Understanding Synthetic Speech and Language Processing of Students With and Without a Reading Disability

by

Todd Richard Cunningham

A thesis submitted in conformity with the requirements
for the degree of Doctorate of Philosophy

Human Development and Applied Psychology
University of Toronto

Understanding Synthetic Speech and Language Processing of Students with and without a Reading Disability

Todd Cunningham

Doctorate of Philosophy

Human Development and Applied Psychology
University of Toronto

2011

Abstract

To help circumvent reading disability (RD) decoding difficulty, Text-To-Speech (TTS) software can be used to present written language audibly. Although TTS software is currently being used to help RD students, there is a lack of empirically supported literature to inform developers and users of TTS software on best practices. This dissertation investigated two methods to determine whether they increase the effectiveness of TTS for RD and typically-developing students. The first method compared low and high quality TTS voices in regards to understanding. TTS voice quality was identified by having 40 university students listen to and rate the quality of 10 commonly used TTS voices and 2 human voices. Three voices were chosen for the subsequent study based on the ratings; one low quality TTS, one high quality TTS, and one natural voice (Microsoft Mary, AT&T Crystal, and Susan, respectively). Understanding was assessed with tests of intelligibility and comprehensibility. Forty-five grade 6 to 8 students who were identified as having a RD were compared to same-age typically-developing peers. Results showed high quality TTS and natural voice were more intelligible than the low quality TTS voice, and high quality TTS voice resulted in higher comprehensibility scores than low quality TTS and natural voice.

The second method investigated whether it is possible to increase a student's comprehension when using TTS by modifying the presentation style of the TTS voice. The presentation style was manipulated in two ways: varying the speed at which the TTS presented the materials (120, 150, 180 words per minute) and the presence of pauses varied (no pauses inserted, random pauses inserted, or 500 millisecond pauses at the end of noun phrases). Due to a floor effect on the comprehension of the texts the expected results were not obtained. A follow up analysis compared the participants' prosodic sensitivity skills based on whether they had a specific language impairment, (SLI) a reading impairment (RI), or were typically-developing. Results suggested that SLI has significantly less auditory working memory then RI impacting their auditory processing. Recommendations for future research and the use of TTS based on different learning profiles are provided.

Acknowledgments

It is a pleasure to thank those who made this thesis possible. To my supervisor and mentor, Dr. Esther Geva, it has been an honor and rich learning experience learning from you over the past 8 years. You have provided me with guidance throughout the process of completing this thesis. Your encouragement, support for the project, and outstanding analytical skills were essential to the success of the study. It has also been an honor for me to have Dr. Maureen Lovett as a part of my committee. It was your 2000 publication on PHASE that inspired me to pursue research in the area of education, and I thank you for your ongoing support over the years and for your thoughtful comments on my dissertation. It has also been a pleasure to have Dr. Lesly Wade-Woolley who introduced me to a new body of research in prosody. Dr. Wade-Woolley's review of and suggestions for improving the thesis were very much appreciated. The comments from the external reviewer, Dr. Dave Edyburn, allowed for a more refined paper, and were very much appreciated. In addition, the writings of Dr. Edyburn have helped shape my thinking regarding the use of assistive technology with students that have learning disabilities.

I am grateful for the educational staff that supported the study and welcomed me and the research assistants into their classrooms. Special thanks are also offered to the students who participated in the study, particularly for their cooperation throughout the assessments. The willingness of the students to participate in the research project has enabled us to learn more about the use of text-to-speech software, and will hopefully lead to more developments in helping other students learn.

I would like to thank the group of undergraduate research assistants that travelled far and wide to the various schools to conduct testing, score tests, enter data, and monitor the project. This study would not have been possible without your commitment and professionalism. I am grateful for your dedication.

The second section of this thesis would not have been possible if my friend Dr. Stephanie Timmer did not volunteer her programming talent in developing the UTReader. I enjoy our common vision of developing new innovative assistive technology tools.

This research would not have been possible if it were not for the assistance of Bob Spall at the Ontario Ministry of Education, and the financial support of this project by the Ontario Ministry of Education. It is the goal of this research to help with the development of new tools to assist struggling readers across Ontario.

To my best friend and partner, Julianne, I love you, and I thank you for loving me through this process. I am also thankful for your support through sharing ideas and giving a great deal of time to help with editing and revisions. You have shown me unconditional love and have filled my life with joy. Thank you for helping to keep me a balanced person.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1
Intelligibility and Comprehensibility of Low and High Quality Text-To-Speech Voices for Students with and without a Reading Disability

Abstract

Text-to-speech (TTS) software converts text on a computer screen into audible speech, and may be used to help students with a reading disability circumvent decoding difficulties. This study examined the intelligibility and comprehensibility that different TTS voices have for students with a reading disability and controls. Experiment 1 compared 10 TTS voices and 2 Natural voices to determine the lowest and highest quality TTS voice, and highest quality Natural voice. In Experiment 2, grade 6 to 8 students with a reading disability (RD) and controls with no reading disability were randomly assigned to one of the voice conditions and completed two intelligibility tasks (pseudoword and real word discrimination) and one comprehensibility task (sentence comprehension). To assess the cognitive processing load of the voices, response latencies were compared. The lowest quality TTS voice resulted in the lowest accuracy scores for intelligibility on the real word discrimination task, and was the least comprehensible on sentence comprehension. Students with a reading disability performed significantly more poorly than controls on all voice conditions in the real word discrimination and sentence comprehension tasks. No interactions between student group and voice conditions were found. Findings support the use of high quality TTS voices for students with or without a reading disability.

A primary difficulty for people with a reading disability is the decoding of written text. Over the past decade, TTS programs have become a common tool used to help people with a reading disability. TTS converts text inputted into a computer into synthetic speech. By circumventing the need to decode words by presenting them auditorally, TTS is thought to enable people with a reading disability to comprehend text more easily. Research to date has shown inconsistent findings on the effectiveness of TTS with regards to passage comprehension (Strangman & Bridget, 2005). This is surprising, as students with reading disabilities often have stronger listening comprehension than reading comprehension skills (Badian, 1999).

The discrepancy in findings may be due to different characteristics of the TTS voices used in the studies (i.e., not all TTS voices are created equal). For example, Mirenda and Beukelman (1990) compared eight TTS voices with a natural voice and found not only that participants had more difficulty understanding the TTS voices, but that there was significant variability in their understanding of different TTS voices. Research on the comprehension of synthetic speech has also found that the response latencies of adults varied amongst different TTS voices, and were significantly longer in comparison to natural voices (Hux, Woods, Mercure, Vitko, & Scharf, 1998; Manous et al., 1985 cited in Duffy & Pisoni, 1992; Pisoni, Manous, & Dedian, 1987; Reynolds & Fucci, 1998; Reynolds & Givens, 2001; Reynolds, Issacs-Duvall, Sheward, & Rotter, 2000; Reynolds & Jefferson, 1999). This raises the question of what is different between TTS and natural voices in regards to how well they are understood.

One difference between TTS and natural voices is in the quality of prosodic cues. Natural speech is full of rich prosodic cues that help listeners identify individual spoken words and understand the overall meaning and intention of oral communication. Prosody involves the "phonological system that encompasses the tempo, rhythm and stress of language." (Whalley & Hansen, 2006, p. 288). Prosody plays a role in the signaling of the boundaries of phonemes, words, phrases, and sentences; additionally, prosody may reflect the emotional state of a speaker, such as anger and amusement, and is used for irony and sarcasm. Prosody is used to emphasize an idea, and to indicate if an utterance is a statement, a question, or a command. Essentially, it allows for the communication of elements of language that are not encoded by grammar or vocabulary, through variation in syllable length, loudness, pitch, and the formant of speech sounds (Scherer, 1979).

A great deal of research has been done to try to replicate prosodic cues with TTS. TTS voices, such as the ones used in this study, are commonly generated through the use of what is known as the waveform method, which links prerecorded natural speech units together. Although it is beyond the scope of this paper to describe the waveform method in detail, there are two important points to mention that relate to how TTS speech is generated and how TTS attempts to synthesize prosody. Speech units are created from prerecorded natural speech and are divided into specific segments (in the form of phones, diphones, phonemes, syllables, or words). For each speech unit, the number of stored representations varies from one to several thousand. More natural sounding TTS voices have hundreds to thousands of stored representations for each speech unit (Schroeter, 2005A). When a TTS voice concatenates speech units together, it performs a "join cost" calculation to minimize discontinuities between speech units. "Join cost" analysis takes into consideration key features of speech units in order to choose speech units that best match one another, and to minimize the "cost" or disjointed transition between units, thus improving intelligibility (O'Shaughnessy, 2007). Because speech units are chosen from diverse sources and each unit has distinctive acoustic boundaries (e.g., duration, pitch, intensity, formant), if two speech units are joined together with different acoustic boundaries the result is disjointed sounding speech. It is for this reason that diphones (the section of speech from the middle of one phone to the middle of the next phone) make up the majority of speech units in TTS voices as it is at the point of co-articulation that speech has the most variability. In addition, acoustic filters are applied to modify the wave (intensity, duration, or pitch) which improves intelligibility by lowering the join cost (Schroeter, 2005B). On the other hand, with natural speech, the acoustic wave flows smoothly from phone to phone due to the natural ability of people to co-articulate. As such, the speaker produces a cohesive utterance in a single speech unit that does not sound disjointed. To get around the disjointed sound, some TTS voices standardize the duration, pitch, and intensity throughout the utterance. The results are very low join costs without disjointed transition, though the voice sounds monotone. In addition, these voices do not require a large number of speech units as all sorted units are at about the same pitch, intensity, and formant. In contrast, more dynamic TTS voices that have large number of stored speech units do try to replicate prosody by having stored units with different pitch and intensities. Though there are larger number of speech units sorted, the TTS voices needs a method for trying to understand how to manipulate duration, pitch, and intensity to replicate the prosodic cues within speech.

TTS voices use different methods to synthesize prosodic cues, with some methods resulting in better quality prosodic replication (O'Shaughnessy, 2007). However, the prosodic cues of TTS are not as sophisticated as with natural speech. For example, when a person reads aloud, they naturally pause at main phrases, use pitch to accent an idea or change the duration of words or phrases to create interest and draw attention to important information. TTS is not able to analyze sentences sufficiently to replicate the same acoustic cues used by natural speakers. TTS voices use a Natural Language Processor (NLP) that examines sentences for punctuation marks to help determine when to use prosodic cues. For example, when the NLP sees a "?" it increases the pitch of the last word preceding the "?". If there is a comma, a pause is added. However, prosody is not only communicated by grammatical marks. For example, speakers use intonation to signal the end of a statement by lowering the pitch. For example, the pitch is lowered at the end of *Julianne parked the car* to indicate the end of this statement within the sentence *Julianne parked the car in the parking lot*.

In addition, prosody is involved in the communication of emotions such as anger, sadness, joy, and surprise, all of which are not identified by grammatical markers. Thus, the task of TTS adding prosodic cues is very difficult as text does not provide sufficient markers to inform a TTS voice how to accurately synthesize prosody. To work around this, modern TTS voices use statistical models of the sentences to predict the curve that represents the final pitch used to tone the particular word, the durations of voice phones, and the presence of pauses (Chandak, Dharaskar, & Thakre, 2010). However, TTS voices still have a long way to go to sound natural (Eide, et al., 2003). There is considerable variation amongst TTS voices in how they generate synthetic speech and how natural they sound.

Although developers of TTS voices do not provide detailed descriptions regarding the algorithms used to reproduce speech, there are three important factors to consider. The first is the number of speech units stored in a voice. Voices that have a greater number of speech units stored are able to create smoother sounding speech. When there are more speech units to choose, a voice is able to create lower joint costs as more samples of a speech unit are available at different pitches. A second important difference between TTS voices is the quality of prosody replicated. Voices that poorly replicate prosody may sound monotone and artificial. A third consideration is the NLP used to create the voice. The NLP influence quality of prosody based on the punctuation and homophones within a passage. TTS voices differ in regards to number of speech units, ability to

replicate prosody, and NLP, which all contributed to voice quality. As summarized by O'Shaughnessy (2007), research suggests that proper choice of speech units is the greatest factor in achieving "excellent naturalness" in TTS voices.In addition to subjective ratings of voice quality, researchers have tried to compare the intelligibility and comprehensibility of TTS voices. Intelligibility is the listener's ability to recognize phonemes and words when presented in isolation (Moody, Joost, & Rodman, 1987; Ralston, Pisoni, & Mullennix, 1989). In contrast, comprehension involves a higher order cognitive process in which the listener constructs a coherent mental representation of the meaningful information contained in a linguistic message and relates this representation to previously or currently available information in memory (Kintsch & van Dijk, 1978; Duffy & Pisoni, 1992). In regards to the intelligibility of natural voices, each human voice is unique, with some being initially more intelligible than others. On average, female voices and speakers that have larger vowel spaces are more intelligible (Bradlow, Torretta, & Pisoni, 1996). However, people possess a remarkable ability to adapt to different voices over a short period of time. Prosodic cues help listeners to identify the individual spoken words of less intelligible natural voices, enabling them to understand the overall meaning and intention of oral communication. Prosodic information helps natural voices achieve intelligibility scores in excess of 99 percent (Hoover, Reichle, van Tassell, & Cole, 1987; Mirenda & Beukelman, 1990).

Efforts to improve the intelligibility of TTS voices have continued over the last 30 years. Mirenda and Beukelman (1990) found that TTS voices created prior to 1983 are significantly less intelligible than voices created after 1983. Despite these improvements, children find TTS voices to be less intelligible than do adults, whereas with natural voices research has found no difference between these age groups (Drager, Reichle, & Pinkoski, 2010). For example, Mirenda and Beukelman (1990) compared TTS voices to a natural voice using word verification and sentence verification tasks with 7 to 8 year olds, 11 to 12 year olds, and adults. For the word verification tasks, participants listened to a word presented auditorally and tried to select the stimulus word from a list of written words. For the sentence verification tasks, the participants verbally repeated the sentence they heard. Scores for both tasks were based on the number of words correctly verified. On the word verification task, Mirenda and Beukelman (1990), found no difference between the three age groups with the natural voice; however, all three age groups scored significantly lower with the TTS voice, with the children scoring significantly lower than

adults when listening to TTS. On the sentence verification task, the adults showed no difference in their intelligibility scores between the two types of voices, but children performed significantly more poorly with TTS, with the 7 to 8 year olds scoring the poorest. Although the authors suggest caution regarding the interpretation of the children's results, having used a difficult task, it is important to note that unlike with TTS, no difference was found between the children and adults in the natural voice condition for both word and sentence verification.

A possible explanation for the discrepancy in intelligibility scores obtained from child and adult TTS users may be the less developed language processing and working memory ability of children. Several models of language processing have argued that working memory is a limited-capacity system (Baddeley, 1996; Gathercole & Baddeley, 1993; Just & Carpenter, 1992). These models argue that people have limited cognitive resources available for performing computations such as listening and understanding. To comprehend speech successfully, one must actively maintain and integrate the linguistic material in working memory. When the demands of a task exceed the available cognitive resources, the storage and processing of the information is compromised. Research on adults has shown that as the syntactic complexity of a sentence increases, it takes longer to read the sentence, and adults with lower working memory ability make more comprehension errors (King & Just, 1991). Children have considerably more limited working memory capacity in comparison to adults (Case, 1985; Dempster, 1981), however this capacity develops over time (see Gathercole, 1998). Research on children has also found that auditory working memory ability can be used to distinguish typically developing children from those with a language impairment (Conti-Ramsden, Botting, & Faragher, 2001; Conti-Ramsden & Hesketh, 2003; Gray, 2003), and that there is a strong positive correlation between auditory working memory ability and reading ability (Gathercole, Alloway, Willis, & Adams, 2006).

Due to their more limited working memory ability, it is not surprising that when children are presented with impoverished acoustic codes such as those generated by TTS, they do not recognize words and sentences as accurately as adults. This is especially true for students who have a RD and working memory difficulty (Siegel, 1994; Swanson, 1994; Swanson H. L., 1999; Swanson, Ashbaker, & Carole, 1996). Having lower working memory may predispose students with RD to having poorer intelligibility scores when listening to TTS versus a natural voice.

In addition to their working memory weakness, a key trait of students with a RD is difficulty processing phonological information and poor phonological awareness. Phonological awareness is the metacognitive and associated skills needed to understand and manipulate the small units of sound that comprise speech (Shankweiler & Fowler, 2004). The National Reading Panel (2000) reported that, once letter knowledge has been acquired, phonological awareness is the strongest predictor of reading ability. Indeed, students with a RD, in comparison to their peers, perform more poorly on tests of phonological awareness that assess the ability to segment, isolate, and blend phonemes (Wagner & Torgesen, 1987; Torgesen, et al., 1999). Mitterer and Blomert (2003) report that when listening to TTS in comparison to natural speech, individuals with a RD are poorer at identifying two phonemes in a continuous range, for example, /ta/ to /ka/. Age-matched controls do not have difficulties with the task. In the natural condition (human voice), there was no different in the accuracy rate between age-matched controls and RD students when listening to naturally presented sound segments. However, there was a significant difference in accuracy when sound segments were generated using TTS. The students with a RD had significantly lower accuracy scores in comparison with the age-matched controls (Mitterer & Blomert, 2003). These results underscore the possibility that the intelligibility scores of RD children with poor phonological processing and working memory will be negatively affected by less than optimal TTS voice quality.

Furthermore, it might be argued that if intelligibility suffers with TTS, so would comprehensibility. While many studies have examined the intelligibility of TTS voices, relatively few have investigated their comprehensibility. Studies that have compared the comprehensibility of TTS with natural voices have found the comprehensibility of TTS voices to be significantly poorer (Hux, Woods, Mercure, Vitko & Scharf, 1998; Reynolds & Fucci, 1998; Reynolds, Issacs-Duvall, Sheward & Rotter, 2000; Reynolds & Jefferson, 1999). Comprehensibility is expected to suffer when TTS voices have poor intelligibility as cognitive resources are taxed by trying to understand individual words, reducing available resources for comprehension of the overall meaning of the text. The main measure of comprehensibility has been the response latency between the end of the presented stimuli and the response by subjects to a task. Duffy and Pisoni (1992) have postulated that response latency can capture the processing cost of TTS and natural voices. That is, greater response latencies imply the use of more cognitive resources in order to comprehend.

Research has found that children's response latency time is affected by age, ability, and whether they listen to a natural or TTS voice. One study compared two age groups (6 to7 year olds and 9 to 11 year olds) who listened to either TTS or natural voices. The children listened to three-word sentences and were instructed to hit a button indicating whether they believed each sentence was true or false. The response latencies of correct responses were significantly longer with the TTS voices (Reynolds & Jefferson, 1999). In addition, there was a significant age effect with older children being faster than younger children. Similar findings were reported in a study comparing students with a Specific Language Impairment with non-disabled students on a similar task. Both groups responded significantly faster to natural voices than TTS, with the students with a Specific Language Impairment having longer response latencies overall (Reynolds & Fucci, 1998).

Research has also found that the comprehension scores of students vary depending on the TTS voice they listen to (Koul & Hanners, 1997). Participants were 10 individuals with intellectual disabilities and 10 non-disabled students with a mean age of 8 years – 7 months (SD=5-6). For the current discussion, only the students' results will be reported. Using a sentence verification task, these students listened to three TTS voices: two DECtalk voices (Perfect Paul and Beautiful Betty) and RealVoice. The students were presented with sentences and asked to indicate whether they were true or false. Participants had significantly higher accuracy scores (i.e., their comprehension was better) and shorter response latencies when listening to the two DECtalk voices than with RealVoice. The authors concluded that students have a harder time comprehending lower quality TTS voice (RealVoice). In summary, the longer response latencies observed with TTS in comparison to natural voices, and with low quality in comparison to high quality TTS voices, may be due to greater demands on cognitive resources (Koul & Hanners, 1997; Reynolds & Jefferson, 1999).

Research has also investigated the effect of increased exposure time to TTS on comprehension, by allowing the cognitive system to adapt to the impoverished acoustic signal (Reynolds, Isaacs-Duvall, and Haddox, 2002). In one study, twenty young adults listened to both a recorded natural voice and the DECtalk synthesized voice (TTS) for 30 minutes a day over 5 consecutive days. After hearing a sentence read to them they selected a "yes" or "no" button to indicate if they thought the sentence was true or false. The latency between the end of the sentence and the correct response was also recorded. Only correct responses were included for analysis as they

suggest comprehension of the sentences. Results showed that with both the natural and TTS voices, response latency only decreased significantly from day 1 to day 2. Response latencies continued to shorten throughout the 5 days of practice, but the gap between response latencies of the different voices did not close. The practice effects from day 1 to day 2 accounted for 88.2% of the reduction in response latency for the TTS voice across the 5 days (Reynolds, Issaac-Duvall, & Haddox, 2002). The authors concluded that the participants were able to better comprehend the TTS on the second day due to more efficiently processing the impoverished acoustic signal.

Although a significant improvement in response latency only occurred between day 1 and 2, the response latencies were shorter with each additional day of practice. To determine whether a more significant practice effect could occur with even more exposure to TTS, Reynolds and his colleagues (2002) did a linear model analysis to project across time whether enough exposure could eventually eliminate the difference in response latency between the TTS and natural voice. It was found that at no point would the response latency between a TTS and natural voice intersect. Reynolds et al. (2002) concluded that although practice at listening to a voice (natural or TTS) improves the ability to process its acoustic signals, TTS will always require an additional cognitive load (see Koul, 2003 for a review).

As such, students with a RD who use TTS software face two difficulties. First, they are presented with synthetic speech that is less intelligible than natural speech, which is particularly difficult for them due to their difficulty with phonological processing. Second, compared to natural speech, the poorer intelligibility of TTS requires additional working memory, which is a deficit for many students with a RD. Although TTS is often used to help students with a RD overcome their decoding difficulties, the impoverished intelligibility of TTS voices presents challenges to other areas of cognitive weaknesses (i.e., phonological processing and working memory) that are common in this population.

An investigation was required to determine the influence that TTS and natural voices have on intelligibility and comprehensibility when used by individuals with a reading disability. Two experiments were conducted to explore this question. Experiment one investigated the perceived quality of a variety of TTS voices in comparison to two natural voices. Although past research has compared TTS voices (O'Shaughnessy, 2007), it was important to examine a range of TTS

voices currently used in the education system. As such, a sampling of TTS voices commonly used in the Ontario education system were chosen for the comparison. It was expected that more recently developed TTS voices, which have a greater number of speech segments and produce more prosodic cues, would be rated as higher in quality. The second experiment compared the intelligibility and comprehensibility of the lowest and highest quality TTS voice and a natural voice in students with and without RD. Intelligibility and comprehensibility of the voices were assessed using both accuracy and response latency measures. It was hypothesized that as the quality of the voices increased, so would intelligibility and comprehensibility. Furthermore, in comparison to non-disabled students, the intelligibility and comprehensibility scores of students with a reading disability were expected to be poorer overall.

Experiment One

The aim of this experiment was to rate the perceived quality of commonly used TTS voices in the Ontario education system. Participants listened to a variety of TTS voices and natural voices, then rated them. It was hypothesized that newer TTS voices would be rated as higher quality than older TTS voices.

Method

Forty students (21 females; 19 males) from the University of Toronto participated in the study. Participants were recruited around the university and consented to take part in the study. The participants ranged in age from 18-6 to 53 years (M=28-1, SD=11), and all participants endorsed that they spoke English proficiently, with 62.5% speaking English as their first language. Twenty-five percent of participants were attending an undergraduate program, and 75% attended a graduate program (42.5% Bachelors of Education, 25% Masters of Art, and 7.5% in a Doctorate of Philosophy; see Table 1).

Insert Table 1 about here

Materials:

Materials included MP3 players that stored the 10 computer generated voices and 2 natural voices, and Sony MDR-V150 headphones. Five different TTS voice developers were chosen, including AT&T, Acapela, ScanSoft, Microsoft, and NeoSpeech. The voices chosen are widely used in the Ontario educational system. Each developer produces a variety of voices, and the newest male and female voices available from each developer were chosen (except for ScanSoft, for which only a female voice was used). The name and manufacturer of each voice can be found in Table 2. The chosen TTS voices were compared with a male and female human voice. The "natural" voices were undergraduate students associated with the project who were deemed by the primary investigator to have clear articulation.

Insert Table 2 about here

Procedure:

The ten TTS voices recited the same phrase at the default speed (approximately 160wpm), as did the two natural voices that also approximated 160wpm. The phrase used, "The girl with the bow in her hair was told to bow deeply when greeting her superiors", is frequently used in TTS research. The same phrase was used to allow participants to make comparisons across voices.

MP3 players were loaded with the twelve voices, and the presentation of voice order was randomized. After consenting to take part in the study, participants listened to all 12 voices. After participants listened to a voice they answered 3 questions, and their responses were recorded on a 5-point Likert scale. The questions asked were as follows:

1. *What does the voice sound like? A* response of 1 indicated that the voice sounded like a computer, and a response of 5 indicated it sounded like a human.

2. *How well do you understand the voice?* A response of 1 indicated they did not understand the voice well, and a response of 5 indicated they understood the voice very well.

3. *Would you choose to listen to this voice?* A response of 1 indicated they would not choose to listen to this voice at all, and a response of 5 indicated they would definitely choose to listen to this voice.

Results

First, a correlation between the three questions was conducted. As shown in Table 3, all questions correlated highly with each other, ranging between r=.53 and r=.71. Due to the high correlation values, scores from the three questions were averaged to create a Voice Quality Index. Voices with a high Voice Quality Index score had been rated as sounding more like a human, as being easier to understand, and as being a voice that participants were more willing to listen to. As shown in Table 4, the voices are ranked from highest to lowest quality based on their Voice Quality Index score.

Insert Table 3 about here

Insert Table 4 about here

A one-way repeated ANOVA between voices was carried out on the Voice Quality Index score. The results indicate a significant voice effect on the Voice Quality Index, $F(11, 370)=37.43$ MSE=.67, $p<.001$, $\eta^2=.53$. Post hoc tests using the Tukey HSD test indicated that the natural voices had significantly higher Voice Quality Index scores than any of the TTS voices. AT&T Crystal, AT&T Mike, Acapela Ryan, Neospeech Kate, and Neospeech Paul had significantly lower Voice Quality Index scores than the natural voices, but did not significantly differ from each other. All of the Microsoft voices (Mary, Sam, and Michael) had significantly lower Voice Quality Index scores compared to the other voices, with none of the Microsoft voices being significantly different from each other (see Table 5). As such, AT&T Crystal was selected as the High Quality TTS voice as it received the highest Voice Quality Index score of the TTS voices. Microsoft (MS) Mary, having achieved the lowest female TTS Voice Quality Index score, was selected as the Low Quality TTS voice.

Insert Table 5 about here

Experiment 2

The goal of the second experiment was to compare the intelligibility and comprehensibility of high and low quality TTS voices and a natural voice with both reading disabled and non-reading disabled middle school students. All of the voices compared in Experiment 2 are female, as research has shown that female voices are more intelligible than male voices (Bardlow, Torretta, & Pisoni, 1996). Three voices were compared that vary in the extent to which they provide prosodic cues. The lowest and highest quality female TTS voices from the first experiment were compared with the highest overall rated voice (a natural voice). It was expected that the natural voice would have the greatest intelligibility and comprehensibility, followed by the high quality and low quality TTS voices, respectively, with the controls outperforming the RD students in all three voice conditions.

Intelligibility was assessed with a pseudoword discrimination task and a word discrimination task. Pseudowords are phonetically accurate but are not actual words in the English language. It was hypothesized that all students would have greater difficulty discriminating pseudowords produced by the low quality or high quality TTS voices, respectively, in comparison with the natural voice. It was also expected that students with a RD would perform more poorly in each condition. This would be consistent with research that has found that students with a reading disability perform more poorly on pseudoword naming tasks in comparison to students who do not have a reading disability (Stanovich, Siegel, & Gottardo, 1997).

Regarding the word discrimination task, it was hypothesized that there would be a main effect for voice, such that students listening to the natural or high quality TTS voice would have greater intelligibility scores than those who listened to the low quality TTS voice. There would also be a significant interaction in that both students with a RD and controls would have lower intelligibility scores for the low quality TTS voice. Higher quality voices should yield an increase in intelligibility scores, with RD students showing consistently lower performance than controls. No group difference was expected for the natural voice. It is thought that the high

quality TTS voices and the natural voices would not put the same demands on working memory; this interaction is expected given that the WM demands of the low quality TTS voices will exceed the cognitive resources of students with a RD.

