for teachers and education professionals to introduce TTS as a class-wide support as a part of Universal Design for Learning (UDL) supports in their lesson planning.

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