Comprehensibility was assessed with a task where participants were asked to listen to sentences, and following each sentence they were asked to select a picture from a set of four that best matched the sentence. An interaction between the two reading groups and the voices was expected. It was hypothesized that due to the increased demand on WM, RD students would have a significantly lower comprehension score when listening to the low quality TTS than controls. For the high quality TTS, both RD and controls were expected to have significantly improved comprehension scores with the RD students showing greater positive change from the low quality TTS. That is, the gap between RD and control scores would decrease from the low to the high TTS condition. With the Natural voice, no change in comprehension scores was expected in the control condition, but the RD students were expected to show gains in comprehension scores to the extent that there would be no significant difference between RD and controls.

In addition, the cognitive load involved in processing the three intelligibility and comprehensibility tasks was evaluated based on response latencies. It was expected that students with a RD would have longer response latencies than controls due to their working memory difficulty. It was also hypothesized that an interaction would be found between Voice and Group. That is, a greater difference in response latency was expected between the two student groups when listening to the low quality TTS, with a smaller difference when listening to the high quality TTS and Natural voice, respectively. This is expected as the low quality TTS voices will place greater working memory demands on the students. RD students who have impoverished working memory will have substantially greater difficulties comprehending the low quality TTS voice. As the quality of the voice increases (high quality TTS and Natural), then the demands on working memory for these students will decrease and they will have substantially higher comprehension scores. The controls are thought to also have a significantly harder time comprehending the low quality TTS voices, though the high quality TTS and natural voices are thought to be similar. As the RD students' comprehension scores will continue to increase over the three voice conditions, and the controls will remain the same for high quality TTS and natural, the differences between the RD and the controls will decrease.

The Moment-to-Moment Variability in response latency was also investigated. Moment-to-Moment Variability analysis assesses within-subject variability on a task. This is measured by examining the within-subject standard deviation. If a participant has a very small standard deviation it indicates a very consistent response pattern as the response latency remains about the same. However, if a participant has a greater standard deviation on the reaction time scores, this indicates that their response latency is quicker for some items and longer for other items. It was assumed that greater Moment-to-Moment Variability in response latency suggests that some items required less cognitive processing and therefore lead to quick responses, whereas more cognitively challenging items demand longer processing time and results in longer response latency. It was expected that students with a RD would have greater Moment-to-Moment Variability in response latency due to their difficulty with processing auditory information and limited WM.

The hypothesized response latency and Moment-to-Moment Variability results for Voice conditions was as follows:

1) The low quality TTS voice would result in longer response latencies due to poor intelligibility, but less Moment-to-Moment Variability due to consistently producing a poor speech signal, in comparison to the high quality TTS and Natural voice.

2) The high quality TTS voice would result in a shorter response latency and would have less Moment-to-Moment Variability than the low quality TTS voice due to greater intelligibility.

3) The Natural voice would have the shortest response latency of the three voice conditions due to its superior intelligibility, and the least Moment-to-Moment Variability as it would produce the most consistent speech signal.

Methods

Participants

The participants, middle school students (grade 6, 7, and 8) in the Greater Toronto Area, came from nine schools within two school boards. Students were nominated to take part in the study by their teacher. Teachers who nominated students with a reading disability were asked to

nominate other students from the same classroom to be control students. The students were divided into two groups based on their Ellision and Word ID scores. Students whose scaled scores were one standard deviation below the mean on both Ellision and Word Identification were placed in the RD group. Students who scored in the average range or higher on Ellision and Word Identification were placed in the Control group. Those who scored one standard deviation below the mean on only one of the measures were not included in the analysis. As such, a total of 10 students were removed as they did not meet the criteria. The RD group was comprised of 45 students (21 female, 19 males), with a mean age of 12 years – 3 months (SD=13.38 months). The Control group was comprised of 45 students (30 female, 15 males), with a mean age of 12 years – 2 months (SD=10.304 months). There were no differences between the two groups on age; however, there was a significant group difference for schools, Pearson $\chi^2(5, n=90)=18.62$, $p<.01$. As can be seen in Table 6, more RD students came from school 4 and 5, whereas more of the Control Students came from school 3.

Insert Table 6 about here

Materials

Language and Literacy tests

Nonverbal reasoning: Nonverbal reasoning will be measured using the *Matrix Analogies Test* (Naglieri, 1989). The task requires that the students point to the design that completes the pattern. This measure was administered to all participants to ensure that their reasoning ability was broadly within the average range.

Working Memory: *Digit Span* from the *Wechsler Intelligence Scale for Children-Fourth Editio*n (WISC-IV) was used to assess working memory. In *Digits Forward*, students are asked to repeat back number strings starting with four digits. The number of digits is increased until the student makes errors on both trials of a given length. *Digits Backwards* has students repeat back a string of digits in reversed order. *Digits Forward* and *Digits Backward* were added together to create the overall *Digit Span* score, and will be referred to as WM.

Phonological Awareness: The *Ellision* subtest of the *Comprehensive Test of Phonological Processing* (Wagner, Torgesen, & Rashotte, 1999) was administered. In the *Ellision* subtest, students say a word without saying a part of the word (e.g., "Say toothbrush without saying tooth"). Testing is discontinued after three consecutive errors.

Listening Comprehension: The *Listening Comprehension* subtest of the *Woodcock Language Proficiency Battery* (Woodcock, 1991) was used to evaluate oral language proficiency. Students are asked to provide the final word of orally-presented sentences (e.g., "this is a snake"). After six consecutive errors, testing is discontinued.

Decoding Skill: The *Word Attack* subtest of the *Woodcock Reading Mastery Test-Revised* (WRMT-R; Woodcock, 1987) was used to evaluate students' ability to sound out words. The *Word Attack* subtest consists of 50 pseudowords (e.g., "tat" and "op") that comply with English phonology. Testing stops after 6 consecutive errors. It should be noted that the WRMT-R was used and not the Woodcock Reading Mastery Test-Revised/Normative Update (WRMT-R/NU; (Woodcock , 1998). It has been reported elsewhere that the WRMT-R/NU systematic inflates 5 to 9 standard scores from the WRMT-R (Pae, et al., 2005) and that the WRMT-R better reflects the true ability of student.

Word Reading: The *Word Identification* subtest of the *WRMT-R* will be used to evaluate the children's word recognition and pseudoword reading skills (Woodcock, 1987). On this subtest students read as many real words as they can.

Reading comprehension: The *Passage Comprehension* subtest of the *Woodcock Language Proficiency Battery—Revised* (WLPB-R; Woodcock, 1991) was used to evaluate reading comprehension. This closed passage test has students read brief but progressively more difficult passages and fill in the missing words ("The house is bigger than the…"). Testing is discontinued after six consecutive errors.

TTS and Natural Voices

Two TTS voices and one Natural voice were used for comparison in the study. The lowest and highest quality female TTS voices were chosen based on the results of Experiment One. The highest quality TTS voice was AT&T Crystal (AT&T, 2007), which is an example of more

recently developed synthetic speech, and is a commercially available synthetic voice production software that has greater pitch and intonation control. AT&T Crystal received the highest ratings in the first study for sounding the most like a human voice, being perceived as easier to understand, and being the TTS voice to which participants were most willing to listen. The lowest rated TTS voice was Microsoft (MS) Mary (Microsoft, 1998). This voice received the lowest ratings in the first study, indicating it sounded more like a computer, was perceived to be harder to understand, and participants indicated they were least likely to want to listen to this voice. Both AT&T Crystal and MS Mary use a wave concatenation approach to string diphones, phonemes, diphthongs, or syllables together to form words. AT&T Crystal has a larger number of stored wave segments to choose from and is able to better approximate the prosody within text (Beutnagel, Conkie, Schroeter, Stylianou, & Syrdal, 1998). In addition, AT&T Crystal has a procedure that allows the TTS voice to examine the text structure to assign prosodic cues before concatenation occurs. This allows for better production of prosodic cues in the TTS voice.

All auditory stimuli were synthesized using TextAloud TTS software (NextUp, 2008) at a sampling rate of 16 kHz and 16-bits quantization and stored in a wave file.

For the Natural voice, a female college student with a Canadian (Mideast) English accent was recorded. The student spoke into a Samson C03U Multi-Pattern USB Studio Condenser Microphone positioned approximately 2 cm away from and slightly below her mouth.

The volume level of all sound files was set to a mean between 735.5 dB and 735 dB power using Audacity (SourceForge.net, 2008) sound editing software. Apart from controlling for the overall power of each sound file, the intensity of individual words and sounds varied depending on the values used by the TTS program.

All wave files were saved on a hard drive for later playback.

Computer Hardware

The study used IBM Personal Computers 300PL with an Intel Pentium M, 2Ghz processor with 2GB of RAM, and a 70GB hard drive. The computer was loaded with Microsoft Windows XP Professional Service Pack 2. E-Prime1 (Psychology Software Tools, INC, 2008) was also installed. No other software was installed.

Headphones

The Sony Dynamic Stereo Headphones (MDR-Vi50) headset was used. The headphones have frequency responses of 18Hz – 22,000Hz, a power handling capacity of 550Mw and a sensitivity of 98dB/Mw.

Stimulus Presentation

The intensity level was set to a conversational level, at 79 dB (Bess & Humes, 1995). The rate was set to 170 words per minute.

Intelligibility Measures:

Pseudoword Discrimination Task: This task assessed intelligibility by testing the students' ability to discriminate between pairs of pseudowords (e.g. same: togg / togg or different: bish/ biss). The pseudoword discrimination task was used as previously published studies have linked discrimination to phonological skills (Moore, Rosenberg, & Coleman, 2005; Snowling, Chiat, & Hulme, 1991; Van Bon & Van Der Pijl, 1997). In addition, administration of pseudoword discrimination has been shown to consistently activate Brodmann's areas 44 and 45, which have been associated with the processing of phonological information among control individuals (Medler, Medler, Desai, Conant, & Liebenthal, 2005; Mechelhi, et al., 2005). Therefore, the task was used to investigate the different voices' intelligibility for phonemes (phonological awareness). In the present study, students were presented with a priming pseudoword, followed by the sound of a bell for 500ms, and then the target pseudoword. Students were asked to indicate if the two pseudowords were the same or different. To indicate that the words were the same they pressed the [v] key, and pressed the [n] key to indicate that the words were different (see for diagram). Students first had to achieve an 80% accuracy rate on trial items before the program allowed them to begin the main test. They were then presented with 34 test items, which were adopted from the WEPMAN Pseudoword Task (see (Wang & Geva, 2003). The software e-Prime V1.0 (Psychology Software Tools Inc, 2008) was used to record reaction time in hundredths of milliseconds. Two scores were gathered: accuracy and reaction time.

Insert Figure 1 about here

Word Discrimination Task: This task assessed intelligibility by measuring the students' ability to discriminate between real word pairs (e.g. book / book or coast/ toast). This task was chosen to investigate word intelligibility between the different voices. Like the pseudoword discrimination task, a student first heard a priming word followed by a bell for 500 ms, and were then presented with the target word (see Figure 2for diagram). Similar to the Pseudoword Discrimination Task, the participants had to achieve an 80% accuracy rate on trial items before proceeding to the main task. Students were asked to press the [v] key if the words were the same, or the [n] key if they were different. For this test, 53 word pairs were presented For this task e-Prime V1.0 (Psychology Software Tools Inc, 2008) was also used to record reaction time. Again, accuracy and reaction time scores were gathered.

Insert Figure 2 about here

Comprehensibility Measure:

Sentence Comprehension Task: The aim of this task is to assess the ability to understand spoken sentences (see Figure 3 for an example for the statement "Here is the sun"). This is achieved by having a student listen to a sentence spoken aloud, after which the student chooses from 4 line drawings the one that accurately represents the sentence. Students used their dominant hand to hit the keys from 1 to 4 on the computer keyboard. Recent research into the comprehensibility of TTS has used the method of presenting a sentence then having the listener choose a corresponding picture (Koul & Clapsaddle, 2006) as it provides both an accuracy score and reaction time score. In the current study, the Reading Comprehension subtest of the Peabody Individual Achievement Test – Revised (PIAT-R; Markwardt, 1997) was modified for the study in that only the first 70 items were used as the remaining 30 were deemed to be too difficult. The first 70 items were chosen based on the norms which have shown that 75% of grade 7 students answer them correctly. The items were scanned onto a computer. E-Prime V1.0 (Psychology Software Tools Inc, 2008) was used for the recording of reaction times. Two scores were gathered; accuracy and reaction time. Accuracy scores were based on the number of correctly identified images, with reaction time being the period between the end of the stimulus and the selection of one of the drawings.

Insert Figure 3 about here

Setting

Sessions were carried out in a room at the participating schools. The rooms used were often in the main offices or close to the participants' classrooms. Only the experimenter and participant were present during experimental sessions. Environmental noise was measured at the beginning of each testing session with a sound level meter (Scosche SPL1000F), and the average noise level was 62 (SD=11) dB.

Procedure

After school board officials, school principals, and classroom teachers agreed to participate in the study, classroom teachers distributed a letter and consent form to students that described the study. Students whose parents consented were enrolled in the study. The students participated over two sessions. Trained research assistants and the author worked with the students. In the first session, students were informed about the study, assent was obtained, and language and literacy test batteries were administered. During the second session, students were randomly assigned to one of the voice conditions (MS Mary, AT&T Crystal, Natural) and listened to their assigned voice read for 30-minutes to expose the students to the voice. Research has shown that with 30 minutes of exposure to high quality TTS voice, the intelligibility scores of non-disabled adults increased by 88.2%. After listening to the TTS voice for an additional 30 minutes, however, no significant increase in intelligibility was found (Reynolds et al. 2000). Following the voice familiarization process, the students completed the Pseudoword Discrimination Task, the Word Discrimination Task, and the Sentence Comprehension Task. Testing took place between March and June of 2009 and was conducted by research assistants and the principal investigator.

Statistics

The aim of the second experiment was to identify if there was a difference in accuracy, mean reaction time, and Moment-to-Moment Variability in reaction time scores on the Pseudoword and Word Discrimination Tasks, and the Sentence Comprehension Task as a result of listening to

the different voices (MS Mary, AT&T Crystal, and Natural). In particular, the goal was to identify whether students with a reading disability perform more poorly on these tasks under these condition than controls.

To answer these questions a 2 (Group) by 3 (Voice) two-way ANOVA was conducted for each of the tasks. All assumptions of the two-way ANOVAs were met prior to running the analyses. Post-hoc analyses were conducted on main effects and interactions that were significant. Accuracy scores were converted to percentage of items correct for comparison purposes (see Table 8).

To evaluate cognitive load, two aspects of reaction time were analyzed: mean reaction time for Response Latency and the average standard deviation for Moment-to-Moment Variation. Reaction time was measured in milliseconds (ms), and only correct responses were analyzed. A minimum reaction time of 100 ms was set for responses to be included in the analysis as it has been demonstrated (Segal-Seiden, 1997) that this is shortest time possible for the psychological processes of stimulus perception and motor response. The maximum reaction time limit was set at 3000 ms as it may be argued that any additional time may indicate that a participant did not pay adequate attention and correct responses could be attributed to lucky guesses.

Results

Cognitive and Language Profile of RD and Controls

The language and literacy skills of the participants were assessed. The test battery measured their nonverbal reasoning, oral language comprehension, phonological awareness, decoding, sight recognition of individual words, and reading comprehension. Comparisons between the RD and Control groups were carried out using multiple paired t-tests using the Bonferroni multiple-significance-test correction. Means and standard deviations of raw scores are presented in Table 7. On all tests, students with a RD scored significantly lower than Controls.

Insert Table 7 about here

The results of the language and literacy tests demonstrate significantly lower performance for the RD group in all areas assessed. This is surprising as extant literature suggests that in the areas of nonverbal reasoning, listening comprehension, and receptive vocabulary, the groups would not have differed. However, this RD group appears to represent a lower functioning group of RD students than would be typically found in the regular population.

Pseudoword Discrimination Task

Prior to analyzing pseudoword scores, items 1, 2, 24, and 26 were removed due to systematic errors in computer scoring.

A 2 (Group: RD vs. Control) x 3(Voice" Low Quality TTS, High Quality TTS, Natural) between-subjects ANOVA was conducted on Accuracy of the Pseudoword Discrimination Task. The means and standard deviations for accuracy (percentage correct) for the two groups are presented in Table 8. The ANOVA indicates no significant interaction between Group and Voice, $F(2, 85)=.69$, MSE=1.28, $p=.69$. The Group main effect was also not significant, $F(1, 85)=.02$, MSE=3.37 $p=.88$, however, there was a significant main effect for Voice, $F(2, 85)=6.85$, MSE=89.92, $p<.01$, Partial $\eta^2=.14$. Post hoc tests revealed that the students who listened to the Natural and MS Mary voices had significantly higher accuracy scores than those that listened to AT&T Crystal.

Insert Table 8 about here

The finding that MS Mary voices had significantly higher pseudoword discrimination scores than AT&T Crystal were unexpected. To explore the unexpected finding, an item analysis was conducted. As can be seen in Figure 4, there was an overall pattern of lower accuracy scores for AT&T Crystal; however, there was one item (konn/komm) resulted in a considerably lower score for MS Mary. Reanalysis of the konn/komm item showed that MS Mary did not articulate /komm/ properly. As can also be seen in Figure 4, there was less item-to-item variability among the voices when the same pseudowords were presented. When different pseudowords were presented in a pair, there was greater item-to-item variability among the voices. However, MS

Mary produced the opposite pattern, as this voice resulted in the least item-to-item variability when the items were different rather than when they were the same.

In addition, accurate response rate for AT&T Crystal on the Pseudoword discrimination task was not better than chance for both the RD (z=.97, p>.05) or Control (z=1.31, p>.05). When students were listening to AT&T Crystal presenting the pairs of pseudowords, they had a fifty percent change at guessing if they were the same or different. As the two groups were not better then chance, then it would be assumed that students were not able to distinguish between the pairs due to the poor phonetic representation of the pseudowords.

Insert Figure 4 about here

Response Latency on the Pseudoword discrimination task was investigated. Descriptive statistics for the two-way ANOVA for are presented in Table 9. There was no significant interaction between Group and Voice regarding the Response Latency of correct responses, F(2, 89)=.02, MSE=1042.20, p>.05. There was also no significant main effects for either Group (F(1, 89)=1.24, MSE=86158/18, p>.05) or Voice F(2, 89)=1.9, MSE=132445.03, p>.05. In regards to Moment-to-Moment Variability, students that listened to MS Mary had significantly less variability in their responses compared to the other voices. This was indicated through the main effect for Voice F(2,89)=3.41, P<.05 η^2=.077. Both the main effect for group and the interaction of Group and Voice were not significant for Moment-to-Moment Variability (F(1, 89)=1.88, MSE=47159.31, p>.05 and F(2, 89)=.147, MSE=3687.95, p>.05, respectively).

Insert Table 9 about here

Real Word Discrimination Task

Transformations were conducted for Accuracy and Mean Reaction Time for the Real Word Discrimination Task. The Response Latency data were slightly skewed, therefore a squared

transformation was used. The transformed data resulted in no significant differences in results, and therefore the untransformed data are reported.

No significant interaction between Group and Voice was found for Accuracy with the Real Word Discrimination Task. There was a significant main effect for Voice $F(88,2)=8.83$, MSE=233.85, $p<.001$, $\eta^2=.18$ (see Table 10). Students who listened to either the Natural voice or AT&T Crystal voice were significantly more accurate on the Real Word Discrimination Task than those who listened to MS Mary. There was also a trend for Group effect $F(88,1)=3.14$, MSE=83.09, $p=.08$. Overall, students with a RD obtained poorer Accuracy scores than controls.

No significant difference was found for Response Latency with the Real Word Discrimination Task: main effect Group ($F(1, 88)=.452$, MSE=39279.65, $p>.05$), main effect Voice ($F(2, 88)=.36$, MSE=31213.94, $p>.05$), interaction between voice and group ($F(2,88)=.05$, MSE=3958.88, $p>.05$). Regarding Moment-to-Moment Variability, there was a significant main effect for Voice, $F(82,2)=4.57$, MSE-153103.29, $p<.05$, $\eta^2=.10$ (see Table 10). Students who listened to the Natural voice or AT&T Crystal had less Moment-to-Moment Variability in their responses, showing they were more consistent in their speed of response. However, individuals who listened to MS Mary had greater Moment-to-Moment Variability. There was no significant main effect for Group ($F(1,88)=1.38$, MSE=47637.77, $p>.05$) and the interaction of Group and Voices was also nonsignificant ($F(2,88)=3.07$, MSE=105882.23, $p>.05$).

Insert Table 10 about here

An item analysis was conducted to examine the interplay between individual Real Word Discrimination task items by the different Voices. As can be seen in Figure 5, a similar overall finding is observed for the Real Word Discrimination task as for the Pseudoword discrimination task. When the pairs included “same” words or pseudowords there was no less variability then when the pairs were “different”. In addition, there were more items that presented greater difficulties for MS Mary (e.g. thought vs. taught; bale vs. gale) and less for AT&T Crystal and a Natural voice. There was no one item that all three voices had low responses on consistently.

Insert Figure 5 about here

Regarding the intelligibility of the voices, the Pseudoword and Real Word Discrimination Task produce different results. Students that listened to the Natural or MS Mary voices were more accurate at the Pseudoword Discrimination Task than those who listened to AT&T Crystal. MS Mary had significantly less Moment-to-Moment Variability in Response Latency. An item analysis conducted to follow up on this unexpected finding revealed that when the pairs were "different", students listening to MS Mary were more accurate than when pseudowords were the "same". The pattern for Natural and AT&T Crystal voices was the opposite. For the Real Word Discrimination Task, there was a trend for RD to have lower scores then controls. Both groups of students listening either to the Natural or AT&T Crystal scored significantly higher than MS Mary. This pattern was also reflected in the Moment-To-Moment Variability scores. MS Mary had greater Moment-To-Moment Variability in Reaction Time over the other two voices. Unlike the Pseudoword Discrimination task, all voices showed less item difficulty when the words pairs were the "same" than when they were "different".

Comprehensibility

A two-way ANOVA for Accuracy with the Sentence Comprehension Task revealed no significant interaction of Group and Voice ($F(2,88)=.145$, MSE=17.491, $p>.05$; See Table 8 for descriptive statistics). There was a significant main effect for Group $F(83,1)=3.72$, MSE=679.29, $p=.05$ $\eta^2=.05$. Comparing the means of the Groups revealed that RDs had lower accuracy scores on the Sentence Comprehension Task than controls. There was a significant difference between Voices on Accuracy, $F(2, 85)= 7.54$,MSE=609.51 $p<.001$ $\eta^2=.15$. Post hoc tests indicated a significant difference between all three Voices with AT&T Crystal receiving highest Accuracy scores, followed by the Natural voice and MS Mary, respectively. The interaction, main effect for Group, and the main effect for Voice were all not significant for Response Latency on the Sentence Comprehension Task $F(2, 88)=1.591$, MSE=517502.42, $p>.05$, $F(1,88)= 1.73$, MSE=563897.82, $p>.05$, and $F(2,88)=.792$, MSE=256258.88, $p>.05$, respectively. A follow up analysis was conducted to investigate the Response Latency of correct responses and the Item Difficulty of the Sentence Comprehension Task. Accuracy scores for all participants were summed for each item of the Sentence Comprehension Task to generate a Total Item Accuracy

score. A Pearson's correlation coefficient was conducted between Total Item Accuracy and average Response Latency. A significant negative relationship was found between Total Item Accuracy and Response Latency, r=-.65, p (two-tailed) <.01. As the Total Item Accuracy score decreased, Response Latency increased for Sentence Comprehension

Regarding Moment-to-Moment Variability, there was not a significant interaction or Group effect (F(1,88)=3.78, MSE=286737.41, p>.05 and F(2,88)=, 1.46, MSE=111007.18, p>.05 respectively). However, there was a significant main effect for Voice F(2, 83)=4.32, MSE=324761.01, P<.05, η^2=.10 (see Table 11). Post hoc analyses revealed that students who listened to the Natural voice had significantly greater Moment-to-Moment Variability in comparison to those who listened to either of the TTS voices.

Insert Table 11 about here

In summary, students with a RD obtained lower comprehension scores then typically developing controls. Also, students who listened to AT&T Crystal had significantly higher comprehension scores than those that listened to the Natural voice or MS Mary. The Natural voice also had significantly greater moment-to-moment variability indicating that the consistency in response latency varied more than either of the TTS voices. The Natural voice was also associated with significantly higher comprehensibility scores than MS Mary.

The Role of Working Memory

Earlier in this paper, it was reported that RDs had significantly poorer Working Memory scores than Controls. In addition, it was hypothesized that the Working Memory difficulties of the RDs would contribute to poorer performance on the intelligibility and comprehensibility tasks. To determine the role of Working Memory, separate 2 (Group) by 3 (Voice) ANCOVAs were conducted with the Accuracy, Response Latency, and Moment-to-Moment Variability scores for the three tasks (Pseudoword and Real Word Discrimination Tasks, and the Sentence Comprehension Task), controlling for Working Memory. The results of the ANVOCAs showed that for all experimental tasks the main effect for Voice remained significant, however, the main effect for Group on all comparisons were not significant (see Table 12). To address the question

of whether Working Memory accounts for the differences between RDs and Controls on Listening Comprehension, a one-way Between Groups ANCOVA was conducted on Listening Comprehension while controlling for Working Memory. The results showed a significant difference between Group $F(88, 1)=15.02$, MSE=114.65, $p<.001$. In summary, students with a RD had significantly poorer Listening Comprehension scores even after controlling for Working Memory. However, Working Memory was found to influence comprehensibility and intelligibility when listening to the different Voices in the experiment.

Insert
Table 12 about here

Discussion

In the past, research on the effect that TTS has on the comprehension of students with a reading disability (RD) has produced mixed results with some studies showing that TTS increases comprehension scores and other studies finding no effect on performance (Strangman & Bridget, 2005). The aim of the current research was to investigate whether the quality of voice used to present text auditorally impacts students' (with or without a RD) comprehension of text. The first step (Experiment 1) was to evaluate the different TTS voices to identify whether they were perceived to be of low or high quality in comparison to natural voices. The second step (Experiment 2) was to compare the intelligibility and comprehensibility of the lowest and highest ranked TTS voices from Experiment 1 with a natural voice. In addition, the cognitive load associated with these three voices for students with and without a RD was assessed by examining response latencies. It was hypothesized that low quality TTS voices would result in lower intelligibility and comprehensibility scores as well have long response latency and more moment-to-moment variability. It was hypothesized that RD students would demonstrate overall lower performance, but that the gap between control and RD performance would decrease as voice quality increased.

To investigate this goal, the first step was to ascertain low and high TTS voices. Comparisons of ten TTS and two Natural voices revealed that listeners perceived a difference in the quality of the

voices. The TTS voice called MS Mary was the female voice that received the lowest overall ratings from participants, and was used in Experiment 2 as the low quality TTS voice. Overall, it was rated as sounding the most like a computer, being the hardest to understand, and was the least preferred voice for listening. The highest rated TTS voice, AT&T Crystal, was the highest rated female TTS voice, and was used in Experiment 2 as the high quality TTS voice. In contrast to the low quality TTS, this high quality TTS voice was rated overall as sounding the most like a human, being easier to understand, and being a voice that participants are more willing to listen to. The Natural voices received higher ratings than all TTS voices. Therefore, the female Natural voice was used for Experiment 2.

The finding that TTS voices received lower ratings when compared to natural voices is consistent with previous studies. Research with adults found that TTS voices were less intelligible than natural speech (Mirenda & Beukelman, 1990; Reynolds, Issacs-Duvall, Sheward, & Rotter, 2000) and that some TTS voices are perceived as more intelligible than other TTS voices (Greene, Logan, & Pisoni, 1986; Mirenda & Beukelman, 1990; venKatagiri, 2004) However, the key is in how well the voices are able to replicate a variety of natural speech conditions. Handley (2009) argued that the different methods used to generate the voices are responsible for the between voice differences. Although it is beyond the scope of this paper to explain the technological differences in TTS voice generation processes, it is likely that the poorer ratings for the low quality TTS relative to the high quality TTS voices are related to an inability to generate smoother transitions and replicate prosody. For instance, the low quality TTS voices were developed prior to certain advances in TTS voice generation technology. Namely, the low quality TTS voice uses a smaller library of speech samples, which have been found to result in TTS voices that sound more monotone when linking speech samples together (Dutoit, 1997). In contrast, newer, higher-quality TTS draw from a significantly larger library of speech samples, allowing for smoother transitions between speech units (O'Shaughnessy, 2007). The newer TTS programs also use methods to generate prosody based on the prosodic context within text (Beutnagel, Conkie, Schroeter, Stylianou, & Syrdal, 1998; Campbell & Black, 1997). This suggests that users of TTS should listen to a variety of voices to determine which one they prefer. The findings also suggest that users prefer to listen to TTS that sounds more natural and has a more sophisticated prosody synthesizer.

Despite technological advances, TTS voices continue to be rated as inferior to Natural voices, suggesting that there is considerable room for improvement of the TTS voices. In light of the limitations of TTS, the second experiment assessed the intelligibility and comprehensibility of the low quality TTS and high quality TTS, relative to a natural voice, when listened to by students with a RD and by controls. In addition, the second experiment aimed to determine the extent of cognitive load that was required by the voices.

It is important to note that in Experiment 2, students with an RD were compared to typically developing control students. The profiles of the typically developing children were representative of other children their age in regards to working memory, phonological awareness, word reading, and word decoding. As expected, the students with an RD scored one standard deviation below the controls on working memory, word reading, and decoding and 1.5 standard deviations below the controls on phonological awareness. This profile is similar to that reported by Fletcher, Morris, and Lyon (2003) who found that students identified as having a learning disability in the area of reading were 1 standard deviation below the mean on phonological awareness. The RD group in the present study, however, had lower receptive vocabulary scores than typically developing children, which was different than expected based on the study of Fletcher and colleagues (2003). This suggests that the RD students in the present study may have more language impairment than expected. This needs to be taken into consideration when making interpreting the findings of the present study.

Regarding the comparisons of the voices, it was expected that the natural voice would produce the most intelligible pseudowords, followed by the high quality TTS and low quality TTS, respectively. Instead, the Natural and low quality TTS were found to be comparable, and the high quality TTS was the least intelligible. In contrast to the high quality TTS, the low quality TTS produced the pseudowords in a way that made it easier for participants to identify when they were different. This was found in an item-by-item analysis (see Figure 4). This analysis indicated that when presented with pseudoword pairs in the low quality TTS voice, students were more likely to correctly identify identical items such as /togg/-/togg/; /nush/-/nush/, or /tekk/-/tekk/. On the other hand, when a high quality TTS or natural voice was used, students were much less accurate in their ability to distinguish between different word pairs (e.g. /bish/-/biss/; /ting/- /tig/; or /thop/- /zop/). Although the low quality TTS produced pseudowords in such a way that the students could differentiate between pseudowords as well as when listened to a Natural

voice, this does not mean that the low quality TTS produced the pseudowords as well as a human would. Rather, the low quality TTS mispronounced the pseudoword pairs. The mispronunciation did not impact results when the pseudowords pairs were the same as the TTS voice consistently mispronounced the same pseudoword. When the pseudowords were differing on one phoneme, what should have been a subtle manipulation of sound became a pronounced difference as a result of the mispronunciation. The pseudowords were made to differ only on one phoneme (e.g /bi*s*s/-/bi*s**h*/), but when pronounced by low quality TTS, the phonemic information was perceived differently. In comparison, the high quality TTS voice had a larger store of speech samples and allowed for a smoother transition between speech sounds. Although the high quality TTS also did a poor job articulating the pseudowords, its intelligibility was likely undermined by the fact that it produced the pseudowords with a shorter duration of utterance. It is notable that in this condition, the high quality TTS had a shorter duration of utterance than the natural voice and low quality TTS voice (articulating the pseudowords 40.79% faster than the Natural voice, and 18.94% faster than the low quality TTS). As a result, the high quality TTS provided less acoustic information to help participants discriminate between pseudowords.

In contrast, the intelligibility of the TTS programs when producing real words showed the opposite results. With real words, the high quality TTS was found to be as intelligible as the natural voice, and the low quality TTS was found to be less intelligible then either the high quality TTS or Natural voice. It is surprising that although the high quality TTS voice was rated as less preferable than the Natural voice in Experiment 1, the intelligibility of these two voices for real words was identical. This may be due to advancements in TTS voice generation technology used by the high quality TTS, such as the larger library of speech sounds permitting better transitions between speech units. The fact that the high quality TTS outperformed the low quality TTS in the real word condition was expected as it has a newer, more sophisticated method of voice generation. The difference between the TTS voices with pseudowords and real words does not necessarily indicate that the low quality TTS is superior at producing pseudowords. Rather, it may be argued that both TTS voices had incorrect articulation, but the low quality TTS produced them in a way that made pairs of different pseudowords sound more distinct (making it easier to differentiate between pseudowords). In contrast to the distinct sounds of the pairs of pseudowords, the high quality TTS voice also did not create intelligible pseudowords as students did not perform better then chance responding. The high quality TTS

applies a more advanced process of smoothing the coarticulation leading to aquatic sounds that were hard to discriminate.

An interaction was also not found between the two groups for all three voices. This suggests that although students with a RD, in general, have more difficulty due to their weakness in phonological processing, when pseudowords are produced by either the high or low quality TTS, both RD and control students are equally challenged. This discrepancy is likely due to the TTS programs failing to pronounce the pseudowords properly. When listening to the TTS voices create pseudowords, one can hear the misrepresentation of the pseudowords. The findings on the intelligibility of pseudowords suggest that the TTS voices were not created to produce pseudowords and should not be used in to do so. As TTS use diphones, some of the phoneme patterns within the pseudowords are not represented in English. Therefore, the TTS presents the phones in isolation. This creates a choppy sounding word as the coarticulation between the phones is not replicated. In addition, TTS voices would not be appropriate for use in software that models the production of phonemes, as they are not reliable for this task. Instead, a human voice should be recorded to ensure accuracy.

It was interesting that the comprehensibility of the high quality TTS assessed with Sentence Comprehension was higher than when the sentences were uttered by a human voice or by low quality TTS. The difference in the comprehensibility of the two TTS voices was expected as the high quality TTS was also found to be more intelligible with real words, and in Study 1 as being perceived as being more understandable. What was unexpected, however, was that the high quality TTS voice was more comprehensible than a Natural voice. It was anticipated that the Natural voice would be more comprehensible, as research has found that the prosodic information produced by natural voice help achieve intelligibility scores in excess of 99 percent (Hoover & Gough, 1990; Mirenda & Beukelman, 1990). Amongst other things, prosody plays a role in the signaling of the boundaries of phonemes, words, phrases, and sentences. TTS voices, in contrast, have been found to have less prosodic cues than natural voices (O'Shaughnessy, 2007). The advantage of high quality TTS over the human voice may be attributed to technological advances in TTS voice. Past research that has found TTS voices to be less comprehensible than human voices was conducted over five years ago with adults (Hux, Mercure, Wood, Scharf, & Vitko, 1998; Manous et al., 1985 cited in Duffy & Pisoni, 1992; Pisoni, Manous, & Dedina, 1987; Reynolds & Fucci, 1998; Reynolds & Givens, 2001; Reynolds,

Isaacs-Duvall, Sheward, & Rotter, 2000; Reynolds & Jefferson, 1999), and children (Reynolds & Jefferson, 1999; Reynolds & Fucci, 1998). In the present study, the high quality TTS comprehensibility scores were on average 10% higher than with the natural voice. Perhaps it is the case that the high quality TTS voice used in this study articulates all of the phonemes in words with more accuracy and consistency than the natural voice. In contrast to the high quality TTS voice, the natural voice had greater moment-to-moment variability. When listening to the natural voice, it was discovered that the person who recorded the voice did not pronounce final phoneme position consistently, had a rate of speech that varied within the utterance, and provided less distinction between the boundaries of words (e.g. slurred between some words). Past research has shown that even in ideal recording conditions, natural voices vary in regards to such things as pitch, loudness and articulation, and degree of vowel nasalization (Harrington & Cassidy, 1999). As such, it may have been the case that the voice of the woman who recorded the natural voice was more variable in regards to certain factors than the high quality TTS. Clearly, a follow-up study is required that compares aspects of natural speech variability with the high quality TTS voice to better comprehend what features of high quality TTS that might make it advantageous over natural voice. On the positive hand, in terms of developing intervention software, it is promising to find out that some more recently developed synthetic voices are now equivalent and perhaps surpass the human voice in comprehensibility.

The findings for the comprehensibility of the voices was not as predicted, although the findings are understandable based on the cognitive and language profiles of the students participating in this study. It was hypothesized that there would be an interaction between the two groups and the different voices. This interaction would consist of a larger comprehension gap with RD having significantly lower scores then controls for the lower quality TTS with this gap closing for the high quality TTS and then no significant differences for natural voices. It was found that for all three voice conditions the RD students were significantly lower on the comprehension task than controls. The fact that RD students have phonological processing difficulties is well established (e.g., Snowling, 2000; Stanovich & Siegel, 1994; Torgesen, et al., 1999).

As for the comprehension task, many of the answers depended on the correct recognition of a single phoneme. For example, take the element of "There is the s*un*" (see Figure 3). The participant is presented with 4 pictures representing: s*un*, s*aw*, s*ub*, and s*ing*. The rhyme /un/ is the key to the comprehension of the sentences. In this case, the comprehension task resembles

an intelligibility task in that participants had to correctly recognize all the phonemic elements, which is a weakness of the RD population(Snowling, 2000). The RDs performance on the comprehension task is expected based on their cognitive profiles, which found they have poorer phonological awareness, oral language comprehension, and receptive vocabulary ability than the typically developing students. .

It was expected that when the students with a RD, in comparison to controls, listened to low quality TTS, the low quality voice would yield lower intelligibility and comprehensibility overall, and that the difference between these groups would reduce as voice quality improved. This was expected as students with a RD have poorer working memory ability than typically developing students (Siegel, 1994; Swanson L. , 1994; Swanson, 1999; Swanson, Ashbaker, & Carole, 1996) as well as phonological processing difficulties (Wagner & Torgesen, 1987), making the low quality TTS particularly difficult for them to understand. However, it was surprising that for intelligibility and comprehensibility alike, no interaction was found between reading group (i.e., controls vs. RDs), and the effect of the type of voice to which they listened. In other words, regardless of the quality of the voice that the RDs listened to, they had the same intelligibility scores as controls, but lower comprehensibility scores than controls.

One possible explanation for the finding that RDs had lower comprehensibility scores is their poorer WM. Past research has shown that WM contributes to difficulty when listening to text-to-speech voices (Duffy & Pisoni, 1992). Therefore, students with poorer WM would be expected to have lower accuracy scores when listening to TTS voices. Although this was not true for the intelligibility task, it was the case for the comprehensibility task. When controlling for WM, the difference between RDs and controls on comprehensibility became nonsignificant. Therefore, WM contributes to the discrepancy between the comprehensibility of RDs and controls when listening to TTS voices.

It was originally thought that students with an RD would have the same comprehensibility scores as control students when listening to the natural and high quality TTS voices. However, this was not found as the RD students always performed more poorly on the comprehensibility task regardless of TTS voice. This unexpected finding may be due to the fact that the RDs in the present study overall had poorer cognitive and language abilities than expected. That is, they may have performed more poorly due to having greater weaknesses overall (i.e., lower oral

vocabulary, lower working memory ability, and lower nonverbal intelligence) .These cognitive abilities have been found to contribute to comprehension (see Rapp, van den Broek, McMaster, Kendeou, & Espin, 2007). Further research in the area of TTS needs to match students on nonverbal intelligence or listening comprehension. This research design may provide the opportunity to test specific hypotheses regarding the role of underlying cognitive abilities such as WM. In the present study, the RDs and controls were not matched on these variables, and therefore this comparison could not be conducted.

Working Memory and the Intelligibility and Comprehensibility of TTS

The response latency of participants was also measured for the different voices on the intelligibility and comprehensibility tasks. It was assumed that the response latencies reflect cognitive load. That is, an item that results in short response latency may reflect less of a cognitive load than a task that results in longer response latency (Duffy & Pisoni, 1992). In this study the response latency is based on the time interval between the end of the stimulus (i.e., the pseudoword, real word, or sentence) and the participant's response. In the pseudoword and real word discrimination tasks, as well as for the sentence comprehension task, it was hypothesized that the shortest response latency would be found with the natural voice, followed by the high quality TTS and low quality TTS, respectively. In addition, it was expected that regardless of task and voice quality condition, students with a RD would have longer response latencies than the controls. These hypotheses were not supported in the current study; no difference in response latency was found between the students with a RD and controls, regardless of the type of voice to which they listened. This finding is different from previous research involving children and adults, where RD had longer reaction times when they listened to TTS voices in comparison to a natural voice (Duffy & Pisoni, 1992). This difference was maintained even after participants had practice listening to TTS voices over several days (Reynolds et al., 2002; Reynolds et al., 2000; Reynolds & Jefferson, 1999).

A number of possible explanations can be considered for the contradictory results. One explanation concerns the differences in the nature of the comprehension measure used in the present study and in previous research. Whereas previous research used a sentence verification task (Axmear, Reichle, Alamsaputra, Kohnert, Drager, & Sellnow, 2005), the current study used a sentence comprehension task. In general, with sentence verification tasks, participants listen to

a 3-word sentence and indicate whether they believe the sentence is true or false (e.g., dogs can fly). The 3-word sentences are developed so that the responses of participants are highly accurate and there is often a ceiling effect. As such, the task requires very little cognitive processing, ensuring that only the manipulated condition is being measured. In contrast, the current study used the Peabody Individual Achievement Test-Revised (PIAT-R), whose sentences become increasingly more difficult to comprehend as one progresses through the test. The complexity of the sentences in the test is modified based on vocabulary, number of clauses, and syntax. As the sentences become more difficult to comprehend, latency response time was expected to become longer as participants tried to process the sentence information. Indeed, the present study found a highly significant negative correlation between sentence accuracy and response latency (r=-.65). This high correlation suggests that as the sentence difficulty increased, there was an increase in cognitive load resulting in students taking more time to respond. This was the case for both reading ability groups and all three voices. In other words, sentence difficulty, comprehensibility of voice, and reading ability may have all contributed to the observed response latencies. The influence of multiple variables on a sensitive measure could explain why nonsignificant results were found, as there was too much within-subject variability. In future research, two different measures of listening comprehension need to be used to assess the accuracy and response latency of comprehension separately, and the response latency measure should require minimal levels of cognitive load. Not taking into consideration the effect of the test items, the non-significant findings for response latency suggests that cognitive load (as represented by response latency) is equivalent for all the voices independent of reading ability.

Although no significant difference for response latency was found among the students or voices, a difference was found in regard to moment-to-moment variability. An interesting pattern emerged when moment-to-moment variability and accuracy scores were considered together. When the pseudowords were uttered by low quality TTS, there was less moment-to-moment variability compared to other voices. On the other hand, when the low quality TTS uttered real words, greater moment-to-moment variability was noted, than when the other two voices uttered these items. This was somewhat consistent with what was expected. As suggested earlier, the low quality TTS did not produce phonologically accurate pseudowords, and as a result the participants were more accurate when the pseudoword pairs were different. As this made the discrimination task easier, it is understandable that a more consistent speed of response was

found with low quality TTS. In contrast, when real words were produced by the low quality TTS it was less consistent at producing intelligible words. When low quality TTS uttered real words intelligibility scores decreased, and this was concomitant with an increase in moment-to-moment variability.

An examination of moment-to-moment variability with regard to comprehensibility data supports the overall conclusion that the high quality TTS voices are more consistent in their production of speech than natural voices. The Natural voice had significantly greater moment-to-moment variability, indicating that listeners did not perceive this voice as consistently as either of the TTS voices. The greater comprehension scores with the high quality TTS may be attributed to it having a more consistently intelligible voice. Although users may prefer to listen to a natural voice, listening to a high quality TTS appears to result in clearer and more consistent comprehension of short passages by all learners.

Background noise in the testing environment could have also contributed to the non-significant difference found in response latency for the two intelligibility and the comprehensibility tasks. The testing rooms were usually located next to classrooms or in the main office of the elementary schools. The background noise in elementary classrooms is often significant and can appropriate 55-65 dB (Nelson, Soli, & Seitz, 2002). In the current study, background noise was rated to be within this range. This may have been a limitation as past research has found that a signal-to-noise differential as small as 10 dB can result in significant differences in intelligibility when listening to TTS speech output. The regular classroom environment was chosen as the current study wanted to simulate the environment in which the TTS software would be used. To investigate response latency, a sound controlled environment may be needed and the study needs to be replicated. In addition, listening comprehension of students who use TTS in elementary classrooms may be negatively impacted by background noise. The current study used a high quality head-phone to help reduces background noise. This would suggest that high quality head-phones that have good noise cancelation or reduction properties should be used by students when listening to TTS voices in the classroom.

Educational Implications

The findings suggest ways students with a reading disability can better use TTS. The current study found that the TTS voice rated as preferable by listeners was more intelligible and comprehensible, and sounded more like a human voice than the less preferred TTS voices. Users of TTS should be encouraged to select the type of voice they prefer to listen to, which is likely to be the most natural sounding. Importantly, voice quality was found to influence listeners' willingness to listen to the voice, and newer voices received higher ratings in comparison to older voices.

Implications for use of TTS

TTS software is often recommended for use by students that have a RD to enable them to better understand printed text, however, past research has produced mixed findings regarding the effectiveness of TTS for reading comprehension with students with a RD (Strangman & Bridget, 2005). As the present study has shown, the quality of the TTS voice influences the extent to which an individual understands what they hear. For all students, a low quality TTS voice results in poorer intelligibility and comprehensibility in comparison to a natural voice. Therefore, students who use TTS, regardless of whether they have a RD or not, should be advised to use a high quality TTS voice to improve their understanding of what the voice. As much of the research on TTS with individuals with a RD has either not reported the TTS voice used, or has given participants the option to choose a voice, the contribution of type of voice to the mixed results of these studies is unknown. Therefore, it is important that future research identify what TTS voices were studied to allow for comparisons, as this may help explain discrepancies in findings between different studies. In addition, it is important to replicate the work of Elking and his colleagues (2003) and Higgins and Raskind (1997) who compared the unaided reading ability of students with an RD to their aided reading ability. A replication study should measure the students' reading comprehension and reading rate without the use of any accommodations (unaided condition) and with the use of TTS (aided condition). For the aided condition, a high quality TTS voice which has a large number speech units, the ability to replicate prosody, utilizes an advanced NLP, and has been rated as high quality, should be used. With these conditions, it is expected that students with an RD will show gains in reading comprehension.

Chapter 2

Increasing the Effectiveness of Text-To-Speech Software for Students with Reading Disabilities

Abstract

Text-to-speech (TTS) software is used by children with reading disabilities (RD) to help them comprehend written text by "reading aloud", and thereby circumventing the need to decode. Past research has shown mixed results regarding the effect of TTS on reading comprehension. The present study examined two modifications of the way TTS presents text: presentation rate of text and the use of pauses within sentences. Forty-seven students with a RD and 54 typically developing students between grades 6 and 8 were presented with passages by TTS at a slow, medium, and fast presentation rate, and with no pauses, random pauses, or noun-phrase pauses. Students listened to two passages in each condition for a total of 18 passages. At the end of each passage, the students answered three factual and two inferential multiple-choice questions. Unfortunately, due to a floor effect with the multiple choice questions the analysis could not be carried out. Explanations regarding the floor effect and changes to the study are provided.

Individuals with a reading disability (RD) have a weakness in the ability to fluently decode and recognize words, which often leads to poorer comprehension. Having a computer read text auditorily via text-to-speech software (TTS) has been considered a means to circumvent this weakness, and has led to TTS being widely used as an academic accommodation for students with reading disabilities (Dalton & Strangman, 2006). However, research on the effectiveness of TTS at increasing comprehension for students with a RD has produced mixed results, with some studies finding it to be effective (Elbro, Rasmussen, & Spelling, 1996; Elking, Cohen, & Murray, 1993; Lundberg & Olofsson, 1993; Montali & Lewandowski, 1996), and other studies finding it to be ineffective (Farmer, Klein, & Bryson, 1992; Leong, 1995; Wise & Olson, 1995).

One possible explanation for these inconsistent findings is differences in the impact that TTS voice quality has on students with a RD compared to age-matched controls. As prior research has shown (see study 1), a high quality TTS voice resulted in greater intelligibility and comprehensibility than a low quality TTS voice for both students with a RD and age-matched controls, however, students with a RD demonstrated poorer comprehension overall.

The discrepancy in listening comprehension may be due to differences in the working memory (WM) ability of RD and typically developing students, and the WM demands of different voices. WM is often described as a "mental workspace" with the ability to hold task relevant information in mind during processing of information or problem solving (Just & Carpenter, 1992). It is a limited-capacity system (Baddeley, 1996; Gathercole & Baddeley, 1990; Just & Carpenter, 1992) that has a direct impact on listening comprehension. Most models of WM describe two systems, one for short-term maintenance of information and one for the manipulation of information during complex cognitive tasks. The short-term maintenance system is often described as having the two functions of maintaining verbal and visual-spatial information (Baddeley, 1996), with verbal information maintained in the phonological loop, and visual information held in the visual-spatial sketchpad. The information in the short-term maintenance system is manipulated by the central executive in order to carry out complex cognitive functions. To comprehend speech, one must actively maintain and integrate the linguistic material in WM. When the demands of a task exceed the available WM, the storage and processing of the information is compromised. WM has also been linked with a number of language outcomes, such as reading comprehension (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Swanson, 1999), vocabulary

acquisition (Baddeley, Gathercole, & Papagno, 1998), and early academic achievement (Gathercole & Pickering, 2000).

The lower WM capacity of students with a RD puts them at a disadvantage when using TTS, as TTS demands more WM than natural voices for listening comprehension (see Study 1). Research has found that adults with low WM who are presented with increasingly complex syntactic text have poorer comprehension than controls (King & Just, 1991). Furthermore, in regards to TTS, research found that a low quality TTS voice requires more WM capacity and results in poorer intelligibility and comprehensibility than a high quality TTS or natural voice for both RD and typically developing children (see Study 1). In Study 1, RD students who listened to low quality TTS, high quality TTS, or natural voices had more difficulty identifying pictures that corresponded to statements they heard than controls. When WM was controlled for, this difference between RD and controls was no longer significant. This indicates that the lower WM capacity of RD students impairs their listening comprehension in comparison to controls, with comprehension particularly reduced with low quality TTS.

In light of the fact that TTS voices, particularly low quality TTS, place greater demands on WM, and this is a disadvantage for students with a RD as they have lower WM, the question arises as to how the demand on WM may be reduced when using TTS. The current study investigated two methods intended to reduce the demands on WM when listening to TTS: varying presentation rate (i.e., the speed at which the computer reads the text), and the use of pauses. To examine this possibility, the present study investigated whether slowing the rate of TTS speech and having the TTS voice pause at the end of phrases would compensate for the lower WM capacity of RD students, and thereby improve comprehension.

Presentation Rate

Research conducted over 50 years ago found that when the speed of a voice exceeds a certain threshold, comprehension of the speech decreases. These early studies showed that adults are able to repeat short sentences they have heard at a rate between 125 wpm and 225 wpm (Harwood, 1955; Nelson, 1948). However, once 225 wpm is exceeded, there is an accelerating decline in comprehension (Foulke & Sticht, 1969). In addition, it has been established that for

children, there is a linear relationship between natural speech rate and working memory (Henry, 1994).

In addition, it has been argued that TTS presentation rate has an impact on comprehension. That is, even if users recognize individual words, if the presentation rate is too fast they may not be able to comprehend text even if the individual words are intelligible. One way of reducing the processing demands of TTS may be to slow down the presentation rate of the TTS voice. Early research on TTS voices lends support to this idea. A study by (Marics & Williges, 1988), had adults listen to a short sentence, press a bar to indicate they were ready to respond, and then write down what they heard. The passages were presented at 3 rates: 150 words-per-minute (WPM), 180 WPM, and 210 WPM. The response latency of correct responses was examined. The study found that the presentation rates of 150 and 180 WPM, in comparison to 210 WPM, resulted in shorter response latencies. The quicker responses suggest that when TTS reads text at a slower rate, adults are able to process the information more efficiently into meaningful idea units.

In contrast, a study by Reynolds and Givens (Reynolds & Givens, 2001) did not find a difference in response latency when TTS or natural speech was presented at different rates. In the study, 8 groups of college students listened to a natural or TTS voice at 4 speech presentation rates: 130, 150, 170, or 190 WPM. Thirty sentences were presented with the last word either making the sentence plausible (e.g., scissors, that cut paper, are *sharp*) or implausible (fire, that burns wood, is *cold*). Participants hit one of two keys to indicate if sentences were plausible or not. The response latency of correct responses was recorded. No significant difference was found between the four speech presentation rates for either voice.

Differences in the cognitive demands needed for tasks in the Marics and Williges (1988) and Reynolds and Givens (2001) studies may account for the discrepancy in findings. In the study by Marics and Williges (1988), response latency was measured between the end of the stimulus (i.e., the voice had finished reading the sentence) and when participants pressed a bar to indicate they were ready to write. Reynolds and Givens (2001) point out that it may take more working memory and processing time to rehearse sentences before writing them down than to make a judgment of whether a sentence is plausible, resulting in the significant difference in response latency between 150 and 180 WPM, and 210 WPM found in the Marics and Willages (1988) study. In contrast, the Reynolds and Givens (2001) study used a judgment task that may have

required less cognitive resources (e.g., working memory), making speech presentation rate less influential as participants did not need to retain each word in memory, but could simply make a judgment about what they heard before responding.

Another difference between the two studies is the presentation rate of the speech. Marics and Willages (1988) used the fastest presentation rate of 210 WPM. At 210 WPM, WM may be overtaxed such that it does not retain auditory information in short-term memory as well as at slower presentation rates. In the Reynolds and Givens (2001) study, the fastest presentation rate was 180 WPM, which is approximately the rate of speech during natural conversation, and may not have been fast enough to exceed the WM capacity. The 15% faster presentation rate of 210 WPM, on the other hand, appears to have exceeded WM capacity and thereby prolonged the time needed to prepare to write down the sentence.

Additional research has found support for the hypothesis that comprehension suffers when the presentation rate of TTS is sufficiently faster than that of natural speech (Greenspan, Nusbaum, & Pisoni, 1988; Mirenda & Beukelman, 1987; Venkatagiri, 1991;Higginbotham, Drazek, Kowarsky, Scally, & Segal, 1994). In one study, Venkatagiri (1991) had college students do a sentence verification task when listening to TTS or a natural voice, and TTS was found to result in lower intelligibility scores. To try to improve intelligibility, two slower presentation rates were compared to the normal rate. Early TTS could not manipulate the rate of word utterance, so to slow down the presentation rate the delay interval between words was increased. The non-manipulated presentation rate of the TTS voice had a delay interval of approximately 50 milliseconds between words. This rate was compared with “slow” and “very slow” presentation rates that had a delay interval of approximately 200 and 650 milliseconds, respectively. Eleven college students listened to the TTS produce sentences and wrote down what they heard, with the presentation rate randomly varied. Venkatagiri (1991) found that the TTS had significantly higher intelligibility scores at the slow and very slow presentation rates in comparison to the natural rate. He concluded that at a rate of about 139 syllables per minute (about 109.81wpm) resulted in more intelligible TTS.

One group that commonly uses TTS to read is the visually impaired population. In contrast to non-disabled adults, adults who have a visual impairment tend to listen to TTS at a significantly faster rate (Torihara, Nakamura, Ueda, Wada & Ishizaki, 2006). It is hypothesized that the

visually impaired students who took part in the Torihara and colleagues (2006) study had been using TTS for some time. If this was the case, they would have been very familiar with the voices. It has been shown that with practice, one's cognitive system is better able to process TTS voices (Reynolds, Isaacs-Duvall, & Haddox, 2002) . The study also did not provide information about the visually impaired participants' cognitive abilities. It is assumed that the participants in Torihara and colleagues (2006) study did not have auditory working memory or processing weaknesses which would otherwise impair the understanding of TTS. It is thought that due to their experience listening to TTS voices and not having a cognitive weakness in the area of auditory working memory and processing, these visually impaired participants were able to use a significantly faster presentation rate than their non-disabled peers.

Unlike typically developing students and visually impaired adults, it is hypothesized that students with a RD would have greater comprehension with a slower TTS presentation rate which reduces the load on their poorer WM capacity. Furthermore, as a low quality TTS voice particularly taxes WM (study 1), it is expected that the presentation rate of low quality TTS would need to be even slower than high quality TTS to facilitate the comprehension of students with a RD.

Pause When Reading Test

In contrast to unaided reading, text presentation by TTS is uninterrupted. That is, after loading text into TTS software and selecting the "read" command, the selected text is presented continuously from beginning to end. Although most TTS software pauses briefly at sentence boundaries before presenting the next sentence, this is nevertheless a very restricted way of "reading" text. Research on eye movements when reading unaided has found that the gaze of proficient readers does not glide across the page, but rather, makes a series of saccades from one place on the text to another. Furthermore, as the complexity of text increases, eye fixation time lengthens and the distance between saccades becomes shorter. About 10% to 15% of the time, regressions are made to reread sections of text (see Rayner & Slattery, 2009), for a review of eye moments and reading comprehension). Hence, unlike unaided reading which enables readers to naturally pause for longer eye fixations to allow for cognitive processing of a difficult idea, or to make regressions to check comprehension, TTS users are presented with text in a continuous, uninterrupted manner.

Research suggests that a combination of a TTS presentation rate that is too fast and has insufficient pausing may impair comprehension. Higgins and Raskind (1997) found a strong negative correlation between reading ability and comprehension scores of college students when using TTS. Whereas very poor readers showed a significant improvement in their comprehension scores with TTS compared to unaided reading, the comprehension scores of proficient readers were poorer. In contrast, a study by Montali and Lewandowski (1996) found that listening to a TTS system did not hinder the comprehension of proficient readers. The discrepancy in findings may be explained by differences between the studies in terms of presentation rate and pausing. Whereas Higgins and Raskind (1997) allowed participants to select the TTS reading speed, Montali and Lewandowski (1996) controlled for speed of presentation. Although neither study reported the reading speed, if the controlled speed in the Montali and Lewandowski (1996) study was slower it may have led to the improved comprehension of the proficient readers. In addition, Montali and Lewandowski (1996) presented one sentence of text at a time on the screen, whereas Higgins and Raskind (1997) had a full text document open and the computer read continuously. The greater comprehension scores in the Montali and Lewandowski (1996) study may be due to the text being presented in smaller segments with a pause between sentences, enabling participants to focus on small amounts of information at a time, reducing demands on their WM.

Returning to the eye-movement studies, it has been shown that in normal reading conditions, there are positions within text that proficient readers pause at for longer periods of time. The normal pause or fixation time is about 225 millisecond (ms) and 275ms when reading aloud (see Rayner, 1998). Fixation times are longer on words that end a clause (Hill & Murray, 2000; Rayner, Kambe, & Duffy, 2000) or a sentence (Rayner & Pollatsek, 1989). This longer fixation, or pause, is known as the wrap-up effect and is signaled by a comma, period, or clause boundary. The wrap-up is thought to be a period of time when unfinished interpretive processing and updating of discourse representation takes place. That is, to insure that any within clause information has been comprehended and any comprehension problems resolved (Rayner, Kambe, & Duffy, 2000). For example, when sentences are manipulated by stretching the clause boundary, or when sentences are more ambiguous, the wrap-up time at the end of the sentence is longer. Although text-to-speech software does provide a longer pause at grammatical markers (e.g. periods, comas, semicolons), the software does not recognize clause boundaries. Therefore, when a TTS program is reading to an individual it violates the natural pauses that proficient

readers insert that support efforts at comprehension. In addition, TTS always provides the same length of wrap-up time no matter how simple or complex the sentence. That is, TTS is not sensitive to grammatical complexity. This may have an impact on students' comprehension of the information they listen to by TTS. If students are presented with a simple sentence and have a long pause time they may become frustrated with the software. On the other hand, if the computer does not provide sufficient pause time their comprehension could be impaired. Therefore, it is thought that the insertion of pauses at meaningful boundaries within text should aid in students' comprehension of TTS voices.

Building on previous research that has shown that the quality of TTS voices influences comprehension (study 1), the aim of the present study was to investigate methods that may reduce demands on WM for students with a RD and thereby improve their comprehension. The methods investigated included manipulation of presentation rate, use of pauses, and the quality of TTS voice. Students with a RD were compared with typically developing students. The participants listened to passages that were read at a slow, medium, and fast rate, with no pauses added, random pauses, and phrase pauses, by either a high quality TTS or low quality TTS voice.

The study examined the following questions:

1. How does presentation rate, use of pauses, and TTS voice quality, differentially impact the comprehension of students with a RD in comparison with typically developing students?
2. What presentation rate is optimal for comprehension?
3. What type of pause (i.e., random pauses or phrase pauses) is optimal for comprehension?
4. Do the recommended settings (i.e., voice quality, presentation rate, use of phrase pauses) differ from the settings preferred by participants?

To test these hypotheses, students with a RD and typically developing students were assigned to either a low or high quality TTS voice. They listened to a total of 18 passages read aloud that varied in regards to presentation speed (slow, medium, and fast), and use of pause (no additional pauses, additional random pauses inserted within sentences, and additional pauses inserted at the end of noun phrases). The students heard two passages in each condition and were asked to answer 5 multiple choice questions after each passage.

It was hypothesized that the comprehension scores of students with a RD would be higher when listening to a high quality TTS voice than a low quality TTS, and when text is presented at the slowest rate along with the use of phrase pauses (in comparison to a fast presentation rate along with random pauses or no pauses). Typically developing students are expected to have higher comprehension scores overall. The condition leading to the highest comprehension scores for typically developing students is expected to be high quality TTS reading at the medium presentation rate with the use of phrase pauses.

Method

Participants

The participants, middle school students (grade 6, 7, and 8) in the Greater Toronto Area, came from nine schools within two school boards (see Table 13). Consent to participate was obtained from the parents of the participants, and assent was obtained from the students. The group was divided into RD and typically developing students (Controls) based on their Ellision and WordID scores. Students who scored one standard deviation below the mean on scale scores for both Elison and WordID were placed in the RD group. A total of 10 students were not included in the analysis as they scored below one standard deviation on only one of the measures. There were 47 (21 females; 26 males) students with a RD, with a mean age of 146.68(13.38) months. The Controls were comprised of 54 students (30 female, 24 males) with a mean age of 146.41 (10.304) months. There were no differences between the two groups on age.

Insert Table 13 about here

The language and literacy skills of the participants were assessed. The test battery measured their nonverbal reasoning, oral language comprehension, phonological awareness, decoding, sight recognition of individual words, and reading comprehension. Comparisons between students with a RD and Controls were carried out using multiple paired t-tests using the Bonferroni multiple-significance-test correction. Means and standard deviations of raw scores are presented in Table 14. On all tests, students with a RD scored significantly lower than Controls.

Insert Table 14 about here

Materials

Passage Comprehension

Passage comprehension was assessed using expository passages of approximately 150 words in length. Expository texts were chosen to avoid genre effects and simulate textbook reading in order to focus on relevant school learning. At the end of each of the passages was a series of five multiple-choice questions to assess explicit and inferential comprehension.

Passage Selection Procedures

Due to the large number of passages, a "passage effect" was possible (i.e., some passages could be more difficult than others). To prevent passage effects, text structure, vocabulary, and overall readability levels were controlled to ensure the same level of difficulty among the passages (Foorman, Francis, Davidson, Harm, & Griffin, 2004).

The following steps were taken to select passages:

1. Assessing the expository text, number of words per passage, and number of syllables per sentence.

2. Vocabulary level was calculated.

3. The overall readability level of the passages was assessed.

Expository passages were selected from grade 6 textbooks in the subjects of science, history, social studies, and geography, which were not being used at the time in the participating schools. Once a large selection of passages were scanned into the computer, the passages were analyzed to identify those that fell within 1 standard deviation of the target readability range. Text properties (i.e., number of words per passage, average number of words per sentence, and average number of syllables per sentence) were calculated using the Word Calculator (WordCalc.com, 2010), which provides counts and averages for the number of syllables, words,

sentences, and paragraphs in each passage. The information was entered into the Statistical Package for the Social Sciences (SPSS). The mean and standard deviation was calculated for the average number of syllables per text. Any text that fell outside one standard deviation was removed from the study.

One way of creating text equivalency is measuring word frequency. Word frequency was measured by comparing the number of words in the passages to a standard vocabulary list. The Biemiller vocabulary list for grade 6 was used, which is a list of words that 40-80 percent of grade 6 students know (Biemiller, 2009). For each passage, the percentage of words on the list was calculated, and passages that fell outside of a 95% confidence interval were discarded. Passages close to the cutoff had difficult words replaced with more common synonyms. For example, the word conciliate which according to Biemiller (2009) is typically not known by grade 6 students, could be replaced by the word satisfy which is known by most grade 6 students.

The final step was calculating the Lexile for each passage (Lennon & Burdick, 2010). A Lexile score is determined through a linear equation based on word frequency and sentence length, and represents the readability of the passage. Students in a grade that corresponds with the readability level of the Lexile score are expected to comprehend at least 75% of the text (Lennon & Burdick, 2010). Lexile scores range from 0 to 1800, with a Lexile score of 200 representing grade 1 reading level, and a Lexile score of 1200 representing grade 10 reading level. Lexile scores have been shown to have good construct validity (Stenner, Burdick, Sanford, & Burdick, 2006; Walpole, Hayes, & Robnolt, 2006), and are widely used by book, magazine, and newspaper publishers (National Center for Education Statistics, 2001). The passages used in the present study had a Lexile score between 90l and 95l, so that participants in grade 7 were expected to comprehend at least 75 to 80 percent of the text. Correspondingly, participants in grade 6 were expected to obtain lower comprehension scores than those in grade 7, whereas the grade 8 participants were expected to obtain higher comprehension scores. In total, 27 passages met the criteria, and of those 18 were selected for the study to reflect a wide range of topics (See Table 15 and Appendix A for passages)

Insert Table 15 about here

Following each passage participants were presented with 5 multiple choice questions. Three of the questions referred to information explicitly mentioned in the text, and 2 required inferences based on the texts. The explicit questions asked students to recognize a specific fact presented in the text, with answers found in the beginning, middle, and end of the passages. The inferential questions asked the student to make an inference based on the facts presented in the text. All the questions were presented on a computer screen and were read one at a time by the research assistant to the student. The students were allowed to ask to have questions repeated, however, the research assistants did not provide additional information. The research assistants recorded the responses (See Appendix B for response book).

Computer Hardware

The study used IBM Thinkpad Laptop Computers, T43, with an Intel Pentium M 750 processor (1.86GHz, 2MB L2 Cache, 533MHz FSB), with 2GB of RAM and a 70GB hard drive. The following software was installed on the computers: Microsoft Windows XP Professional Service Pack 2, E-Prime2 (Psychology Software Tools, 2008), and UTReader.

TTS Voices

The lowest and highest quality female TTS voices as established in Study 1 were used in the current study. The highest quality TTS voice, AT&T Crystal (AT&T, 2007), is an example of more recently developed synthetic speech, and is a commercially available synthetic voice production software that has greater pitch and intonation control. In Study 1, AT&T Crystal received the highest ratings for sounding the most like a human voice, was perceived as easier to understand, and was rated as the TTS voice participants were most willing to listen to. The lowest rated TTS voice was Microsoft Mary (MS Mary) by Microsoft (1998). This voice received the lowest ratings, indicating it sounded more like a computer, was perceived to be harder to understand, and participants indicated they were least likely to want to listen to this voice. Both AT&T Crystal and MS Mary use a wave concatenation approach to string diphones, phonemes, diphthongs, or syllables together to form words. AT&T Crystal has a larger number of stored wave segments to choose from and is able to better approximate the prosody within text (Beutnagel, Conkie, Schroeter, Stylianou, & Syrdal, 1998). In addition, AT&T Crystal has a

procedure to examine text structure in order to assign prosodic cues before concatenation occurs. This allows for better production of prosodic cues by the TTS voice.

Phrasing Parsing Software

The Stanford Parser (The Stanford Natural Language Processing Group, 2010), an open source JAVA based application, informed the placement of phrase pauses by determining noun and verb phrase boundaries. The Stanford Parser can be downloaded from The Stanford Natural Language Processing Group (2010) website. When a sentence is inputted, the parser works out the grammatical structure. For example, it determines what groups of words go together such as noun phrases, verb phrases, and inflections, and which words are the subjects or objects of a verb. The grammatical structure is returned as the parse structure tree with all the components and words of the sentence tagged. The Stanford Parser works on a probabilistic model based on 40,000 sentences in the Penn Treebank (for overview of project see (Marcus, Santorini, & Marcinkiewicz, 1993). The Penn Treebank was developed at the University of Pennsylvania by researchers who, using articles from the Wall Street Journal and Brown Corpus, parsed and annotated all 40,000 sentences in a format that could be read by a computer. The Stanford Natural Language Processing Group then developed probabilistic grammatical rules that are applied to novel sentences in order to parse them (Klein & Manning, 2003). Twenty-five percent of the noun phrases were checked by an individual trained in linguistics to ensure reliability of the Stanford Parser for the current study. A 100% reliability score was obtained.

UTReader

To minimize variations in the presentation of passages, a "Wizard of Oz" procedure (see (Kelley, 1983) for description) was used. In this procedure, instead of using software in real time, parsing of the passages was done off-line. XML tags were inserted within the passages, and software (see Figure 6). The defined period used in the study was 500 ms. Once the pause tags were added, the document was parsed into an XML document that retained the pause tag but did not make it visible to the user (see Figure 7).

Insert Figure 6 about here

Insert Figure 7 about here

Use of Bimodal Presentation

Research on bimodal reading has shown the importance of presenting passages in both visual and auditory formats. In one study, the comprehension scores of poor and proficient readers using TTS were significantly lower when text was presented auditorily, in comparison to when text was presented bimodally (Montali & Lewandowski, 1996). Furthermore, in the bimodal condition, there was no significant difference between the poor and proficient readers' comprehension scores, in contrast to when text was presented in auditory or visual only conditions (for which the poor readers had lower comprehension scores than the proficient readers). Based on these findings, in the present study, as each word was presented auditorily it was simultaneously highlighted yellow on the computer screen. This is a common default setting used in commercial TTS products (e.g., Kurzweil Educational Systems, 2006; Freedom Scientific Group, 2010).

Presentation Rate

UTReader has a built in presentation rate adjuster. The software could adjust the presentation rate from -5 to +5 with 0 as the default presentation rate. To determine WPM for each setting the software was loaded up with a passage rated at the grade 7 level and containing11,840 words. Next, the software created a wave file of the TTS voice reading aloud. To determine the presentation rate, the length (in time) of the wave file was divided by the number of words in the passage (see Table 16 for the presentation rate of each setting for the two voices).

Insert Table 16 about here

Presentation rates were randomized to prevent an order effect. Based on the work of Reynolds and Givens (2001), the planned presentation rates were 130, 150, and 170 WPM. As the low quality TTS and high quality TTS voices were unable to present the words at those exact speeds,

the average speeds of 117, 148, and 185 WPM were used, and coded as Slow, Medium, and Fast, respectively (see Table 17 for the exact presentation rates of each voice).

Insert Table 17 about here

Types of Pauses

Text files were loaded into the Stanford Parser (The Stanford Natural Language Processing Group, 2010), which output a parse structure tree for each sentence. Based on the parse structure tree, XML tags were placed at the end of noun phrases using the UTReader. The UTReader converted each XML tag to a 500ms pause. Therefore, a 500ms pause was inserted at the end of all noun phrase boundaries.

A 500ms pause was chosen based on findings of eye-movement research, as well as studies that have used pauses to enhance oral language communication. Eye-movement research has found that the length of time for pauses at natural linguistic breaks (e.g., at clause boundaries and commas), is approximately 500ms. Specifically, there is approximately a 444ms pause with commas (Hirotani, Frazier, & Rayner, 2006), and a 627ms pause with noun phrases and at the beginning of sentences (Staub, 2007). In one study, elderly participants who listened to time-compressed speech[1] that had silent intervals (i.e., pauses) inserted at the end of clause and sentence boundaries had greater comprehension than when listening to time-compressed speech without the pauses. The pause time of 125% of a normal pause yielded the best comprehension scores. Unfortunately, the actual pause time was not reported (Wingfield, Tun, Kon, & Rosen, 1999). Another study found that an inter-clause pause of 40ms to 100ms was insufficient to enhance the comprehension of elderly participants who listened to time-compressed speech (Grdo-Salant, Fitzgibbons, & Friedman, 2007). Although the pause time is not reported in Wingfield and colleagues (1999) study, the pause time they used was 125% longer than a regular

[1] Time-compressed speech involves the process of taking an original recording and reducing the length of the recording by shortening spacing between words. Therefore, the articulation of words remains the same but the speed at which phrases are presented increases. For the elderly who have slower processing speeds, time-compressed speech has been shown to impair their comprehension (Gordon-Salant & Fitzgibbons, 1993).

pause. If a regular pause is about 500 ms at the end of a sentence or clause boundary, they would be expected the insert pause was about 625 ms. Taken together, these findings suggest that the length of pauses differentially impacts comprehension. For the present study, a 500ms pause was used in the hopes of maximizing comprehension.

To control for whether the presence of pauses alone improves comprehension, another condition was presented to participants in which 500ms pauses were randomly inserted into passages. Approximately the same number of random pauses were inserted as were presented in the phrase pause condition. The randomized pauses were not closer than 3 words apart or further than 10 words apart.

In the third condition, only the pauses automatically generated by TTS were presented. This condition is labeled the "no pause" condition as no additional pauses were added. The TTS system automatically inserts pauses at grammatical markers, such as following a period or comma. Therefore, these automatically inserted pauses were present in all conditions.

For both presentation rate and use of pauses, there were a total of 9 different conditions. That is, 3 Presentation Rates (Slow, Medium, Fast) by 3 Uses of Pauses (No Pause, Random Pause, Phrase Pause). Two passages were presented in each condition for a total of 18 passages (see Table 18).

Insert Table 18 about here

Listening Environment

Students wore headphones with the volume level equated to a mean of 735.5 dB. This is consistent with the volume level used in the study by VenKatagiri (2004). Sessions were carried out in a room at the participating schools. The rooms used were often in the main offices or close to the participants' classrooms. Only the experimenter and participant were present during experimental sessions. Environmental noise was measured at the beginning of each testing session with a sound level meter (Scosche SPL1000F), and the average noise level was 62 (SD=11) dB.

Procedures

Participants were welcomed and given an introductory briefing which informed them that the test would take between forty to sixty minutes, and that they could take a brief break at any point. They were informed that the first task involved listening to a computer read text that was simultaneously presented on a computer screen. After having been randomly assigned to MS-Mary or AT&T Crystal, the students listened to a passage presented to them by their assigned voice for 30 minutes to allow them to become familiarized with the voice. Research has shown that with 30 minutes of exposure to a TTS voice, the intelligibility scores of non-disabled adults increased by 80%. This research also found that listening to the TTS voice for an additional 30 minutes resulted in no additional significant improvement in intelligibility (Reynolds et al., 2000).

After listening to the sample text read by the computer, participants were told they would then listen to the computer read passages at a slow, medium, and fast rate, and that in each passage there would be either no additional pauses (No Pause), additional pauses inserted randomly (Random Pause), or pauses inserted at the end of noun phrases (Phrase Pause). At the end of each passage they were asked to answer 5 multiple choice questions about each passage. Research assistants read the questions aloud to each participant. The text was left on the computer screen and students were informed that they could refer to the text when answering the questions. The text was displayed using Times New Roman 14-point font. Passages were randomly ordered to control for practice effect.

After testing was completed, user preferences were obtained by asking participants what presentation rate and use of pauses they preferred.

Testing was completed over one 90 minute session, and the students were allowed to take breaks as needed. Upon completion, participants were thanked for their time. At a later date, the classrooms that participants were drawn from received a one-hour training session on how to use TTS and other literacy software when completing schoolwork.

Statistics

Item analysis of the questions was conducted to ensure appropriate level of difficulty. To explore how presentation rate and use of pauses impacted comprehension scores, a 2 (Reading Group) by 2 (TTS Voice) between subjects by 3 (Presentation Rate) by 3 (Type of Pause) within subjects ANOVA was used. Post hoc comparisons were based on paired-t tests. The same ANOVA design was used to examine user preferences.

Results

The 18 passages and corresponding multiple choice questions were piloted on a sample of grade 6 students before being used in the study. For multiple-choice questions with 4 alternatives, as used in the present study, the desirable item difficulty is 63% correct responses (Goodwin, 1998). Item difficulty found to result in less than 30% or more than 90% correct responses needs attention. Although the desired item difficulty was obtained in the pilot study, after analyzing the data from the 101 participants, the item difficulty was not favorable. For the 18 passages and corresponding multiple choice questions, the mean percentage of correct answers per question was 26.29% (SD=6.45%), with item difficulty ranging from 11.9% to 40.6% correct responses, and the median and mode were 26.73% and 25.70%, respectively (see Table 19). Given that each multiple choice question had four possible answers, overall performance was not better than chance responding. These results indicate that the items that were presented to the students were too difficult and a floor effect was obtained. However, item difficulty may have been different between the RDs and Controls. To investigate this, a 2 (Group) between by 90 (Items) within subjects ANOVA was conducted on Item Accuracy. There was a significant main effect for GROUP, $F(1, 8460)=6.00$, MSE=1.14, $p>.05$, $л^2=.00$. Comparing the means, RDs had significantly lower overall accuracy scores on all items (M=24.89%, SD=42.76%) than Controls (M=27.19%, SD=43.73%). Although this was a significant difference, the power is very low due to very large inter group variability in their responses to the items. As expected, there was also significant inter Item differences, $F(89, 8460)=2.09$, MSE=.40, $p<.001$, $л^2=.02$. Although post hoc tests were completed, the pattern of item differences was not meaningful and therefore is not reported. There was also a significant interaction between Group and Items, $F(89, 8460)=1.39$, MSE=0.19, $p<.01$, $л^2=.01$. Post hoc tests showed that there were 11 items that Controls had significantly higher accuracy scores on than RDs, and 5 Items for which RDs had significantly higher accuracy scores than Controls (See Table 19 for means and standard deviations). These

results suggest that the test was too difficult for the participants in this study, and as such, the results are not interpretable.

Insert Table 19 about here

Nevertheless, for reporting in this dissertation, the following analyses were conducted to investigate the effect that manipulating Presentation Rate, Pauses, and Voice had on the comprehension scores of the RD and Control students. A 2 (Group) by 2 (TTS Voice) between subjects and 3 (Presentation Rate) by 3 (Type of Pause) ANOVA was conducted with overall passage comprehension score as the dependent variable (See Table 20 for descriptive statistics). There was a significant main effect for Reading Group ($F(1, 79)=41.21$, $MSE=699.28$, $p<.001$, $л^2=.05$) with RD students scoring lower overall (M=4.48, SD=.22) than Controls (M=6.42, SD=.21). In addition, two significant interactions were found. The first interaction was between Pause and Voice ($F=3.98$, $MSE=$,$p<.05$). Post hoc pairwise comparisons revealed a significant difference between Random Pause and the two Voices (low quality and high quality TTS voices). When the computer presented text with a Random Pause, students that were assigned to MS-Mary (M=5.82, SD=.25) had higher comprehension scores than students who listened to AT&T Crystal (M=5.05, SD=.25; See Figure 8). A second significant interaction was found between Presentation Rate, TTS Voice, and Group ($F(2,158)=4.39$, $MSE=11.74$, $p<.01$, $л^2=.05$). Post hoc pairwise comparisons indicated that for all comparisons RD students had lower accuracy scores than Controls. In addition, amongst the RD students, those who listened to MS-Mary had higher comprehension scores than those who listened to AT&T Crystal at the Slow and Medium Presentation Rate (see Figure 9). Furthermore, in the RD group there was a significant difference between Slow and Fast Presentation Rate while listening to AT&T Crystal, with the Fast Presentation Rate resulting in significantly higher comprehension scores. As such, the power of the results is very low and therefore the results could be spurious.

Insert Table 20 about here

Insert Table 21 about here

Insert Figure 8 about here

Insert Figure 9 about here

As the main findings of the study are not interpretable, an examination of group differences was carried out. Analyses were conducted to compare user preferences in regards to their preferred presentation rate and use of pause. A 2 (Group) by 2 (TTS Voice) between subjects by 3 (Pause) within subjects ANOVA was conducted on participants' ratings. There was a significant main effect for Pause, $F(2,84)=32.34$, $MSE=42.93$, $p<.001$. Post hoc showed Random Pause (M=2.36, SD=1.28) was less favoured than No Pause (M=3.68, SD=1.12) or Phrase Pause (M=3.45, SD=1.24). A 2 (Group) by 2 (TTS Voice) between subjects by 3 (Presentation Rate) within subjects ANOVA was also run for participants' preference. A significant difference was found for presentation rate, $F(2, 84)=28.89$, $MSE=48.36$, $p<.001$. Post hoc comparisons showed that students did not prefer the Slow presentation rate (M=2.36, SD=.13) over the Medium (M=3.78, SD=.12) and Fast (M=3.54, SD=.16; see Table 22) presentation rates. No other significant differences were found.

Insert Table 22 about here

Discussion

When TTS software presents text auditorily it does so at a consistent rate starting at the beginning of a sentence until it reaches a grammatical marker (e.g., periods, commas, colons, and semi colons). It was thought that the continuous presentation of text may tax working memory (WM), and may explain why studies have produced inconsistent findings in regards to comprehension of connected discourse presented via TTS. In addition, the use of a lower quality TTS voice has been shown to also tax WM (see Study 1). The aim of the present study was to investigate methods that may reduce demands on WM and thereby improve comprehension, by

manipulating presentation rate, use of pauses, and the quality of the TTS voice. To this end, the study set out to establish an equivalent readability level and appropriate item difficulty of eighteen expository text passages. A great effort was dedicated to establish text difficulty equivalence and to ensure acceptable item difficulty. Unfortunately, the resultant item difficulty was not acceptable, and therefore the results need to be interpreted with caution. In what follows a number of possible interpretations for the lack of effect are raised and discussed.

The 18 passages and the comprehension questions that were presented after each passage was listened to were piloted on five students in grade 6 who reported not have any reading difficulties, and the passages were found to have an acceptable item difficulty. It is possible that the passages and questions were too difficult, but that this was not identified due to the pilot group having different characteristics leading to better comprehension (e.g., greater motivation, higher IQ, better reading ability, the activation of metacognitive strategies such as taking more time to answer the questions, rereading the passages, and so on). It is also possible that an acceptable level of item difficulty would have been found if the participants were given the opportunity to read them unaided (as was done in the pilot condition), or if they were able to employ comprehension enhancing strategies such as varying eye fixation times and carrying out regressions. It has been well documented that strategies such as predicting upcoming text content, constructing self-explanations and clarifications, generating and answering questions, identifying the gist of the meaning, and self monitoring of comprehension, results in improved reading comprehension (McNamara, 2007; National Reading Panel, 2000; Pressley & Harris, 2006). When passages were presented by TTS, participants who may have tried to use these strategies would have concurrently heard the text presented auditorily without interruption. This may have created a condition of dual codes (e.g., auditory listening and visual reading), taxing WM and interfering with the use of comprehension enhancing strategies, and may explain the poor comprehension scores of the passages when presented by TTS. Although phrase pauses of 500ms were inserted in one of the TTS conditions, students did not have control over when to do such things as pause and regress, and for how long, as they would with unaided reading.

This hypothesis most likely applies to typically developing students, whereas students with a RD would nevertheless be expected to benefit from TTS in comparison to unaided reading. That is, students with a RD do not employ these reading comprehension strategies as effectively, so the dual code present with TTS is not expected to significantly interfere with their comprehension.

In fact, it has been shown that when text is presented simultaneously in auditory and visual form to students with a RD their comprehension is better than when their reading is unaided (Montali & Lewandowski, 1996). This was also supported by a study by Higgins and Raskind (1997), who compared the reading comprehension of college students with severe, mild, moderate, or no reading difficulties when reading unaided or using TTS. That study found that only those with severe reading difficulties had improved comprehension when using TTS, whereas the other participants experienced a decline in comprehension scores when using TTS in comparison to unaided reading. Unfortunately, in the current study it was not feasible to have the students read the same passages without the assistance of TTS in order to compare their unaided and TTS reading comprehension. A follow up study to determine this is needed. It is also possible that the passages and questions were indeed too difficult. Again, a follow up study using different passages is needed. As Fletcher (2006) stated in a special issue of the Scientific Study of Reading dedicted to reading comprehension, "The clear consensus across these articles is that the measurement issues are complicated, reflecting the complex, multidimensional nature of reading comprehension" (p. 323). Indeed, developing 18 passages that yield the same readability levels and have questions of equivalent difficulty is remarkably complex. The process followed to develop the passages was in line with past recommendations. Foorman et al. (2004) and Hiebert (2002) have showed that vocabulary, number of syllables per sentence, and variations in text characteristics are related to the readability of a passage. In the current project, great effort was taken to follow these recommendations and yet the desired comprehension scores were not obtained.

It is possible that the length of the passages and density of information in these texts may have been too demanding. In contrast to the 150 word passages used in the current study, many previous studies that have investigated comprehension of TTS voices have had participants listen to short, 4 to 8 word sentences, and that task was to indicate whether the last word of the sentence is plausible (Paris, Gilson, & Thomas, 1995; Reynolds & Givens, 2001; Reynolds, Issaac-Duvall, & Haddox, 2002; Venkatagiri, 1991). For example, an implausible sentence would be "The ice is *hot*". In these studies, response latency of correct answers is used to assess item difficulty.

Perhaps, had short statements requiring a yes/no response been used in the current study, it would have been possible to measure the impact that presentation rate and use of pauses had on

response latency. Response latency would be used in this condition instead of accuracy scores as participants in all conditions would be expected to achieve a high accuracy score due to the simple nature of the task. Response latency, however, would be expected to vary as more demanding conditions would require additional cognitive processing. This would indicate which conditions reduce WM load as shown by shorter response latencies, and would therefore be expected to facilitate comprehension. At the same time, note that it is possible to respond correctly to such statements on the basis of prior knowledge without relying on the text. It can be hypothesized that text presented by TTS at a slower rate and/or with phrase pauses would result in shorter response latency. In addition, an interaction would be expected between phrase pause and presentation rate, such that phrase pauses would result in shorter response latency even with a fast presentation rate. This finding would be expected as the pauses would allow for short-term memory to retain the presented acoustic information, and during the pause, the central executive could facilitate integration of the information into a comprehension schema. Therefore, when the last word (making the sentence plausible or not) is heard, the individual would already have a conceptual understanding of the passage leading to a quicker response.

Plausible sentences are an interesting paradigm and were considered during the conceptualization of this study; however they do not reflect how TTS is commonly used. It was desirable to replicate the actual conditions students encounter when using TTS for academic work. Therefore, the current study aimed to go beyond short sentences and investigate comprehension of passages from grade appropriate textbooks. Longer passages are commonly used in reading comprehension tests such as the WIAT-IV, GORT, and the Iowa Test of Basic Reading Ability. These standardized reading comprehension measures could not be used as their passages increase in difficulty throughout the tests, whereas the design of the current study required 18 passages at the same readability level.

The passages created were very dense with factual information, to an extent that they may have been a better test of memory than reading comprehension. A common reading strategy of proficient readers is to reread sections of text to find the answers to questions (e.g., Daneman & Hannon, 2001; Farr, Pritchard, & Smitten, 1990; Skakum, Maguire, & Cook, 1994; Pressley & Harris, 1995). An observation made during the administration of the tests was that the participants did not review the passages when presented with questions, despite the fact that the texts remained accessible on the computer screen and the fact that the participants were informed

that they could reread the text before responding to the comprehension questions. The participants in this study probably relied on the information they had listened to with only one exposure per passage. The combination of the use of TTS, text length, density of facts, compounded with lack of experience with or motivation to activate comprehension monitoring strategies probably overtaxed their WM and ability to respond to the comprehension questions. Andreeassen (2010) has shown that WM accounts for a significant amount of variance in reading comprehension, even after controlling for gender, word recognition, comprehension strategies, and motivation for long passages (i.e., 95 word passages). The even greater length of the passages in the current study, at 150 words, probably exceeded the WM capacity of participants, resulting in poorer comprehension.

Future research that looks at the comparison of TTS and unaided reading should use a combination of plausible sentences and passages to assess comprehension. The plausible sentences will allow for the assessing of the cognitive load that TTS or unaided reading places on the reading ability groups, while the longer passages will assess the interaction of compression strategies, motivation, WM capacity, with the modality of reading (TTS vs unaided).

It is also possible that problems associated with the construction of the multiple choice questions contributed to the results. Each multiple choice question consisted of 4 options, with one correct answer, two plausible distractors, and one non-plausible distractor. The item analysis revealed that many questions had two responses with the same level of endorsement, indicating that participants found it difficult to distinguish between the correct answer and one of the distractors. In a follow up study, questions need to be further developed to ensure that participants are better able to distinguish the correct response.

For many individuals with a RD, the use of TTS is recommended as a tool that can help them access information and close the learning gap created when a student's ability is not sufficient to meet the requirements of the curriculum (Edyburn, 2005). It is necessary to try to both remediate academic weaknesses and provide technology to compensate for these weaknesses. When both are done, students should show gains in academic performance. The current study *proposed* that a third component is essential to improve academic performance. That is, it was proposed that the settings of TTS should be customized based on the learning profiles of users. It was thought that customizing TTS presentation rate, use of pause, and quality of voice, would influence the

comprehension of students with a RD by impacting the extent of demands on their WM. It was hypothesized that presenting the text at a slow or medium rate, with high quality TTS and phrase pauses, would reduce WM load and increase the comprehension of students with a RD. Unfortunately, due to the passages having an item difficulty level that was too high, the study was not able to establish if this was the case.

It is important to evaluate how to match TTS customizations to learning profiles, as students may not necessarily select settings best suited for them. Participants were asked which presentation rate and use of pause condition they preferred. There was no significant difference between the controls and students with a RD. Both groups indicated that their preferred presentation rate was at the medium or fast speed, which is understandable as it approximates a normal conversational rate of speech. However, as noted above, these speeds may be in fact too demanding on WM for students with a RD.

As for the use of inter-clause pauses, the participants were not unanimous in their preferences. Surprisingly, students with a RD did not prefer the use of phrase pauses over no pauses, nor did they prefer the slow presentation rate, even though these customizations were hypothesized to reduce WM load. It is thought that students may choose presentation rate based on natural conversation rates, wanting the TTS voice to speak faster to finish the reading material more quickly, or at a speed they perceive they can comprehend well at. Although students may prefer a faster reading speed than the rate hypothesized to improve their comprehension, research is still needed to ascertain whether presentation rate impacts comprehension.

Past research has shown that TTS has the potential to be a useful tool that can help students with a RD improve comprehension, but additional research is needed to identify methods to optimize their comprehension when using TTS. Replication of this study, with modifications based on the above recommendations, is warranted. In order to address the possibility that the hypothesized results were not found due to measurement issues it is necessary to replicate this research with easier passages that are less dense in terms of information, and with different, reliable modes of testing comprehension. In addition, the comprehension of the passages in an unaided versus TTS condition is required to clarify whether the comprehension of students with a RD improves with TTS.

Chapter 3

Language Profiles of Language Impaired, Specific Reading Impaired, and Typically-Developing Students

In studies 1 and 2, the intelligibility and comprehensibility of text-to-speech (TTS) software was evaluated with students who either had a reading disability or were typically-developing. The language and literacy ability of the two groups was assessed to understand whether differences in their abilities may explain their differing TTS intelligibility and comprehensibility scores. In conducting this analysis it was observed that the reading disabled group was in fact comprised of two separate groups. The first group conformed to the reading disabled classification (i.e., 1 standard deviation below the mean on ellision and word attack standard scores), whereas the second group had much greater language impairments, and was identified based on scoring 1 standard deviation of a standard score below the mean on sentence repetition, receptive vocabulary, and oral language comprehension. Due to the unexpected presence of students with specific language impairment (SLI), an analysis was conducted to compare their profile with the reading disabled and typically-developing students.

Although there are 3 distinct groups within this data set, the profiles of the three groups could not be analyzed in study 1 and 2 as there was a significant difference in the number of participants in the between-subject conditions. Non-parametric statistics could not be used as the 3 (Voice) by 3 (Group) design could not be supported. Therefore, this analysis investigated the prosodic sensitivity of SLI, reading impaired (RI; formerly referred to as reading disabled), and typically-developing students between grades 6 to 8.

Students who have a SLI have been reported to have difficulty with speech intelligibility, with their oral language lagging behind other areas of development (Leonard, 1998). These individuals often experience impairment in language processing, such as vocabulary and grammar, and have difficulty with phonological skills. These weaknesses lead to difficulty acquiring basic word reading abilities (Bishop & Snowling, 2004; Snowling & Hayiou-Thomas, 2006). It has been argued that these difficulties may be due to limitations in the capacity of the

phonological short-term memory of SLI students (Gathercole & Baddeley, 1990). In comparison to typically-developing students, SLI students store less phonological information in short-term memory (Elizabeth, Lambon Ralph, & Baddeley, 2004). To help identify students with SLI, Conti-Ramsde, Botting, and Faragher (2001) investigated a set of psycholinguistic markers. Based on previous literature, Conti-Ramsde and colleagues (2001) used a third person singular task, a past-tense task, a nonword repetition task, and a sentence repetition task. Although the group of psycholinguistic markers showed high levels of sensitivity (90%), specificity (85%), and overall accuracy (88%), the sentence repetition task was shown to be the most useful. It is thought that this may be due to having to hold in memory the complete sentence before repeating it. This would rely heavily on short-term auditory memory to hold the sentence verbatim to reproduces it. As sentence repetition is a good identifier of students with SLI, then a key cognitive difficulty to examine would be short-term auditory memory.

Similarly to SLI students, RI students also have difficulty with phonological skills and word reading. These weaknesses cannot be accounted for by low intelligence, poor educational opportunities, or acquired neurological damage (Snowling, 2000). The reading and spelling difficulties of RI students have been attributed to two core cognitive deficits: phonological awareness and naming speed. Phonological awareness is the understanding that language is comprised of small units of sound and the ability to manipulate these sounds (Shankweiler & Fowler, 2004). RI students, in comparison to their typically-developing peers, score lower on phonological awareness tests that assess the ability to segment, isolate, and blend phonemes (Wagner & Torgesen, 1987; Wagner, Torgesen, & Rashotte, 1999). The National Reading Panel (2000) stated that combined with letter knowledge, phonological awareness is the strongest predictor of reading ability.

Prosody is the phonological system comprised of the tempo, rhythm, and stress of language, and plays an important role in language and reading. One common measure of prosody is sensitivity to speech rhythm (Wood, 2006; Wodd & Terrelly, 1998) (Wood C. , 2006; Wood & Terrell, 1998). Infants are able to detect rhyming as early as 7.5 months of age, which is thought to support development of their lexicon (Jusczyk, Houston, & Newsome, 1999) and initial reading development (Wood & Terrell, 1998). Rhyming also supports the development of reading skills, with children's pre-literate rhyme detection ability being a predictor of initial reading development (Wood & Terrell, 1998). Furthermore, prosodic ability has been linked to both

word-level reading and reading comprehension (Whalley & Hansen, 2006). For word-level reading, research has found a relationship between the prosodic skills and decoding speed of both children and adults (Schwanenflugel, Hamilton, & Kuhn, 2004; Kitzen, 2001). One study found that rhythm production (an aspect of prosody) correlates significantly with the reading ability of children from grades 1 to 5 (David, Wade-Woolley, Kirby, & Smithrim, 2007). In addition, the study found that rhythm production predicted significant variance in the reading ability of grade 5 students when phonological awareness or naming speed is controlled for. In addition, Whalley and Hansen (2006) found that the performance of children on a component nouns task predicted unique variance in word identification. The component nouns task assesses the prosodic features of intonation, stress, and pauses by having children distinguish between phonemically identical compound nouns (e.g., 'ice-cream') and noun phrases (e.g., 'ice, cream'). It may be that prosodic information supports word reading by helping access words from the mental lexicon (Lindfield, Wingfield, & Goodglass, 1999).

Prosody is also important for reading comprehension. In one study of grade 4 students, prosodic skills were shown to explain a unique part of the variance in reading comprehension scores after controlling for word reading accuracy, phonological awareness, and non-phonemic rhythmic sensitivity (Whalley & Hansen, 2006). The contribution of prosodic skills to reading comprehension may be mediated through oral language comprehension, which is consistent with the simple view of reading. The simple view of reading argues that language skills used for listening comprehension are the same as those needed for reading comprehension (Hoover & Gough, 1990). If the simple view of reading is correct, individuals with difficulty reading may also have difficulty processing prosodic information.

Both SLI and RI students have difficulty with processing phonological information and word reading (Bishop & Snowling, 2004). The current study investigated whether these two populations also have difficulty with processing prosodic information. To compare the prosodic ability of SLI, RI, and typically-developing students, two measures of prosodic sensitivity were administered. The first measure, the sensitivity to phrase rhythm task, assesses prosodic sensitivity at the phrase level. This measure is a reiterative speech task which retains the prosodic patterns of phrases (e.g., stress, rhythm, and intonational pattern) by replacing phonemic information with a single meaningless syllable, in this case 'dee' (Nakatani & Schaffer, 1978). Students listened to a nondistorted phrase, followed by two distorted phrases using the "dee"

sound in place of phonemic information, and selected which one sounded most like the nondistorted phrase. The second measure, the sensitivity to sentence rhythm task, assesses prosodic sensitivity at the sentence level. Students were asked to discriminate between the metrical stress contours of two sentences. The students first listened to a basic sentence (no distortion), followed by a second sentence created using a low-pass filter (and thereby distorted). The low-pass filter removes phonemic information from spoken sentences while maintaining the metrical stress contours of phrases. Students were asked to determine if the sentences were the same or different. Children with a SLI have been shown to do poorly on this task (Fisher, Plante, Vance, Gerken, & Glattkey, 2007). It was expected that due to the phonological difficulties of SLI and RD students, both groups would have difficulty processing prosodic information. In comparison to typical developing students, it was expected that the SLI and the RD would have lower scores on the two prosodic measures.

The current analysis had three specific research questions:

1) Using sentence repetition to identify students with SLI, do students with SLI have lower oral language skills than RI and typically-developing students as would be expected?
2) Does the relationship between sentence repetition with short-term memory and working memory have different degrees of strength?
3) Do SLI and RI student have lower prosodic phrase and sentence rhythm sensitivity than typically-developing students?

Regarding the third question the SLI and RI students were expected to perform similarly on both of the tasks as both groups believed to have difficulty processing prosodic information, though the SLI will have significantly lower scores overall. Typically-developing students, on the other hand, were expected to do significantly better than the SLI or RI students on both tasks, given that they are able to process prosodic information effectively.

METHOD

Participants

The participants, middle school students (grade 6, 7, and 8) in the Greater Toronto Area, came from nine schools within two school boards. Students were nominated to take part in the study by their teacher. Teachers who nominated students that had a reading disability were asked to nominated students from the same class as control students. The participants were grouped as specific language impaired (SLI), reading impaired (RD), or typically-developing (Controls) based on their auditory working memory, phonological awareness, and word reading skills. Students who scored below one standard deviation on standard scores of sentence repetition task were placed in the SLI group. The sentence repetition task has been shown to be a good psycholinguistic marker for SLI (Conti-Ramsden, Botting, & Faragher, 2001). Students who scored below one standard deviation on standard scores on both Ellision and Word Identification, but were above one standard deviation on standard scores on the sentence repetition task, were placed in the RI group. Students who scored below one standard deviation on standard scores on only one of the three measures were not included in the analysis. In total, 8 students were removed because they did not meet the double criteria. The SLI group was comprised of 25 students (13 females / 12 males) with a mean age of 12 years – 0 months (SD=13.1 months). The RI group was made up of 28 students (13 females / 15 males) with a mean age of 11 years – 7 months (SD=11.4 months) years. The typically-developing group included 48 students (25 females / 23 males) with a mean age of 11 years – 9 moths (SD=11.76 months).

There was no significant difference between the groups on age, $F(2, 99)=1.11$, MSE=1.06, $p=.99$, grade ($\chi^2=6.5$, $p=.17$), or gender ($\chi^2=.26$, $p=.88$), but there was a significant difference between the groups in regards to the school attended ($\chi^2=19.53$, $p<.05$). There was an uneven distribution of Controls, with school 3 having a high number of Control students, and school 6 having no Controls. This is due to the fact that school 6 is only comprised of students with special needs. See Table 24 for the distribution of each group of students across schools and grades.

Insert Table 24 about here.

Materials

Nonverbal Reasoning: Nonverbal reasoning will be measured using the Matrix Analogies Test (Naglieri, 1989). The test involves having students point to the design that completes a pattern.

Working Memory: Digits Forward and Digits Backwards from the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) was used to assess working memory. In Digits Forward, students are asked to repeat back number strings starting with four digits. The number of digits is increased until the student makes three consecutive errors. Digits Backwards has students repeat back a string of digits in the opposite order than the order they were presented.

Rapid Automatized Naming: The Number and Letter Stimuli Subtest, taken from the CTOPP, consists of 36 digits presented in a 9 x 4 array (Wagner, Torgesen, & Rashotte, 1999). This task was scored according to naming time in seconds as well as the number of uncorrected naming errors.

Phonological Awareness: The Ellision subtest of the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999) was administered. For the Ellision subtest, students say a word without saying a part of the word (e.g., "Say toothbrush without saying tooth"). Testing is discontinued after three consecutive errors.

Sensitivity to Phrase Rhythm: The DEEdee task developed by Whalley and Hansen (2006) as used to assess sensitivity to phrase rhythm. In this task, students listen to phrases consisting of the titles of cartoon movies or television shows (e.g., "The Simpsons"). The title is followed by two DEEdee phrases. One DEEdee phrase retains the prosodic structure of the original phrase (e.g., "deeDEEdee"), whereas the other does not (e.g. "DEEdeeDEE"). In the study, the students were asked to indicate which of the two phrases matched the original phrase. There were two practice trials and 18 test trials.

Sensitivity to Sentence Rhythm: This task was taken from Clin, Wade-Woolley, and Heggie (2009), who had adapted it from Wood and Terrell (1998). The Freddy/Eddy task involves having to discriminate between the metrical stress contours of two sentences. Students heard two

basic sentences: the first with no distortions (e.g., "She made many balloons for the party"), whereas the second sentence was created using a low-pass filter to create distortions. The low-pass filter removed phonemic information while maintaining the prosodic contour of the sentences. The Pratt audio editing computer software (Boersma & Weenink, 2008; Praat: Doing Phonetics by Computer, Version 4.6.34) was used to create the low-pass filter. The low-pass filtered sentences were either the same or different (e.g., "She played higher tunes than her brother did", in comparison to the example sentence given above). After hearing the two sentences, students were asked to state if they had the same rhythm. All sentences in the task were 10 syllables in length. There were two practice trials and 14 test trials.

Sentence Repetition: The Recalling Sentences task of the Clinical Evaluation of Language Fundamentals – 4th edition (CELF-4) was used to assess language processing and auditory working memory (Semel, Wiig, & Secord, 2003). Participants listened to spoken sentences of increasing length and complexity and orally repeated the sentences.

Decoding Skill: The Word Attack subtest of the Woodcock Reading Mastery Test-Revised (WRMT-R) was used to evaluate the ability to sound out words. The Word Attack subtest consists of 50 pseudowords (e.g., "tat" and "op") that comply with English phonology.

Word Reading: The Word Identification subtest of the WRMT-R was used to evaluate the word recognition skills of the students (Woodcock, 1987). On this subtest students read as many real words as they could.

Receptive Vocabulary: The Peabody Picture Vocabulary Test – III (PPVT-III; Dunn & Dunn, 1997) was used to evaluate receptive vocabulary. The students were asked to select one of four pictures that matched the meaning of orally-presented words.

Reading Comprehension: The Passage Comprehension subtest of the Woodcock Language Proficiency Battery—Revised (WLPB-R; Woodcock, 1991) was used to evaluate reading comprehension. On this closed subtest, students read brief but progressively more difficult passages and filled in a missing word.

Listening Comprehension: The Listening Comprehension subtest of the WLPB-R (Woodcock, 1991) was used to evaluate oral language proficiency. Students were asked to provide the final word of orally-presented sentences.

Procedures

Following agreement to participate in the study from school board officials, school principals, and classroom teachers, teachers distributed a letter and consent form to students that described the study. Students whose parents consented were enrolled in the study. During the school day, students were excused from class to participate in the project. The study was explained to each student and assent was obtained. Following this, the language and literacy test battery was administered. Testing lasted one hour on average, and students were allowed to take breaks at any time. Testing took place between March and June of 2009 and was conducted by research assistants and the principal investigator.

Setting

Testing was carried out in rooms at each school which were often near the main office or the students' classrooms. Only the experimenter and student were present during testing. Noise levels were established by using a sound level meter, with the average noise level being 62 db. Past research has shown that classroom noise levels vary between 47 to 73.3 dB, with a mean of 62.6 dB (Sisto et al, 2007).

Results

The first goal of this analysis was to determine whether the sentence repetition task could differentiate between individuals with a SLI, a RI, and who are typically-developing. To investigate whether the Ability Groups (SLI RI, and Controls) scored differently on the language and literacy measures, a One-way MANOVA was conducted. The means and standard deviations are presented in Table 25. Raw scores for the language and literacy measures were used as dependent variables, and Ability Groups were used as independent variables. The multivariate test of differences between groups used the Wilks' Lambda criteria, and was statistically significant (Λ=.094, $F(30, 163) = 12.37$; $p<.001$). Follow-up multivariate comparisons showed that there was a significant group effect for all language and literacy measures, except for RAN Digits and RAN Letters (see Table 26 for Main Effect of Ability Group on Language and Literacy measures).

Insert Table 26 about here

Post hoc tests (Games-Howell) within conditions were conducted to examine individual group differences. (See Table 25 for Ability Group differences on the dependent variables). The results revealed clear differences between the three groups. The Controls obtained the highest scores on all language and literacy measures. The RI group had specific weaknesses in Ellision, Word Identification, Word Attack, and RAN scores. In contrast, the SLI group showed the greatest weakness in the language-related areas of Vocabulary, Listening Comprehension, Sentence Repetition, and Working Memory. Regarding the prosody measures, an interesting finding appeared; on the DEEdee task, there was no significant difference between the SLI and RI groups, although both groups scored significantly lower than Controls. Both the SLI and RI groups scores also were not significantly better than chance responding (z=1.66, p>.05 and z=.99, p>.05 respectively) whereas the Control group did have significantly better than chance scores (z=2.06, p<.05). Furthermore, on the Freddy/Eddy task there was no difference between the RI and Control groups with both groups scoring significantly above chance (z=2.21, p<.05 and z=3.11, p<.01 respectively), however the SLI group scored significantly lower. Like on the DEEdee task, the SLI group did not score above chance (z=1.79, p>.05). To help illustrate comparisons between the three groups, all scores were converted to z-scores and the individual group means were calculated for each measure (see Figure 10).

Insert Figure 10 about here.

In addition, Pearson's r correlations showed that both the DEEdee and Freddy/Eddy tasks correlated significantly with all of the language and literacy measures (see Table 23). Of particular interest, the Sentence Repetition had a stronger correlation with the Freddy/Eddy task than the DEEdee task. This indicates that Freddy/Eddy has a stronger relationship with Sentence Repetition, such that as a student's score on Sentence Repetition increases, so does their score on the Freddy/Eddy task.

Insert Table 23 about here.

One explanation for the different relationships seen in DEEdee and Freddy/Eddy between the Ability Groups may be the level of difficulty of the two prosodic tasks for the different Ability Groups. Bar graphs in Figures 2 and 3 present the total number of correct responses by Ability Group on the DEEdee and Freddy/Eddy tasks. The frequency of students who answered at or below chance on the DEEdee task was 16 % for SLI, 21% for RI and 4% for Controls. For the Freddy/Eddy task, at or below chance scores were 4% for SLI, 4% for RI, and 2% for Control, In contrast, the frequency of students who answered all questions correctly (i.e., received a score of 100%) on the DEEdee task was as follows: 4% of SLI, 11% of RI, and 15% of Controls (see Figure 11). In comparison, on the Freddy/Eddy task the percentage of perfect scores was: 4% of SLI, 25% of RI, and 33% of Controls (see Figure 12). The Freddy/Eddy task had a lower percent of participants performing at or below chance and a greater number of participants obtaining a perfect mark in comparisons to the DEEdee task.

Insert Figure 11 about here.

Insert Figure 12 about here.

The second goal of the analysis was to evaluate the relationship between the sentence repetition task, short-term memory, and working memory. Pearson's r correlations were conducted. Sentence repetition had a significant positive correlation with digits forward ($r=.632$, $p<.001$), which was a significantly stronger relationship than with digits backwards ($r=.457$, $p<.001$; $r1-r2= 0.175$; $t= 1.99$, $p=0.025$) as revealed by a correlation comparison analysis (Cohen & Cohen, 1983).

The final goal of the analysis was to investigate whether the Ability Groups differed on the two measures of rhythm sensitivity. To this end Pearson's r correlations were carried out (See Table 27). The objective was to assess intercorrelations between the two prosodic measures and the other language and literacy task based on Ability Group. In the SLI group there was a significantly positive correlation between DEEdee and Nonverbal Reasoning ($r=-.44$, $p<.05$) and

Word Identification (r=-.45, p<.05). In the RI group there was a significant positive relationship with Nonverbal Reasoning and DEEdee (r=.46, p<.01), and a large significant negative correlation with DEEdee, and RAN Letters and Total Digits, respectively (r-.56, p<.001 and r=-.58, p<.001). For the Control students, there was a significant positive relationship with Freddy/Eddy (r=.29, p<.05), Ellision (r=.31, p<.03), Word Identification (r=.31, p<.05), and Passage Comprehension (r=.31, p<.05). On the Freddy/Eddy task, SLI students had a high significant positive correlation with Ellision (r=.69, p<.001) and Word Attack (r=.51, p<.01), and a significant correlation with Listening Comprehension (r=.4, p<.05) and Passage Comprehension (r=.39, p<.05). In the SLI group there was also a significant negative correlation with the two RAN tasks (Letters and Numbers; r=.48, p<.05 and r=.41, p<.05, respectively). In regards to RI students, their Freddy/Eddy scores did not significantly correlate with any other measure. A similar result was found with Controls, however in the Control group there was a significant positive correlation with DEEdee (r=.29, p<.05). In contrast to the intercorrelations for all participants combined, each of the Ability Groups showed distinct patterns of intercorrelations involving the two prosodic measures. In contrast with the RI group, the SLI groups' DEEdee scores did not correlate with as many of the language and literacy measures, nor did they correlate as strongly with the Freddy/Eddy measure. For the RI group, DEEdee had a strong relationship with the RAN tasks but not with any other tasks. In regards to the control group, DEEdee has several moderate correlations with several of the reading measures and Freddy/Eddy only correlated with DEEdee. In other words, there is a different pattern of relationships between the prosodic measures and other language and literacy measures in the three ability Groups.

Insert Table 27 about here.

Discussion

The current analysis came out of an observation that there were three distinct ability groups within the data set. In addition to the two groups of students that were recruited (i.e., reading impaired (RI) and typically-developing students), about 25% of the participants were found to have a specific identified language impairment (SLI). Consistent with past research on SLI, the participants with a SLI had difficulty with sentence repetition (Conti-Ramsden, Botting, &

Faragher, 2001), receptive vocabulary (Bishop & Adams, 1992), and language comprehension skills (Bishop, 1997). In addition, the SLI students had difficulty with working memory, sensitivity to rhythm, and reading comprehension. The SLI and the RI group in comparison to typically-developing students had difficulty with phonological awareness, sensitivity to phrase rhythm, word reading skills, and nonverbal reasoning ability. Therefore, in comparison to the students with a RI, the students with a SLI had additional weaknesses.

The SLI students were identified based on sentence repetition which has been shown to be a good psycholinguistic marker for SLI not only in English (Conti-Ramsden, Botting, & Faragher, 2001) but in Cantonese as well (Stokes, Wong, Fletcher, & Leonard, 2006). The current analysis also lends support to the use of sentence repetition as a psycholinguistic marker of SLI, as it taps both short-term working memory and language and syntactic processing. Like Conti-Ramsden and his colleagues (2001), this study found that one standard deviation on standard scores was a useful cutoff point in determining whether a student could be identified as SLI.

Difficulty with sentence repetition has been attributed to limitations in short-term memory (Conti-Ramsden, Botting, & Faragher, 2001). In the present study, sentence repetition of all participants correlated strongly with digits forward, which was a significantly stronger relationship than with digits backwards. Digits forward is thought to be a purer measure of short-term memory, whereas digits backwards a better measure of working memory. Short-term memory is the cognitive space that temporarily holds information in mind for a few seconds (Baddeley, 1998)(Baddeley A. , 1998). Therefore, it may be argued that students who have a SLI develop language difficulties because they are not able to hold all the elements of spoken sentences in mind at once. That is, they do not have sufficient short-term memory to store a sentence verbatim in order to adequately reproduce it. Accordingly, an error analysis to identify the type of errors SLI students make with sentence repetition should demonstrate that, as students with a SLI attempt to hold in memory the first part of a sentence, they would quickly run out of cognitive space. This should result in a greater frequency of errors at the end of sentences reproduced. To support this theory, past research with German speaking SLI students that found a significant proportion also had problems acquiring syntactic rules (van der Lely, 2005). SLI and typical developing students were presented with increasingly complex sentences. SLI students had greater difficulties than the typical developing students in correctly responding to the syntactically complex sentences. This suggests that difficulty processing syntactic

information would put additional demand on SLI students' working memory, and thereby impairing their ability to retain and reproduce sentences.

In addition to short-term memory, other language processing skills are thought to be important for success with sentence repetition. In comparison to the RI and typically-developing students, the SLI students had lower scores on receptive vocabulary and oral language comprehension. Receptive vocabulary may have contributed to some of the difficulty the SLI students had with sentence repetition, as they scored almost 2 standard deviations below what would be expected for their age. As such, if an unfamiliar word was presented to a SLI student it would have required more working memory to try to identify it, placing additional demands on their already limited short-term/working memory. This argument may not apply, however, as the words used in sentence repetition are relatively higher frequency. That is, grade 6 to 8 students would likely be able to give a definition of the words used. To determine whether receptive vocabulary plays a role in the difficulty the SLI students had with sentence repetition, a logistical regression could be used, with short-term memory in the first level and receptive vocabulary in the second level. Unfortunately, due to the small sample size of the current study this analysis is not advisable in the present study.

The current analysis also examined the SLI and RI students' ability to process prosodic information. In light of the greater difficulty SLI students have in comparison to RI students with short-term memory, the findings from the prosodic measures make a lot of sense. As hypothesized, the RI and the SLI students obtained lower scores than typically-developing students on the sensitivity to phrase rhythm task. On the sensitivity to sentence rhythm task, however, there was no difference between the RI and typically-developing students, with the SLI students scoring significantly lower. This is in contrast to the hypothesis that RI students would score below the typically-developing students, as research has found that individuals with a RI have difficulty with rhythm detection (McGivern, Berka, Languis, & Chapman, 1991; Whalley & Hansen, 2006).

The discrepancy in the RI students' performance on the sensitivity to phrase rhythm and sensitivity to sentence rhythm tasks may have resulted from an interaction between the groups and the prosodic measures. One difference between the measures is that the sensitivity to phrase rhythm task may be better able to assess sensitivity to rhythm whereas the sensitivity to sentence

rhythm task is more a measure of working memory. With the sensitivity to sentence rhythm, students were presented with two sentences and had to indicate whether they were the same or different. The first sentence was presented undistorted, whereas the second sentence was distorted with a low-pass filter which removed phonemic information. In contrast to the short phrase utterances of the sensitivity to phrase rhyme, the greater length of the sentences may have provided additional auditory information to help students decide whether the sentences were the same or different. For example, the RI and typically developing students may have utilized their greater short-term memory ability to compare the length of the sentences rather than relying on their ability to detect prosody. As such, the relatively stronger short-term memory of the RI students, in contrast to the SLI students, may have enabled them to perform as well as the typically-developing students on the sensitivity to sentence rhythm task.

On the other hand, for the sensitivity to phrase rhythm task, students were presented with short utterances (phrases) that were more similar in length to one another. Students were presented with a non-distorted phrase followed by two distorted phrases that had their phonemic information replaced with the sound "dee", and were asked to indicate which of the distorted sentences had the same rhythm as the first sentence. In contrast to the sensitivity to sentence rhythm task, the sensitivity to phrase rhythm task may require more short-term memory to hold both the non-distorted and the two distorted phrases in mind for comparison. As such, RI students may not have been able to use an alternative strategy, such as comparing the length of the utterances. Therefore, unlike the sentence rhythm task, the phrase rhythm task would have limited them to the use of prosodic information to make the comparison.

Consistent with the current study's findings, Clin and colleagues (2009) used a similar version of the sentence and phrases rhythm detection tasks with typically-developing students in grades 3, 5, and 7. After correcting for the number of questions on the sentence rhythm task (10 in Clin and colleagues 2009, and 14 in the current study), the grade 6 to 8 typically-developing students in the current study had similar raw scores to the grade 7 students in the Clin and colleagues study (2009). Therefore, performance on the sentence and phrase rhythm detection tasks showed similar reliability in the two studies.

Conclusions

Three distinct groups were identified in the present study, consisting of SLI, RI, and typically-developing students. Students with a SLI have specific language, phonological, and reading difficulties, whereas RI students have only phonological and reading difficulties. The SLI group was identified using the sentence repetition task, which has been shown to discriminate between SLI and RI. The sentence repetition task is able to tap into the underlying short-term memory and syntactic processing difficulties of the SLI group, which are either not present or not as severe in students with a RI. Based on these analyses, it is recommended that the sensitivity to phrase rhythm task be used with grade 6 to 8 students when assessing their prosodic ability. In contrast to the sensitivity to sentence rhythm task, the sensitivity to phrase rhythm task is better able to discriminate between RI, SLI, and typically-developing students in regards to their prosodic ability.

Chapter 4

Overall Discussion

Education and Design Implementations

The purpose of the current thesis was to investigate ways of increasing the effectiveness of text-to-speech (TTS) software for students with a reading disability as well as for typically developing readers. Research has shown that students who are diagnosed with a reading disability have specific cognitive weaknesses. These cognitive weaknesses include the ability to process phonological information. For example, individuals with RD have a hard time manipulating phonemes effectively (Wagner & Torgesen, 1987; Wagner, Torgesen, & Rashotte, 1999). Students with a RD also have a weakness in rapid automatized naming (RAN). RAN is an indicator of cognitive speed, particularly associated with naming highly rehearsed units such as digits, letters or colour names. Individuals who have both a phonological awareness and a RAN weakness have difficulty decoding words. Students who have this "double-deficit" are inaccurate decoders and much of their cognitive resources are used sounding out unfamiliar words they read (Bowers & Wolf, 1993). In addition, students with RD are poor at automatically recognizing words as full units. Because of their poor word recognition skills and slow decoding skills, RD students also have a weakness in reading fluency, making them slow readers. It has been shown in the literature that for an individual to have good reading comprehension they must have well-developed decoding and fluent reading skills, as well as good language skills (Kirby, 2007).

To help students who have decoding and reading fluency difficulties, two different approaches can be taken: remediation and compensatory programming. Remediation focuses on the development of the students' natural decoding and fluency skills. At present, there have been several empirically supported programs that foster the reading skills of RD students (Cohen, Sevcik, Woll, Lovett, & Morris, 2008; Swanson, 1999). These empirically supported programs target the underlying skill deficits with sufficient intensity and duration and lead to significant growth in reading skills. Although this is an exciting and important approach to help students with reading disabilities, the present study focused on specific research questions pertaining to a compensatory approach.

In contrast to remediation programs, compensatory programs comprise of accommodations, learning strategies, and assistive technologies that a student can use to help them circumvent an area of weakness to perform more independently. Accommodations refer to special teaching and assessment strategies, augmented with human support that enables students to learn and to demonstrate learning without altering the curriculum expectations for the grade (Ontario Ministry of Education, 2004, p. 24). In this context assistive technology is define as any "item, piece of equipment, or product system, whether acquired commercially off-the-shelf, modified, or customized, that is used to increase, maintain or improve the functional capabilities of individuals with disabilities" (US technology-related assistance for individuals with disabilites act, 1998).

A specific assistive technology that is used for students who have RD is TTS. TTS software assists students who have reading disabilities by circumventing their area of weakness. Instead of having to decode words inaccurately and slowly, a student can listen to a computer with TTS reading the text aloud (Strangman & Dalton, 2005). However, as was discussed in Chapter 1, research to date does not demonstrate the comprehension gains expected for students with reading disabilities who use TTS.

Past research has shown that poor readers do benefit from TTS in the area of reading fluency. For example, college students with reading difficulties were found to significantly increase their reading rate when using TTS. Unexpectedly, no significant difference in comprehension scores was found for those reading with or without TTS (Elking, Cohen, & Murray, 1993). Relatedly, Raskine and Hingines (1997) report that only students with reading comprehension scores that were one standard deviation below on a standard measure seemed to benefit from this software. These results suggest that the effect of the use of TTS is not uniform across different groups of learners.

It is possible that TTS in fact may have a facilitating effect but that poor TTS comprehension outcome scores may be attributed to the features of the TTS voices used. It has been found that TTS voices place a greater demand on cognitive resources to facilitate understanding in comparison to natural voices. Several studies have shown that compared to natural voices, listening to TTS voices, yields longer response latencies (Koul & Hanners, 1997; Reynolds & Jefferson, 1999). For example, even after being exposed to TTS over five consecutive days, users

had significantly longer response latencies when listening to TTS voices than to a natural voice (Reynolds, Issaac-Duvall, & Haddox, 2002).

The purpose of the present series of studies was to investigate how to increase the effectiveness of TTS software for students who have a reading disability as well as typical developing students. Considering jointly the findings from the current series of studies and past research, four key points have emerged that can help inform developers and users of TTS. To maximize the effectiveness of TTS it is important to 1) utilize a high quality voice, 2) use a bimodal reading system, 3) control the reading speed of the software, and 4) have the program insert pauses at meaningful point such as the end of noun phrases.

Finding the right Voice

Based on the findings from the current studies, using a newer, high quality TTS voice is important. A primary characteristic of this high quality TTS voice is that it has a large number of phonemic stored units that it is able to link together to create speech. For example, as demonstrated in Study 1, when comparing the two main voices used in the current study, MS Mary (low quality TTS) and AT&T Crystal (high quality TTS), AT&T Crystal has about 19.5 times more sorted speech units than MS Mary. This allows AT&T Crystal to choose speech units that fall within a more natural pitch range and string these unites together to create a dynamic voice (varying pitch), instead of a monotone sounding voice. When a voice has a large number of speech samples to choose from, the next key feature is the ability of the voice to replicate prosody.

Accurately reproducing prosodic cues involves the "phonological system that encompasses the tempo, rhythm and stress of language" (Whalley & Hansen, 2006, p. 288) and is another essential component of a high quality TTS voice. Prosody plays a role in the signalling of the boundaries of phonemes, words, phrases, and sentences, and allows for the communication of elements of language, which are not encoded by grammar or vocabulary. These acoustic cues are communicated through variation in syllable length, loudness, pitch, and the format frequencies of speech sounds (Scherer, 1979). For example, prosody may reflect the emotional state of a speaker, such as anger or amusement, and can reflect the use of irony and sarcasm in speech. It is used to emphasize an idea, as well as to indicate if an utterance is a statement, a question, or a command. To synthesize prosody, TTS voices use different algorithms to generate

a prosodic curve for the sentence. Though the actual algorithm is proprietary knowledge, research has shown that when listening to a variety of TTS voices one is able to distinguish between different auspices of prosody (Handley, 2009). TTS voices that are better able to replicate prosody have been identified as sounding more like a human (O'Shaughnessy, 2000). Finally, TTS voices that have more refined Natural Language Processing (NLP) capacities are more highly rated on indices of voice quality. NLP works with prosody synthesizing to help handle grammatical markers. For example, when the computer comes across a question mark, it is able to increase the pitch at the end of the sentence. In addition, NLP also helps address homographs within a sentence. To illustrate, words such as /bow/ need NLP to analyze the word in the context of its surrounding words. This is necessary for the computer to know whether it should pronounce /bow/ as “the bow in the girl’s hair” or “make sure you bow when you see the queen”.

High quality TTS voices possessing more speech units, ability to reproduce prosodic cues, and integrated NLP capabilities are not only perceived as being of higher quality, but are also better understood. The present research has shown that in comparison to low quality TTS voices, high quality TTS voices are more intelligible at the word level and result in higher comprehension scores. Notably, students with an RD who listened to high TTS voices had over a 10% higher comprehension score then those that listened to low quality TTS voices. This finding supports the recommendation that when using a TTS system for students with reading disabilities or typically developing students, it is essential that they are provided with newer, high-quality TTS voices that are perceived as being of a high quality. When a student has chosen a high quality TTS voices, it is also recommended they practice listening to the voice for over 30 minutes. Past research has shown that when listening to a TTS voices for 30 minutes or more leads to better processing of the voices (Reynolds, Issaac-Duvall, & Haddox, 2002).

Bimodal Reading

Research has previously shown the importance of presenting a passage in both a visual and auditory format. In bimodal reading students can see the text and hear the word simultaneously spoken aloud. Previous research has shown that when text was presented in an auditory only condition, comprehension scores for both poor and proficient readers were significantly lower than when the text was presented simultaneously in both a visual and auditory form (Montali &

Lewandowski, 1996). In the bimodal condition, there was no significant difference between the poor and proficient readers' comprehension scores, whereas this was the case when text was presented in auditory or visual only conditions. Many of today's TTS programs have the ability to allow for bimodal reading. If the TTS program does not enable bimodal reading, it is important that the student follows along on the screen as the computer reads aloud. The same is also important for those who create MP3 or audio files of the computer reading. When the student is listening to the TTS voice on a portable audio player, they should have a copy of the text in front of them to follow along. This is important in order to maximize their comprehension of the passage.

Reading Speed

A key feature in TTS software is the ability to change the rate at which the computer “speaks”. At the same time, this setting is thought to pose some challenges. Early work on the effectiveness of TTS software showed that for poor readers, the use of TTS software led to an increase in the rate at which they read. For example, (Elking, Cohen, & Murray, 1993) found that college students who were poor readers had an average reading speed of 155 words per minute (wpm) without the aid of TTS. When they used TTS, their reading speed increased to an average speed of 180wpm. Despite this significant increase in speed, the comprehension scores of the poor readers did not change significantly between the unaided and the TTS aided condition.

A possible explanation for the lack of gains in comprehension scores could be that TTS voices were still intelligible though they were no longer comprehensible at high speeds. TTS software starts at the beginning of a sentence and continues presenting at about the same rate until it reaches a grammatical marker such as a full stop. This is a very unnatural way to read, as eye tracking studies show proficient readers move through a sentence at a variable rate. Not only do readers spend more time around punctuation marks, but they also spend significantly more time at clause boundaries. In addition, if understanding decreases, proficient readers will move their eyes to earlier sections of the text to look for clarification before moving on (Rayner, 1998). Using TTS does not allow for this natural style of reading to take place. Therefore, it is thought that if TTS may be presenting the information at a speed which exceeds the cognitive system a lack of understanding would occur. This explanation could be relevant to the discrepancy

findings in the Elking, Cohen, and Murray's (1993) and Elking (1998) studies with regard to the lack of significant change in comprehension scores in spite of increases in reading rate.

Indeed, for students without a RD, having the presentation rate set to the same speed they read unaided (100%) has been shown to maximize their comprehension. Students that had a RD also had significant higher completion scores when TTS was set to a slower reading rate at 50% of their unaided reading speed (Cunningham & Watson, 2003).

Study 2 was developed to build upon past research with intermediate RD students to identify a recommended presentation rate. Due to measurement difficulties, it was not possible to answer this question. It is hypothesized that having a TTS present at a speed between 120 and 160wpm will optimize comprehension. Just as it is important to identify an ideal voice for an individual student, it is also necessary to identify the ideal presentation rate of the software. This is especially important given that the presentation rate of voices varies at the same setting. Correctly identifying a suitable presentation rate is thought to increase the comprehension of students using the software, as the computer will then present at a speed that will not exceed the student's cognitive processing abilities. It is thought that students that have lower auditory working memory and language processing speeds will need to have the computer present at slower presentation rates. At the slower presentation rate will compensate for the cognitive weaknesses.

Noun-Phrase Pause

The same cognitive load justification can be applied to presentation rates at the level of inter phrase pauses. Proficient readers take small inter-sentence breaks when reading. They may not be aware that they take these pauses, but these pauses allow them to integrate what they have just read with prior knowledge. When a TTS voice reads to a student, it does not pause until it reaches a grammatical marker (e.g., commas, periods, question marks, or colons). By inserting phrase pauses, it was hypothesized that students' comprehension scores would increase. It was hypothesized that an increase in comprehension scores would be the result of providing the student's cognitive system with time to integrate what they have just heard with prior knowledge at the phrase pauses. Due to measurement issues this hypothesis could not be evaluated yet it serves additional attention in future research.

Cognitive profiles and TTS

One of the unexpected findings of the present research regarded the differential patterns on…based on the composition of the reading disabled group. Study 2 showed that instead of having a homogeneous group, the reading disabled group was actually comprised of 2 distinct subgroups. The first, a reading impaired (RI) group, was identified by performance of one standard deviation below the standard score mean on a test of phonological awareness and word reading. In addition, there was a specific language impaired (SLI) group as well. The latter was identified by having one standard deviation below the standard score mean on sentence repetition. The realization that the RD group in fact consisted of two subgroups emerged in the attempt to explain some of the variability within the TTS comprehensibility scores. This unexpected group identification finding raises interesting questions regarding the possibility that TTS may have differential effects with different subtypes of students with reading difficulties.

Higgins and Raskind's (1997) research points towards the possibility that some groups do benefit more from TTS then others. In their study, students who scored one or more standard deviation below the mean on reading comprehension standard scores benefited more from TTS than did students who scored above the cut-off point. In the current study, all students with poor phonological processing and word reading had significantly lower comprehensibility scores independent of the voice they listened to. Though there was not a sufficient sample to statistically investigate further, it is hypothesized that the SLI subgroup would have lower comprehension scores than the RI subgroup. That is, students with an SLI have been identified by difficulty of being able to process language information despite average nonverbal learning abilities (Bishop, 1997; Elizabeth et al., 2004). Building on the argument that TTS presents in a manner that could overload the cognitive system, it stands to reason that students who have SLI may not benefit from the use of TTS unless they are able to control also the presentation rate and the amount of linguistic information that is presented at a given time.

As was shown with the sensitivity to rhythm task for a sentence, the SLI group was not able to process prosodic information nor store the acoustic signal in memory to make comparisons. The RI and the typically developing students seemed to be able to employ a strategy in which they were able to buffer the acoustic information of the two presented sentences to help with the comparison. The inability of the SLI to complete such a task may be related to a deficit in

auditory working memory and in the ability to process acoustic information. These cognitive weaknesses would then make it inherently more difficult for SLI to benefit from the use of TTS.

Another implication of the identification of the SLI within the current sample involves the process of diagnosing learning disorders in the education system. During the recruitment phase and approaching participating schools, one of the criteria for a student to participate was that the individuals had to be diagnosed with a learning disability in the area of reading. Students with comorbid conditions such as ADHD, language impairments, or other mental health conditions were excluded. Therefore, based on the identification of the reading impaired group, none of the students should have had SLI. However, based on the psychoeducational assessment conducted, it would seem that a detailed language assessment is not part of the assessment process. Though the specified criteria used by the school system for diagnosing a reading disability where not obtained, it is thought that students were identified by having poor word decoding and word reading skills. As Snowling and colleges have stated (2006), students who have SLI also have impairment in phonological processing, word decoding, and word reading. Therefore, it is not sufficient to be able to identify these individuals based on reading achievement measures. As TTS is often recommended to students who have been diagnosed with an RD, the misidentified SLI students may not be benefit from the use of this tool.

Future Research

Future research needs to look closer at the different cognitive profiles of individuals using TTS. For example, it is thought that students with combined auditory working memory and auditory processing difficulties may not benefit from standard TTS software provided by the manufacturer. Yet, they might benefit from choosing a high quality TTS voice. This may be augmented with then having the computer present a small amount of information (e.g. a phrase or clause) at a time in combination with learning strategies designed to aid in their understanding of the text.

Ongoing research into the effectiveness of text-to-speech software for both RD and typically developing students is warranted. The current series of studies provides the foundation for more specific questions. Future research in RD use of TTS needs to address the cognitive and learning profiles of these students so a better understanding of how groups of RD students with specific cognitive profiles can process and benefit from the auditory information. In addition, models

need to be developed to investigate what the influence of phonological awareness, working memory, and other cognitive process might have on the understanding of TTS. In addition, this type of research also needs to be done on other disability populations that rely on TTS.

Research that brings together the development of software based on cognitive and neural theory lends itself to the use of multidisciplinary teams. The current project is an example of how a multidisciplinary team can come together to help with the development of a research project. In the design of the current study, disciplines such as speech and language pathology, education psychology, computer science, and education were consulted. It is this type of multidisciplinary team with diverse knowledge, skills, and experiences that can provide guidance to a project which leads to the development of new effective tools for educating students.

The direction that the development of TTS tools is taking is that of creating more features. With newer versions of assistive technology software, developers are adding more options to their product such as bimodal reading; however, it is rare to find any developers that are refining the *essence* of their product. As previously demonstrated, the key variable that a user has to modify to meet learning needs is the type of voice, presentation rate, and pitch. Through looking at RD and other TTS user populations, recommendations and innovations need to occur to better adjusting TTS presentation to meet the cognitive profile of this population. Guidelines could be developed that recommend particular voices or reading speed. Some possible methods could include the following:

1. Adding pauses at phrase or clauses boundaries to allow time for the cognitive system to integrate newly presented information.

2. Use of arrow keys to move from one sentence to the next. This would allow users to move on when they feel they have understood what was just presented to them.

3. Integration of TTS with eye tracking. It is known that proficient readers do not continuously move from left to right across the page where TTS does. Integrating eye tracking would allow for reading a word aloud when the user focuses on a given word, This feature would allow for a natural style of reading.

Summary

These studies set out to investigate methods that would increases the effectiveness of TTS software for students with and without an RD. The methods focused on ways to presenting the auditory information to students which would match that of their cognitive profile. Additional research needs to take into consideration the cognitive profile and how the auditory information is processed when developing. The same recommendation is also provided for developers of TTS to insure the target populations are achieving maximum benefit from the TTS tools they use.

Tables and Figures

Table 1: Demographic information of participants from the Voice Quality Testing by current education level.

		No. of Participants				Age	
Education Level	Total	English First	Other Language	Male	Female	M	SD
Undergraduate	10	8	2	3	7	19.55	4.77
B.Ed.	17	9	8	9	8	28.14	10.79
M.A.	10	6	4	3	7	31.16	8.62
Ph.D.	3	2	1	3	0	35.11	15.60
Total	40	25	15	18	22	27.27	10.34

Table 2: Voice names and developers

VOICE NAME	DEVELOPER
Crystal	AT&T
AT&T Mike	AT&T
Kate	NeoSpeech
Paul	NeoSpeech
DJ	Natural Male
Susan	Natural Female
MS Mike	Microsoft
Sam	Microsoft
Mary	Microsoft
Ryan	Acapela
Heather	Acapela
Samantha	ScanSoft

Table 3: Correlations of voice surveys.

	2	3
1. What does this voice sound like?	.71**	.53**
2. How well do you understand the voice?	--	.56**
3. Would you choose to listen to this voice	--	--

Note: ** Correlation is significant at the p=.01, (2-tailed).

Table 4: Mean and standard deviation for voice survey questions by voice type.

VOICE Name	Question 1		Question 2		Question 3		VQI	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Microsoft Mike	1.50	1.06	2.18	1.28	1.48	1.21	1.49	0.67
Microsoft Sam	1.38	0.95	2.05	1.11	1.63	1.16	1.52	0.70
Microsoft Mary	1.28	0.45	2.18	1.17	1.84	1.16	1.72	0.67
Acapela Heather	2.23	1.07	3.05	1.13	2.32	1.17	2.48	0.79
ScanSoft Samantha	2.33	1.31	3.30	1.11	2.48	1.34	2.54	0.95
Acapela Ryan	2.68	1.02	3.30	0.97	2.26	1.09	2.72	0.87
NeoSpeech Kate	2.95	1.11	3.25	0.81	2.71	1.13	2.95	0.78
AT&T Mike	2.78	1.07	3.55	1.06	2.84	1.21	3.05	0.90
NeoSpeech Paul	3.05	1.30	3.59	0.94	2.77	1.28	3.06	0.92
AT&T Crystal	3.08	1.00	3.83	0.98	2.90	1.08	3.28	0.69
Natural Susan	4.48	0.99	4.53	0.88	3.48	1.21	4.18	0.81
Natural DJ	4.11	1.29	4.46	1.07	3.74	1.48	4.20	0.98

Note: Question 1: What does this voice sound like?

Question 2: How well do you understand the voice?

Question 3: Would you choose to listen to this voice?

VQI = Voice Quality Index.

Table 5: Means and standard deviations for voice quality grouped by significant group differences.

	Significant Group Differences							
	1		2		3		4	
VOICE ID	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MS Mike	1.49	0.67						
MS Sam	1.52	0.70						
MS Mary	1.72	0.67						
Acapela Heather			2.48	0.79				
ScanSoft Samantha			2.54	0.95				
Acapela Ryan			2.72	0.87	2.72	0.87		
NEOSPEECH Kate			2.95	0.78	2.95	0.78		
AT&T Mike			3.05	0.90	3.05	0.90		
NeoSpeech Paul			3.06	0.92	3.06	0.92		
AT&T Crystal					3.28	0.69		
Natural Susan							4.18	0.81
Natural DJ							4.20	0.98

Table 6: Number of participants from different schools by grade and reading ability group.

		Grade						
		6		7		8		
		Group		Group		Group		
		RD	Control	RD	Control	RD	Control	Total
School	1	4	11	1	0	0	0	16
	2	7	3	1	7	0	2	20
	3	5	14	2	4	0	2	27
	4	11	5	0	0	0	0	16
	5	0	0	5	2	1	4	12
	6	0	0	3	0	7	0	10
	Total	27	33	12	13	8	8	101

Table 7: Differences in learning and language scores between RD and control groups.

Test Name	Student	N	Range	Raw Scores		Standard Scores		t-value
				M	SD	M	SD	
Nonverbal Reasoning	RD	47	0-35	19.53	6.14	--	--	-4.27***
	Control	54		24.35	5.19	--	--	
Working Memory	RD	47	0-30	12.40	3.03	89.89	14.98	-3.52***
	Control	54		14.48	2.91	99.91	14.52	
Ellision	RD	47	0-20	9.00	2.75	76.81	7.40	-20.23***
	Control	54		17.61	1.39	103.15	7.09	
Listening Comprehension	RD	47	0-38	23.17	3.19	--	--	-5.01***
	Control	54		26.06	2.60	--	--	
Word Attack	RD	47	0-32	26.94	8.88	79.27	14.21	-5.12***
	Control	54		34.41	5.62	98.41	12.91	
Word Identification	RD	47	0-106	67.94	15.45	76.74	12.66	-5.42***
	Control	54		82.13	10.71	102.15	15.85	
Reading Comprehension	RD	47	0-43	21.60	4.93	--	--	-5.35***
	Control	54		26.13	3.56	--	--	

Note: Nonverbal Reasoning (Matrix Analogy Test), Working Memory (Wechsler Intelligence Scale for Children-III Numbers Forward + Numbers Backwards), Ellision (CTOPP Ellision subtest), Listening Comprehension, Word Attack, Word Identification, Reading Comprehension (all subtests of the Woodcock Language Mastery Tests)
Note 1: Standard Scores have a mean of 100 and a standard deviation of 15.
Note 2: *p<.05. **p<.01. ***p<.001.

Table 8: Mean and SD for accuracy of intelligibility and comprehensibility measures for reading ability group accuracy recorded as percent correct.

		Intelligibility				Comprehensibility	
		Pseudoword		Real Word		Sentence Completion	
Group	Voice	Mean	SD	Mean	SD	Mean	SD
RD	Human	86.71	10.99	86.66	9.61	70.95	10.71
	Mary	84.72	12.37	75.98	12.50	68.74	9.37
	Crystal	69.72	20.25	87.30	9.52	80.50	12.86
	Total	80.52	16.55	83.23	11.68	73.13	11.88
Control	Human	87.24	9.92	90.69	8.89	77.91	10.53
	Mary	87.01	11.40	82.02	5.70	72.25	11.88
	Crystal	76.56	20.17	87.79	9.94	82.70	7.77
	Total	83.67	15.04	86.67	8.94	77.30	11.01
Total	Human	86.98	10.30	88.74	9.30	74.55	11.03
	Mary	85.94	11.72	79.18	9.83	70.60	10.76
	Crystal	73.25	20.17	87.56	9.60	81.64	10.40
	Total	82.15	15.78	85.08	10.41	75.31	11.56

Table 9: Mean reaction time and moment-to-moment variability on pseudoword discrimination by voice and reading ability (Summary Statistics).

		Mean Reaction Time		Moment-to-Moment	
Voice	Reader	Mean	SD	Mean	SD
Natural	RD	723.19	287.91	418.46	40.83
	Control	661.00	260.69	396.38	40.83
Mary	RD	676.51	223.91	336.90	40.83
	Control	559.53	221.56	302.94	42.16
Crystal	RD	735.04	255.81	409.85	45.29
	Control	658.53	246.46	357.05	43.64

Table 10: Mean and standard deviation for mean reaction time and moment-to-moment variability for voice by reading ability for real word discrimination task.

		Mean Reaction Time		Moment-to-Moment Variability	
Voice	Reader	Mean	SD	Mean	SD
Natural	RD	765.85	289.96	524.99	202.62
	Control	725.20	364.35	436.85	220.64
MS Mary	RD	646.64	155.89	357.34	115.06
	Control	617.84	305.14	324.61	167.11
AT&T Crystal	RD	786.18	309.36	456.16	181.24
	Control	719.21	279.83	433.41	192.16

Note: Only correct responses were used in these analyses.

Table 11: Mean and standard deviation of mean reaction time and moment-to-Moment variability for sentence comprehension.

		Mean Reaction Time		Moment-to-Moment Variability	
Voice	Reader Group	Mean	SD	Mean	SD
Natural	RD	3224.94	1007.81	1824.64	888.85
	Control	2561.61	869.68	1574.22	666.92
MS Mary	RD	2285.32	776.01	1531.07	1081.00
	Control	2304.42	563.18	1576.21	592.50
AT&T Crystal	Rd	2581.48	573.14	1507.49	429.49
	Control	2523.90	1048.19	1619.39	902.21

Note: Only correct responses were used in these analyses.

Table 12: ANCOVA results for accuracy, response latency, moment-to-moment variability for Pseudoword discrimination, real word discrimination, and sentence comprehension between reading group and voice controlling for working memory.

Task	Test	Effect	*F*	MSE	*P*
Pseudoword Discrimination	Accuracy	Group	0.2	2.54	0.66
		Voice	7.13	89.99	0.001
		Interaction	0.1	1.26	0.91
	Response Latency	Group	0.53	37120.75	0.467
		Voice	1.86	129641.7	0.161
		Interaction	0.09	2035.74	0.97
	Moment-to-Moment Variability	Group	0.576	15441.46	0.45
		Voice	2.24	60231.04	0.11
		Interaction	0.09	2295.82	0.92
Real Word Discrimination	Accuracy	Group	0.979	23.11	0.325
		Voice	13.75	324.6	0.001
		Interaction	0.007	0.17	0.99
	Response Latency	Group	0.04	3412.76	0.84
		Voice	0.28	24155.81	0.76
		Interaction	0.02	1633.56	0.98
	Moment-to-Moment Variability	Group	0.31	10311.3.4	0.58
		Voice	2.83	94566.84	0.06
		Interaction	0.37	12379.81	0.69
Sentence Comprehension	Accuracy	Group	2.51	294.8	0.18
		Voice	6.08	715.4	0.003
		Interaction	0.13	14.71	0.88
	Response Latency	Group	1.43	469054	0.24
		Voice	1.54	507324.1	0.22
		Interaction	0.78	856889.4	0.46
	Moment-to-Moment Variability	Group	1.05	80346.9	0.31
		Voice	3.58	273916.1	0.03
		Interaction	1.39	76544.13	0.26

Table 13: Number of participants by reading groups, gender, and grade.

		RD		Control	
		Female	Male	Female	Male
Grade	6	15	12	21	12
	7	4	8	7	6
	8	2	6	2	6

Table 14: Performance on cognitive, language, and reading tasks by reading groups: summary statistics and t-test group comparisons.

Test Name	Student	N	Range	Raw Scores		Standard Scores		*t* value
				M	SD	M	SD	
Nonverbal Reasoning	RD	47	0-35	19.53	6.14	--	--	-4.27***
	Control	54		24.35	5.19	--	--	
Working memory	RD	47	0-30	12.40	3.03	89.89	14.98	-3.52***
	Control	54		14.48	2.91	99.91	14.52	
Ellision	RD	47	0-20	9.00	2.75	76.81	7.40	-20.23***
	Control	54		17.61	1.39	103.15	7.09	
Receptive Vocabulary	RD	47	0-228	130.19	19.88	89.98	13.61	-4.38***
	Control	54		145.93	16.21	100.89	11.88	
Listening Comprehension	RD	47	0-38	23.17	3.19	--	--	-5.01***
	Control	54		26.06	2.60	--	--	
Word Attack	RD	47	0-32	26.94	8.88	79.28	14.21	-5.12***
	Control	54		34.41	5.62	98.41	12.91	
Word Identification	RD	47	0-106	67.94	15.45	76.74	13.69	-5.42***
	Control	54		82.13	10.71	102.15	15.85	
Reading Comprehension	RD	47	0-43	21.60	4.93	--	--	-5.35***
	Control	54		26.13	3.56	--	--	

Note: Nonverbal Reasoning (MAT); Working Memory (Wechsler Intelligence Scale for Children-III Numbers Forward + Numbers Backwards); Ellision (CTOPP Ellision subtest); Receptive Vocabulary (PPVT-III); Listening Comprehension, Word Attack, Word Identification, Reading Comprehension (subtests of the Woodcock Language Mastery Tests).

Note 2: *p<.05. **p<.01. ***p<.001.

Table 15: Descriptive statistics for the 18 passages used in the current study.

								After Passages were Modified					
Passage #	Topic	Lexile	Word Count	Syllable Count	Mean Syllables per word	Words Not on Biemiller	Percentage of Words not on the Vocabulary List	Lextile	Word Count	Syllable Count	Mean Syllables per Word	Words Not on Biemiller	Percentage of Words not on the Vocabulary List
1	Advertising	830.00	120.00	207.00	1.73	29.00	14.01	940.00	160.00	266.00	1.66	21.00	13.13
2	Kilojoules	780.00	156.00	233.00	1.49	30.00	12.88	910.00	155.00	236.00	1.52	23.00	14.84
3	Misuse of Drugs	850.00	150.00	237.00	1.58	25.00	10.55	910.00	147.00	230.00	1.56	14.00	9.52
4	Preservatives	800.00	175.00	279.00	1.59	35.00	12.54	920.00	159.00	249.00	1.57	22.00	13.84
5	Six Nutrients	880.00	175.00	243.00	1.39	13.00	5.35	910.00	159.00	228.00	1.43	10.00	6.29
6	Stress	880.00	143.00	215.00	1.50	28.00	13.02	900.00	155.00	234.00	1.51	22.00	14.19
7	Commercial Agriculture	1040.00	150.00	222.00	1.48	14.00	9.33	940.00	148.00	218.00	1.47	11.00	7.43
8	Cultural Clusters	970.00	147.00	231.00	1.57	15.00	10.20	970.00	147.00	231.00	1.57	15.00	10.20
9	Dinosaurs	920.00	132.00	187.00	1.42	19.00	10.16	930.00	154.00	228.00	1.48	23.00	14.94
10	Faces of Government	970.00	159.00	234.00	1.47	18.00	11.32	970.00	159.00	234.00	1.47	18.00	11.32
11	Global Warming	1080.00	154.00	264.00	1.71	42.00	27.27	940.00	152.00	238.00	1.57	26.00	10.92
12	Resources	1050.00	146.00	244.00	1.67	34.00	23.29	980.00	146.00	244.00	1.67	34.00	23.29
13	Trees in Finland	910.00	176.00	229.00	1.30	26.00	15.03	900.00	154.00	209.00	1.36	18.00	11.69
14	Earwings	960.00	149.00	198.00	1.33	24.00	12.12	960.00	149.00	198.00	1.33	24.00	12.12
15	Electric Fish	950.00	152.00	238.00	1.57	20.00	8.40	950.00	152.00	238.00	1.57	20.00	8.40
16	Interviewing	980.00	161.00	248.00	1.54	16.00	6.45	990.00	156.00	240.00	1.54	10.00	6.41
17	Bacteria	970.00	167.00	240.00	1.44	19.00	7.92	920.00	151.00	222.00	1.47	17.00	11.26
18	Copernicus	970.00	166.00	227.00	1.37	33.00	14.54	920.00	159.00	218.00	1.37	22.00	13.84
	Mean	932.78	154.33	232.00	1.51	24.44	12.47	936.67	153.44	231.17	1.51	19.44	11.87
	SD	84.14	14.73	21.85	0.12	8.30	5.42	28.08	4.71	15.24	0.09	6.10	3.95

Table 16: Words per minute for the two TTS voices based on presentation rate setting.

Presentation Rate Setting	MS Mary	AT&T Crystal
-5	114.34	95.24
-4	128.02	106.26
-3	142.79	119.68
-2	160.06	133.51
-1	177.44	149.03
0	198.28	170.36
1	219.27	187.66
2	247.70	208.31
3	273.97	235.29
4	310.02	265.06
5	338.22	292.87

Table 17: Differences between mean presentation rate for TTS voices.

Presentation Rate	MS Mary	AT&T Crystal	Difference between Presentation Rate
Slow	119.63	115.16	4.47
Medium	149.42	147.07	2.36
Fast	189.63	181.6	8.03

Note: Presentation Rate is presented in words per minute.

Table 18: Outline of conditions used in the current study.

	Use of Pause		
Presentation Rate	No Pause	Random Pause	Phrase Pause
Slow	2 passages	2 passages	2 passages
Medium	2 passages	2 passages	2 passages
Fast	2 passages	2 passages	2 passages

Table 19: Item difficulty statistics by passage and individual questions by reading group presented in percentage of item correct responses.

			RD		Control		
Passages	Questions	Question Type	M	SD	M	SD	Group Difference
1	1	Factual	28.89	45.84	31.37	46.86	RD=Control
	2	Factual	8.89	28.78	17.65	38.50	RD=Control
	3	Factual	17.78	38.66	39.22	49.31	RD<Control
	4	Inferential	15.56	36.65	39.22	49.31	RD<Control
	5	Inferential	31.11	46.82	9.80	30.03	RD>Control
2	1	Factual	17.78	38.66	9.80	30.03	RD=Control
	2	Factual	15.56	36.65	19.61	40.10	RD=Control
	3	Factual	24.44	43.46	15.69	36.73	RD=Control
	4	Inferential	37.78	49.03	33.33	47.61	RD=Control
	5	Inferential	15.56	36.65	15.69	36.73	RD=Control
3	1	Factual	11.11	31.78	17.65	38.50	RD=Control
	2	Factual	20.00	40.45	33.33	47.61	RD=Control
	3	Factual	17.78	38.66	15.69	36.73	RD=Control
	4	Inferential	26.67	44.72	3.92	19.60	RD>Control
	5	Inferential	28.89	45.84	25.49	44.01	RD=Control
4	1	Factual	42.22	49.95	29.41	46.02	RD=Control
	2	Factual	11.11	31.78	25.49	44.01	RD=Control
	3	Factual	20.00	40.45	23.53	42.84	RD=Control
	4	Inferential	35.56	48.41	37.25	48.83	RD=Control
	5	Inferential	35.56	48.41	27.45	45.07	RD=Control
5	1	Factual	35.56	48.41	31.37	46.86	RD=Control
	2	Factual	31.11	46.82	35.29	48.26	RD=Control
	3	Factual	20.00	40.45	21.57	41.54	RD=Control
	4	Inferential	26.67	44.72	27.45	45.07	RD=Control
	5	Inferential	20.00	40.45	31.37	46.86	RD=Control
6	1	Factual	22.22	42.04	27.45	45.07	RD=Control
	2	Factual	28.89	45.84	31.37	46.86	RD=Control
	3	Factual	26.67	44.72	23.53	42.84	RD=Control
	4	Inferential	35.56	48.41	21.57	41.54	RD=Control
	5	Inferential	24.44	43.46	25.49	44.01	RD=Control
7	1	Factual	28.89	45.84	25.49	44.01	RD=Control
	2	Factual	24.44	43.46	15.69	36.73	RD=Control
	3	Factual	22.22	42.04	27.45	45.07	RD=Control
	4	Inferential	26.67	44.72	29.41	46.02	RD=Control
	5	Inferential	22.22	42.04	19.61	40.10	RD=Control
8	1	Factual	31.11	46.82	35.29	48.26	RD=Control
	2	Factual	31.11	46.82	31.37	46.86	RD=Control
	3	Factual	8.89	28.78	27.45	45.07	RD<Control

	4	Inferential	33.33	47.67	21.57	41.54	RD=Control
	5	Inferential	15.56	36.65	17.65	38.50	RD=Control
	1	Factual	15.56	36.65	15.69	36.73	RD=Control
9	2	Factual	26.67	44.72	23.53	42.84	RD=Control
	3	Factual	31.11	46.82	41.18	49.71	RD=Control
	4	Inferential	28.89	45.84	39.22	49.31	RD=Control
	5	Inferential	33.33	47.67	31.37	46.86	RD=Control
10	1	Factual	37.78	49.03	27.45	45.07	RD=Control
	2	Factual	26.67	44.72	15.69	36.73	RD=Control
	3	Factual	26.67	44.72	23.53	42.84	RD=Control
	4	Inferential	26.67	44.72	35.29	48.26	RD=Control
	5	Inferential	24.44	43.46	19.61	40.10	RD=Control
11	1	Factual	28.89	45.84	39.22	49.31	RD=Control
	2	Factual	20.00	40.45	39.22	49.31	RD<Control
	3	Factual	24.44	43.46	31.37	46.86	RD=Control
	4	Inferential	20.00	40.45	35.29	48.26	RD<Control
	5	Inferential	35.56	48.41	19.61	40.10	RD>Control
12	1	Factual	33.33	47.67	49.02	50.49	RD<Control
	2	Factual	28.89	45.84	49.02	50.49	RD<Control
	3	Factual	15.56	36.65	29.41	46.02	RD=Control
	4	Inferential	20.00	40.45	21.57	41.54	RD=Control
	5	Inferential	20.00	40.45	33.33	47.61	RD=Control
13	1	Factual	31.11	46.82	23.53	42.84	RD=Control
	2	Factual	40.00	49.54	21.57	41.54	RD>Control
	3	Factual	24.44	43.46	33.33	47.61	RD=Control
	4	Inferential	20.00	40.45	43.14	50.02	RD<Control
	5	Inferential	22.22	42.04	27.45	45.07	RD=Control
14	1	Factual	22.22	42.04	29.41	46.02	RD=Control
	2	Factual	24.44	43.46	25.49	44.01	RD=Control
	3	Factual	22.22	42.04	19.61	40.10	RD=Control
	4	Inferential	31.11	46.82	35.29	48.26	RD=Control
	5	Inferential	24.44	43.46	35.29	48.26	RD=Control
15	1	Factual	44.44	50.25	21.57	41.54	RD>Control
	2	Factual	24.44	43.46	19.61	40.10	RD=Control
	3	Factual	35.56	48.41	31.37	46.86	RD=Control
	4	Inferential	11.11	31.78	13.73	34.75	RD=Control
	5	Inferential	22.22	42.04	23.53	42.84	RD=Control
16	1	Factual	26.67	44.72	17.65	38.50	RD=Control
	2	Factual	31.11	46.82	41.18	49.71	RD=Control
	3	Factual	22.22	42.04	17.65	38.50	RD=Control
	4	Inferential	26.67	44.72	33.33	47.61	RD=Control
	5	Inferential	17.78	38.66	27.45	45.07	RD=Control
17	1	Factual	26.67	44.72	33.33	47.61	RD=Control
	2	Factual	13.33	34.38	25.49	44.01	RD=Control

	3	Factual	33.33	47.67	27.45	45.07	RD=Control
	4	Inferential	33.33	47.67	33.33	47.61	RD=Control
	5	Inferential	20.00	40.45	23.53	42.84	RD=Control
18	1	Factual	13.33	34.38	35.29	48.26	RD<Control
	2	Factual	20.00	40.45	41.18	49.71	RD<Control
	3	Factual	20.00	40.45	17.65	38.50	RD=Control
	4	Inferential	15.56	36.65	35.29	48.26	RD<Control
	5	Inferential	17.78	38.66	15.69	36.73	RD=Control

Table 20: Means and standard deviations on passage accuracy by reading group, presentation rate, and use of pause by reading and TTS voice.

Group	Voice	Pause	Rate	Mean	SD
RD	Mary	No	Slow	4.44	0.46
			Medium	4.94	0.48
			Fast	4.61	0.47
		Random	Slow	4.61	0.48
			Medium	5.17	0.46
			Fast	5.11	0.43
		Fast	Slow	4.83	0.49
			Medium	4.28	0.53
			Fast	4.28	0.53
	Crystal	No	Slow	4.30	0.41
			Medium	3.65	0.43
			Fast	4.26	0.42
		Random	Slow	4.39	0.42
			Medium	3.78	0.41
			Fast	3.87	0.38
		Fast	Slow	4.87	0.43
			Medium	4.57	0.47
			Fast	4.61	0.47
Control	Mary	No	Slow	6.65	0.41
			Medium	6.70	0.43
			Fast	6.83	0.42
		Random	Slow	6.09	0.42
			Medium	6.48	0.41
			Fast	6.70	0.38
		Fast	Slow	6.04	0.43
			Medium	7.35	0.47
			Fast	6.70	0.47
	Crystal	No	Slow	6.21	0.45
			Medium	5.32	0.47
			Fast	6.26	0.46
		Random	Slow	6.63	0.46
			Medium	6.79	0.45
			Fast	6.11	0.42
		Fast	Slow	6.58	0.48
			Medium	6.21	0.51
			Fast	6.00	0.52

Table 21: Results of 3 (presentation rate) by 3 (use of pause) between 2 (reading group) by 2 (TTS voice) ANOVA for passage accuracy.

Source	df	MSE	F	Power
Rate	2	2.06	0.77*	0.01
Rate * GROUP	2	0.08	0.03	0.00
Rate *TTS Voice	2	5.32	1.99	0.02
Rate * GROUP * TTS Voice	2	11.74	4.39**	0.05
Error(Rate)	158	2.67		
Pause	2	0.09	0.03	0.00
Pause * GROUP	2	1.27	0.47	0.01
Pause * TTS Voice	2	10.83	3.98**	0.05
Pause * GROUP * TTS Voice	2	1.03	0.38	0.00
Error(Pause)	158	2.72		
Rate * Pause	4	1.93	0.77	0.01
Rate * Pause * GROUP	4	2.19	0.87	0.01
Rate * Pause * TTS Voice	4	2.22	0.89	0.01
Rate * Pause * GROUP * TTS Voice	4	3.00	1.20	0.01
Error(Rate*Pause)	316	2.50		
GROUP	1	699.28	41.21***	0.34
TTS Voice	1	31.09	1.83	0.02
GROUP * TTS Voice	1	0.18	0.01	0.00
Error	79	16.97		

Note 1: *p<.05. **p<.01. ***p<.001.

Table 22: Student preferences for different presentation conditions on a five point Likert scale in raw scores.

	Dislike				Like
Condition	1	2	3	4	5
No Pause	5.4	8.5	26.6	34	25.5
Random Pause	30.4	30.4	19.6	10.9	8.7
Phrase Pause	8.6	11.8	28	29	22.6
Slow Presentation Rate	34.4	24.7	20.4	11.8	8.6
Medium Presentation Rate	2.2	9.7	30.1	28	30.1
Fast Presentation Rate	9.7	17.2	19.4	14	39.8

Table 23: Correlations of language and literacy measures.

	2.	3.	4.	5.	6.	7.	8.	9.	10	11.	12.	13.	14.
1. Age	0.23*	-0.22*	0.00	-0.06	0.10	-0.11	0.09	-0.06	0.26*	0.23*	-0.07	-0.04	0.07
2. Nonverbal Reasoning		0.24*	-0.24*	-0.32**	0.40**	0.37**	0.37**	0.40**	0.63**	0.41**	0.33**	0.35**	0.51**
3. Working Memory			-0.25*	-0.14	0.66**	0.27*	0.35**	0.38**	0.37**	0.45**	0.50**	0.50**	0.55**
4. RAN Letters				-0.78**	-0.07	-0.35**	-0.24*	-0.25*	-0.28*	-0.27*	-0.55**	-0.55**	-0.46**
5. RAN Digits					-0.04	-0.25*	-0.15	-0.24*	-0.33*	-0.12	-0.51**	-0.51**	-0.37**
6. Sentence Repetition						0.23*	0.43**	0.49**	0.58**	0.67**	0.39**	0.39**	0.66**
7. Sensitivity to Phrase Rhythm							0.30**	0.32**	0.34**	0.21*	0.33**	0.42**	0.35**
8. Sensitivity to Sentence Rhythm								0.31**	0.32**	0.38**	0.26*	0.26*	0.43**
9. Phonological Awareness									0.40**	0.42**	0.59**	0.56**	0.53**
10. Receptive Vocabulary										0.65**	0.43**	0.53**	0.70**
11. Listening Comprehension											0.31**	0.37**	0.68**
12. Word Attack												0.87**	0.65**
13. Word Identification													0.67**
14. Passage Comprehension													

Note: * P<.05, **P<.001

SLI (Specific Language Impaired), RI (Reading Impaired), Control (Typically Developing), Nonverbal Reasoning (Matrix Analogy Test), Working Memory (Wechsler Intelligence Scale for Children-IV, Numbers Forward + Numbers Backwards), RAN Letters (CTOPP), RAN Digits (CTOPP), Sentence Repetition (CELF-4, Recalling Sentences), Sensitivity to Phrase Rhythm (DEEdee), Sensitivity to Sentence Rhythm (Freddy/Eddy), Phonological Awareness (CTOPP, Ellision), Receptive Vocabulary (PPVT-III), Listening Comprehension, Word Attack, Word Identification, Reading Comprehension (all subtests of the Woodcock Language Mastery Tests)

Table 24: Number of students for grade, group, and school.

	Grade									
	6			7			8			
	Group			Group			Group			
School	SLI	RI	Control	SLI	RD	Control	SLI	RI	Control	Total
1	1	3	11	1	0	0	0	0	0	16
2	3	4	3	3	0	5	0	0	2	20
3	2	4	13	3	1	2	0	0	2	27
4	4	7	5	0	0	0	0	0	0	16
5	0	0	0	2	4	0	1	1	4	12
6	0	0	0	1	2	1	4	2	0	10
Total	10	18	32	10	7	8	5	3	8	101

Note: SLI (Specific Language Impaired), RI (Reading Impaired), Control (Typically Developing)

Table 25: Means and standard deviations of raw and standard scores for group on the language and literacy measures with group comparisons.

Language and Literacy Measures	Group	Raw Scores		Standard Scores		Comparisons	*p* Value for Comparison		
		M	SD	M	SD		SLI vs. RI	SLI vs. C	RI vs. C
Age	SLI	12.58	1.03	--	--	SLI=RI=C	0.13	0.39	0.63
	RI	12.10	0.94	--	--				
	Control	12.25	0.91	--	--				
MAT	SLI	18.71	5.27	--	--	SLI=RI<C	0.21	0.001	0.052
	RI	21.33	6.08	--	--				
	Control	24.48	5.34	--	--				
Digits Total	SLI	10.12	1.88	78.96	18.41	SLI<RI=C	0.001	0.001	0.34
	RI	14.00	2.52	97.96	25.76				
	Control	15.00	2.61	102.19	27.13				
RAN Letters	SLI	32.21	6.82	97.92	27.33	SLI=RI=C	0.977	0.518	0.355
	RI	34.00	9.66	97.04	32.49				
	Control	30.56	5.76	102.08	30.59				
RAN Digits	SLI	30.24	5.93	97.29	23.77	SLI=RI=C	0.713	0.848	0.303
	RI	32.84	7.59	94.44	27.22				
	Control	29.14	5.82	99.06	26.07				
Recalling Sentences	SLI	39.33	7.23	62.29	11.79	SLI<RI<C	0.001	0.001	0.001
	RI	61.73	9.60	88.15	19.25				
	Control	70.55	9.18	97.29	20.52				
DEEdee	SLI	12.71	2.24	--	--	SLI=RI<C	1	0.004	0.002
	RI	12.38	3.40	--	--				
	Control	14.59	2.71	--	--				
Freddy/Eddy	SLI	10.48	1.94	--	--	SLI<RI=C	0.013	0.001	0.764
	RI	12.12	2.32	--	--				
	Control	12.41	1.74	--	--				

Ellision	SLI	11.00	4.70	81.67	29.44	SLI=RI<C	0.411	0.001	0.001
	RI	9.27	2.62	78.33	12.40				
	Control	17.61	1.35	103.23	14.07				
PPVT	SLI	125.14	14.43	83.83	9.19	SLI<RI<C	0.003	0.001	0.028
	RI	135.62	20.53	94.93	13.79				
	Control	147.52	16.24	102.33	11.73				
Listening Comprehension	SLI	22.43	3.78	--	--	SLI<RI<C	0.03	0.001	0.006
	RI	24.81	1.94	--	--				
	Control	26.14	2.41	--	--				
Word Attack	SLI	25.86	7.82	78.48	17.07	SLI=RI<C	0.09	0.001	0.057
	RI	28.38	7.83	83.18	12.09				
	Control	34.41	5.61	98.94	12.09				
Word Identification	SLI	67.43	11.72	77.56	19.93	SLI=RI<C	0.053	0.001	0.029
	RI	70.31	15.04	80.07	13.45				
	Control	82.05	10.55	102.96	15.92				
Reading Comprehension	SLI	20.10	5.18	--	--	SLI<RI<C	0.001	0.001	0.025
	RI	23.58	3.91	--	--				
	Control	26.41	3.57	--	--				

Note: Standard scores have a mean of 100 and a standard deviation of 10.

SLI (Specific Language Impaired), RI (Reading Impaired), Control (Typically Developing), MAT (Nonverbal Reasoning, Matrix Analogy Test), Digits Total (Working Memory, Wechsler Intelligence Scale for Children-IV Numbers Forward + Numbers Backwards), RAN Letters (CTOPP), RAN Digits (CTOPP), Recalling Sentences (Sentence Repetition, CELF-4) DEEdee (Sensitivity to Phrase Rhythm), Freddy/Eddy (Sensitivity to Sentence Rhythm), Ellision (Phonological Awareness, CTOPP, Ellision), PPVT (Receptive Vocabulary, PPVT-III), Listening Comprehension, Word Attack, Word Identification, Reading Comprehension (all subtests of the Woodcock Language Mastery Tests)

Table 26: Results of one-way ANOVA for main effect of group on language and literacy measures.

Language and Literacy Measures	*F*	df	MSE	*p*	Partial Eta Squared
MAT	9.17	(2, 96)	281.09	0.00	0.16
RAN Digits	1.10	(2, 96)	7.37	0.34	0.02
RAN letters	1.17	(2, 96)	10.81	0.31	0.02
Digits Total	28.58	(2, 96)	177.53	0.00	0.37
Recalling Sentences	116.11	(2, 96)	394.50	0.00	0.71
DEEdee	8.46	(2, 96)	67.60	0.00	0.15
Freddy/Eddy	7.95	(2, 96)	2.08	0.00	0.14
Ellision	78.56	(2, 96)	271.93	0.00	0.62
Word Attack	11.39	(2, 96)	2161.57	0.00	0.19
Word Identification	13.57	(2, 96)	4313.71	0.00	0.22
PPVT	19.79	(2, 96)	2753.11	0.00	0.29
Passage Comprehension	21.83	(2, 96)	356.44	0.00	0.31
Listening Comprehension	16.75	(2, 96)	130.87	0.00	0.26

SLI (Specific Language Impaired), RI (Reading Impaired), Control (Typically Developing), MAT (Nonverbal Reasoning, Matrix Analogy Test), Digits Total (Working Memory, Wechsler Intelligence Scale for Children-IV Numbers Forward + Numbers Backwards), RAN Letters (CTOPP), RAN Digits (CTOPP), Sentence Repetition (Language Processing, CELF-4) DEEdee (Sensitivity to Phrase Rhythm), Freddy/Eddy (Sensitivity to Sentence Rhythm), Ellision (Phonological Awareness, CTOPP, Ellision), PPVT (Receptive Vocabulary, PPVT-III), Listening Comprehension, Word Attack, Word Identification, Reading Comprehension (all subtests of the Woodcock Language Mastery Tests).

Table 27: Correlations between DEEdee and Freddy/Eddy tasks and language and literacy measures by ability group.

Group	Task	Age	MAT	Total Digits	RAN Letters	RAN Number	Sentence Repetition	DEEdee	Freddy/Eddy	Ellision	PPVT	Listening Comp.	Word Attack	Word Identification	Passage Comp.
SLI	DEEdee	-0.16	.44*	0.26	-0.04	0.38	0.21		0.27	0.28	0.17	0.17	0.32	0.45*	0.28
	Freddy/Eddy	0.09	0.35	0.23	-0.48*	-0.42*	0.34	0.27		0.69***	0.09	0.40*	0.51**	0.36	0.39*
RI	DEEdee	-0.15	0.45*	0.00	-0.56***	-0.58***	-0.23		0.19	-0.26	0.27	-0.03	0.33	0.35	0.20
	Freddy/Eddy	0.33	0.16	0.26	-0.25	-0.12	0.28	0.19		-0.06	0.20	0.06	0.00	-0.03	0.25
Controls	DEEdee	-0.25	0.08	0.21	-0.16	-0.06	0.14		0.29*	0.31*	0.22	0.24	0.16	0.31*	0.31*
	Freddy/Eddy	-0.01	0.17	-0.01	-0.05	0.00	0.14	0.29*		0.07	0.21	0.14	-0.03	0.09	0.27

Note: *=p<.05, **=p<.01, ***=p<.001

SLI (Language Impaired), RI (Reading Impaired), Control (Typically Developing), MAT (Nonverbal Reasoning, Matrix Analogy Test), Digit Total (Working Memory, Wechsler Intelligence Scale for Children-III Numbers Forward + Numbers Backwards), RAN Letter (CTOPP RAN Letter), RAN Digits (CTOPP RAN Digits), Sentence Repetition (Language Processing, CELF-4) DEEdee (Sensitivity to Phrase Rhythm), Freddy/Eddy (Sensitivity to Sentences Rhythm), Ellision (Phonological Awareness, CTOPP Ellision subtest), PPVT (Receptive Vocabulary, PPVT-III), Listing Comprehension, Word Attack, Word Identification, Reading Comprehension (all subtests of the Woodcock Language Mastery Tests)

Figure 1: Procedure for pseudoword discrimination task.

Figure 2: Procedure for real word discrimination task.

Figure 3: Example of sentence comprehension task.

Figure 4: Item analysis for accuracy scores on pseudoword discrimination task by voice type.

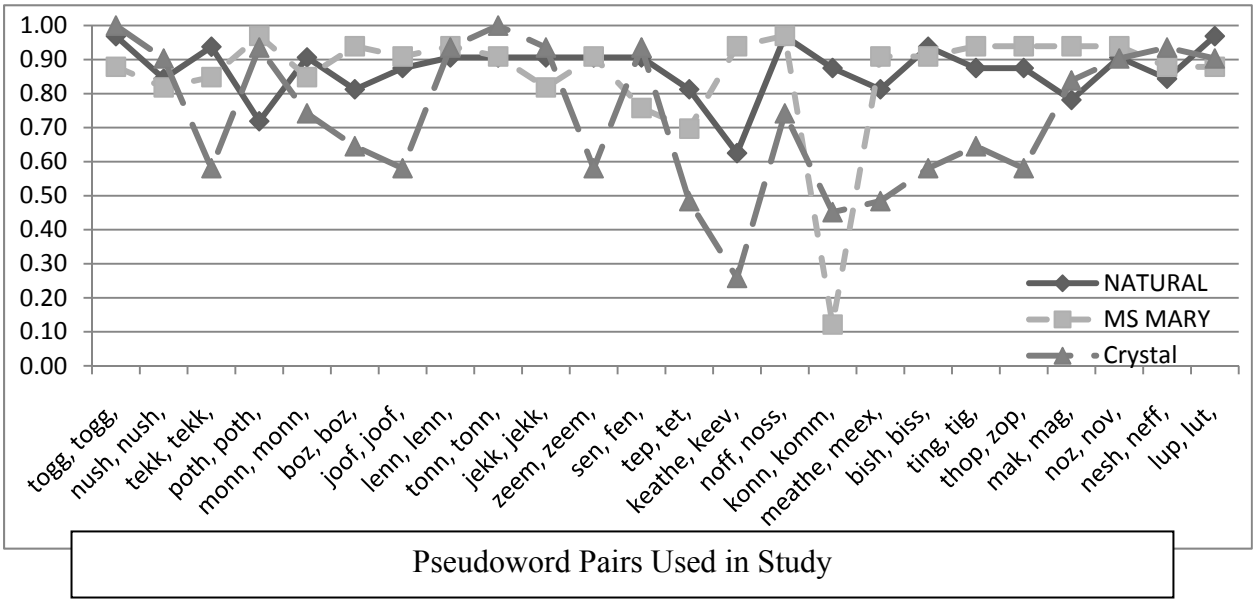


Figure 5: Item analysis of accuracy scores for real word discrimination task by voice.

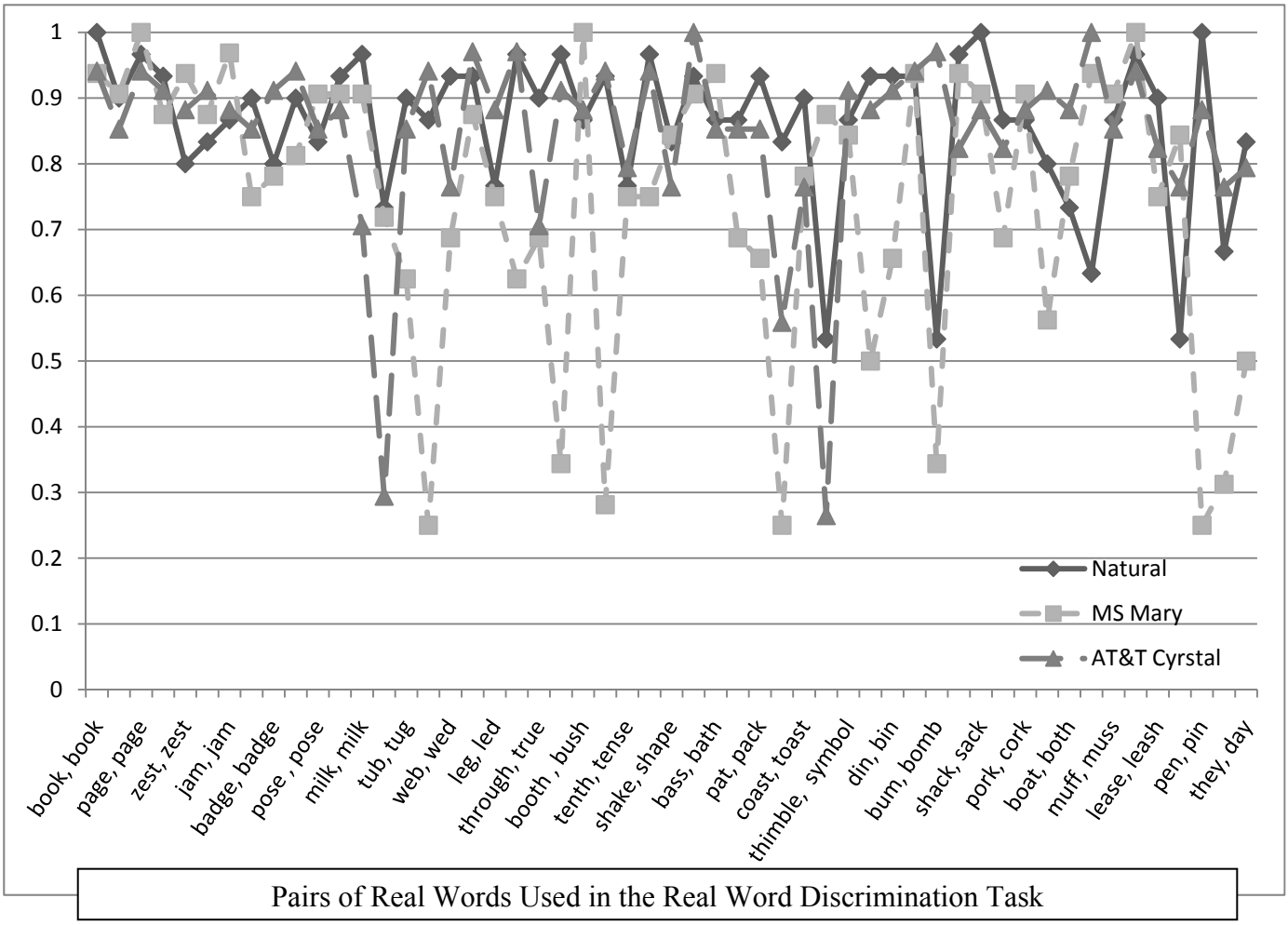


Figure 6: UTReader with XML tags inserted at phrase boundaries before rendering.

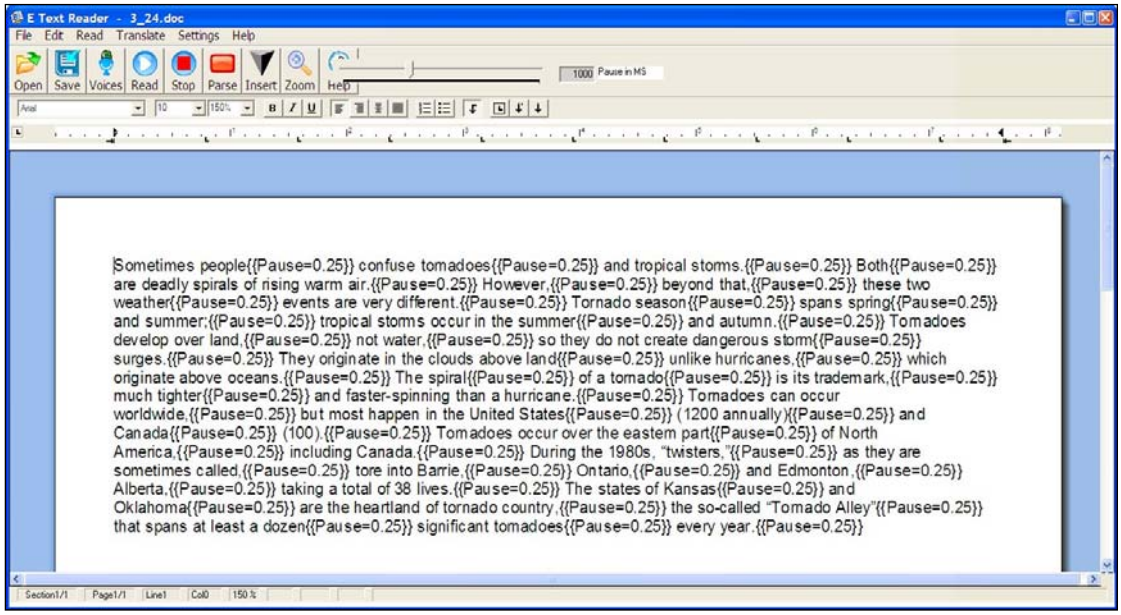


Figure 7: UTReader after rendering XML file, as seen by participants.

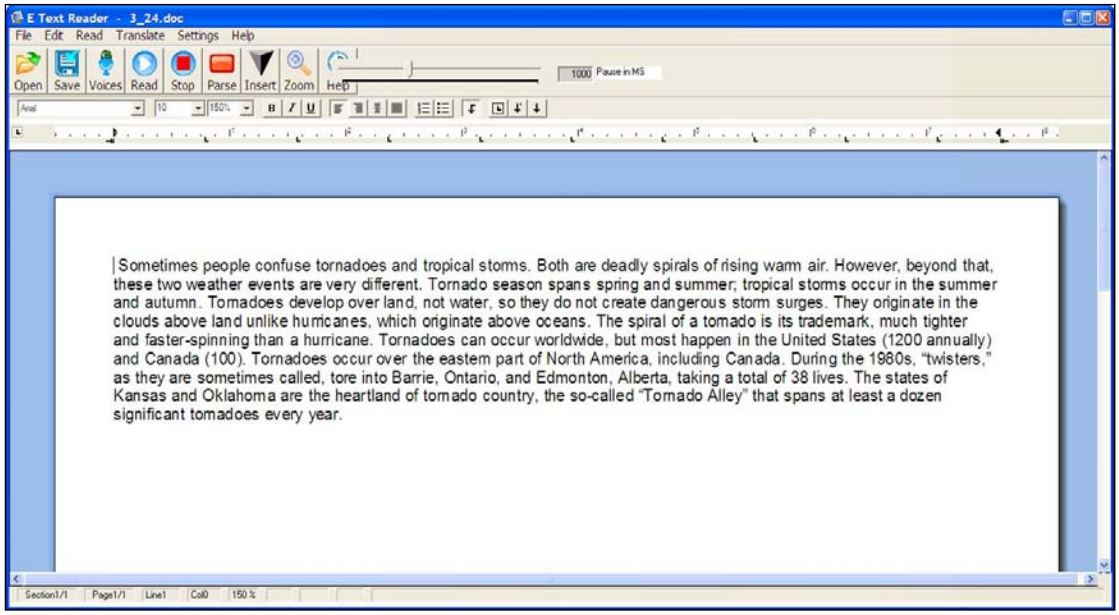


Figure 8: Mean correct responses: interaction between presentation rate and TTS voice by reading group.

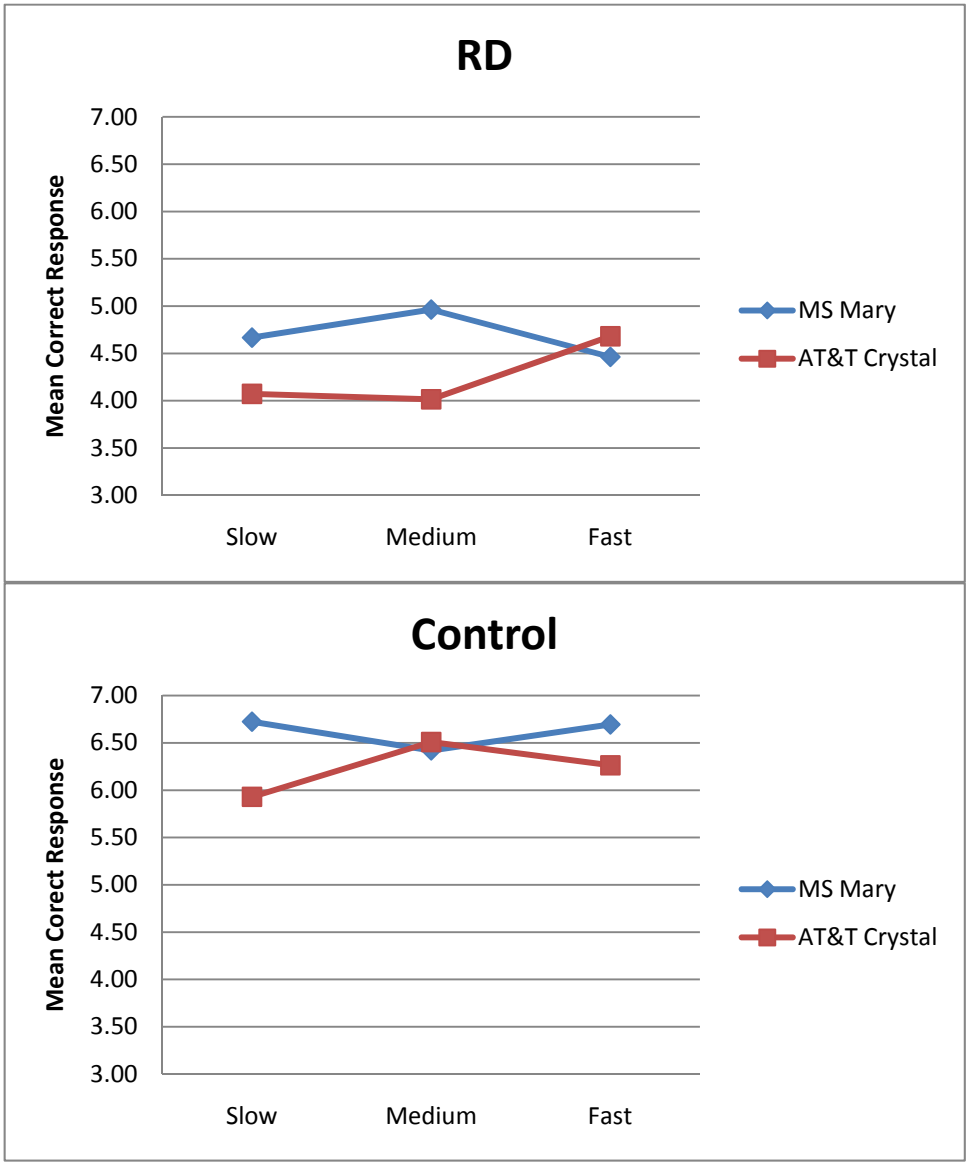


Figure 9: Interaction of TTS voice by use of pause on mean accuracy scores.

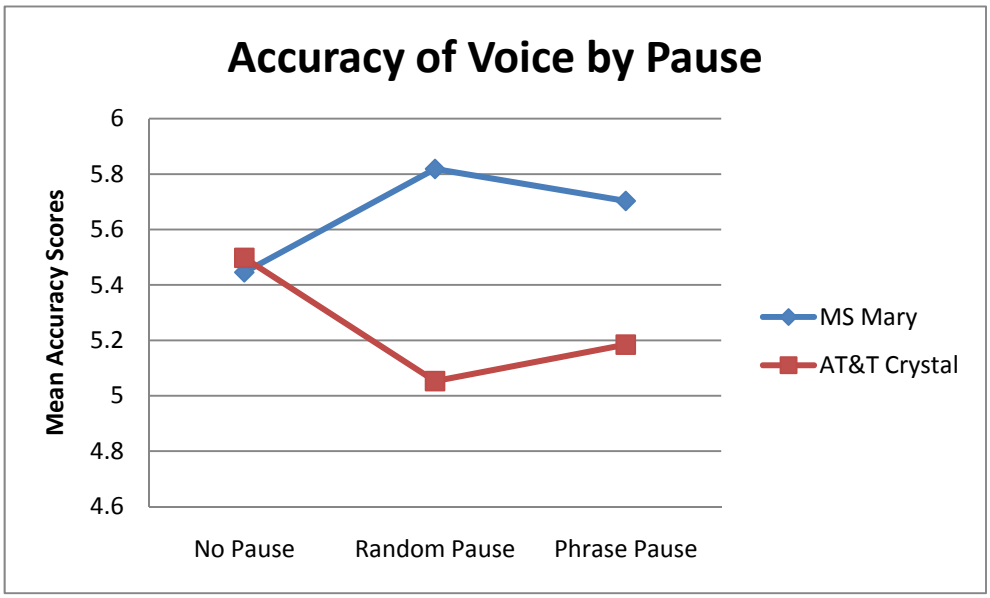
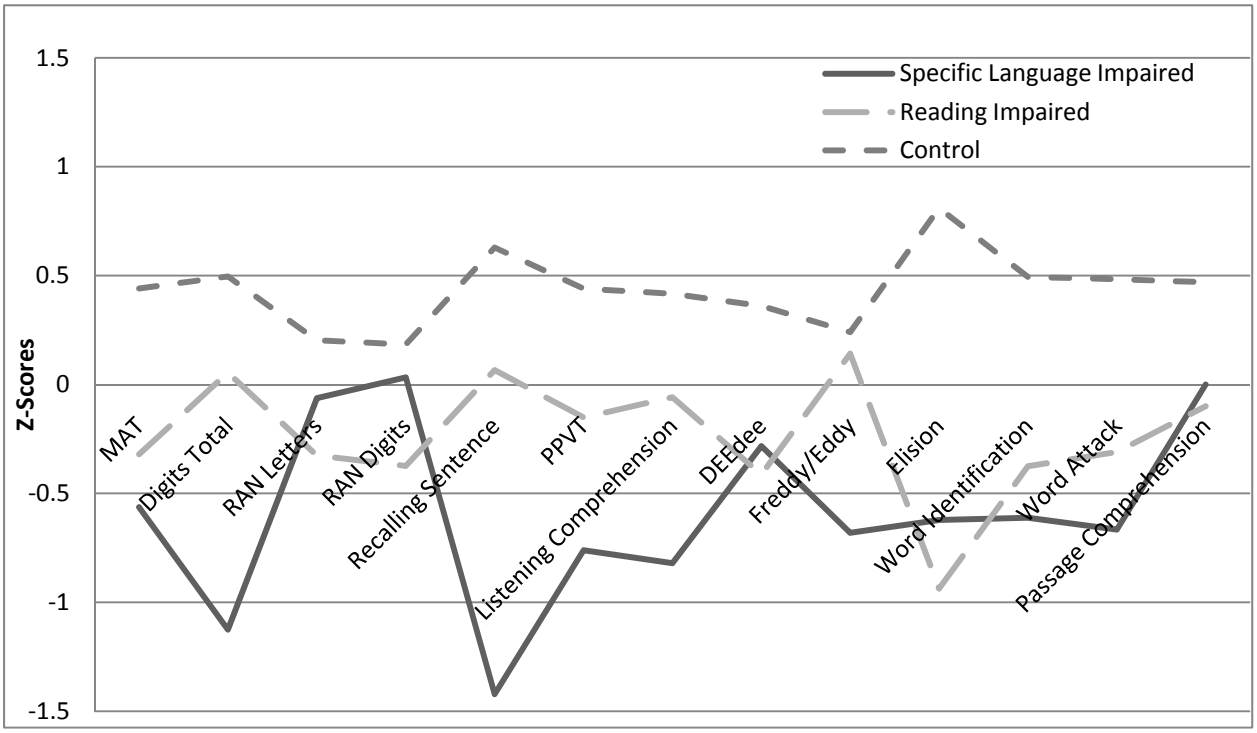
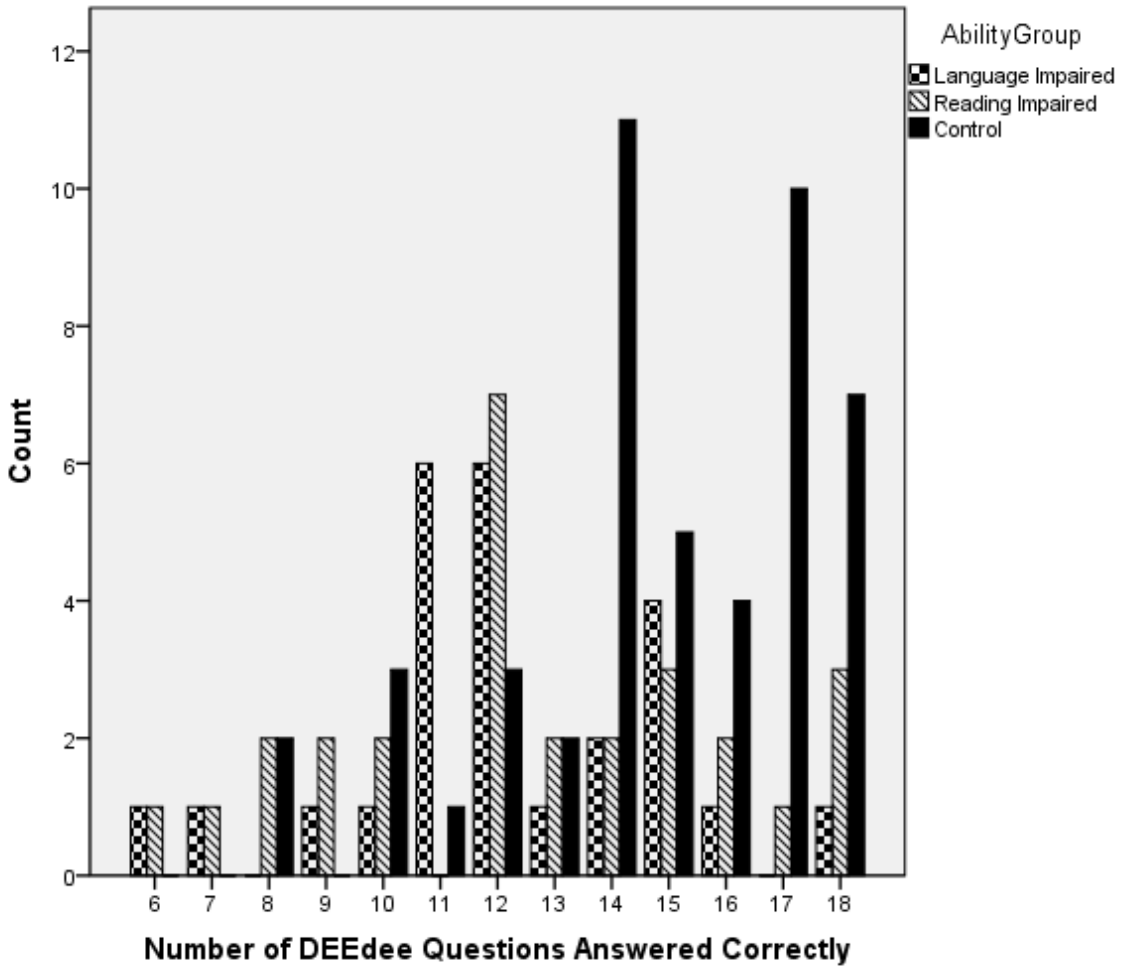


Figure 10: Comparison of groups on language and literacy measures**.**



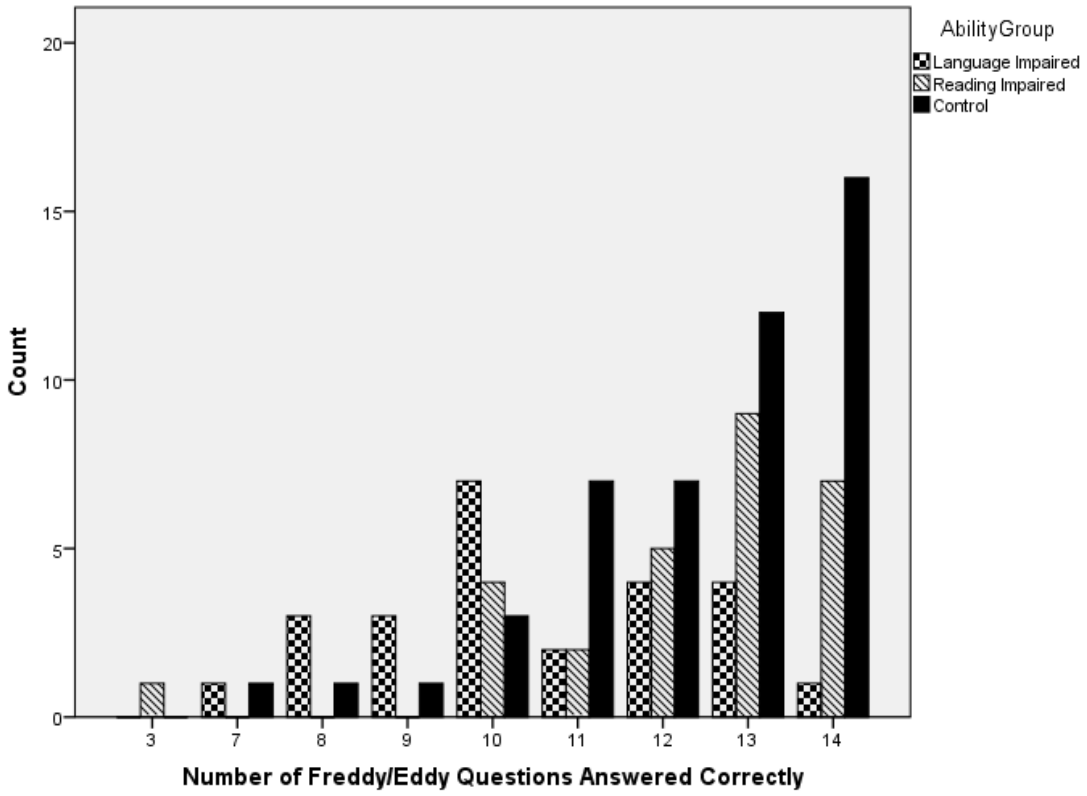
SLI (Language Impaired), RI (Reading Impaired), Control (Typically Developing), MAT (Nonverbal Reasoning, Matrix Analogy Test), Digit Total (Working Memory, Wechsler Intelligence Scale for Children-III Numbers Forward + Numbers Backwards), RAN Letter (CTOPP RAN Letter), RAN Digits (CTOPP RAN Digits), Recalling Sentence (Sentence Repetition, CELF-4) DEEdee (Sensitivity to Phrase Rhythm), Freddy/Eddy (Sensitivity to Sentences Rhythm), Ellision (Phonological Awareness, CTOPP Ellision subtest), PPVT (Receptive Vocabulary, PPVT-III), Listening Comprehension, Word Attack, Word Identification, Reading Comprehension (all subtests of the Woodcock Language Mastery Tests)

Figure 11: Count of number of correct answers to DEEdee questions by ability group.



Note: Maximum score on DEEdee is 18.

Figure 12: Count of number of correct answers to Freddy/Eddy questions by ability group.



Note: Maximum score on Freddy/Eddy is 14.

References

Andreassen, R. (2010). Examining the prediction of reading comprehension on different multiple-choice tests. *Journal of Research in Reading, 33(3)* , 263-283.

AT&T Speech Labs. (2007). *Crystal TTS Voice.* Florham Park, NJ: AT&T Speech Labs.

Axmear, E., Reichle, J., Alamsaputra, M., Kohnert, K., Drager, K., & Sellnow, K. (2005). Synthesized speech intelligibility in sentences: A comparison of monolingual English-speaking and bilingual children. *Language, Speech, and Hearing Services in Schools, 36* , 244-250.

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105(1)* , 158-173.

Baddeley, A. (1998). *Human Memory: Theory and Practice Revised Edition.* Boston, MA: Allyn and Bacon.

Baddeley, A. (1996). Working memory and executive control. *Philosophical Transactions of the Royal Society of London, 351* , 1397-1404.

Badian, N. A. (1999). Reading disability defined as a discrepancy between listening and reading comprehension: A longitudinal study of stability, gender differences, and prevalence. *Journal of Learning Disability, 32(2)* , 138-148.

Balota, D. A., Cortese, M. J., Hutchison, K. A., Neely, J. H., Nelson, D., Simpson, G. B., et al. (2008, 06 01). *The English Lexicon Project: A web-based repository of descriptive and behavioral measures for 40,481 English words and nonwords.* Retrieved 06 01, 2008, from elexicon.wust1.edu

Bess, F. H., & Humes, L. E. (1995). *Audiology: The fundamentals.* Baltimore, MD: Williams & Wilkins.

Beutnagel, M., Conkie, A., Schroeter, J., Stylianou, Y., & Syrdal, A. (1998). *The AT&T Next-Gen TTS System.* Florham Park, NJ: AT&T Speech Lab.

Biemiller, A. (2005). Size and Sequence in Vocabulary Development: Implications for Choosing Words for Primary Grade Vocabulary Instruction. In E. H. Hiebert, & M. L. Kamil, *Teaching and learning vocabulary: Bringing research to practice* (pp. 223-242). Mahwah: NJ: Lawrence Erlbaum Associates Publishers.

Biemiller, A. (2009). *Words Worth Teaching.* Columbus, OH: SRA/McGraw-Hill.

Bishop, D. (1997). *Uncommon Understanding: Development and Disorders of Language Comprehension in Children.* Hove: Psychology Press.

Bishop, D. V., & Adams, C. (1992). Comprehnsion problems in children with specific language impairment: literal and inferential meaning. *Journal of Speech and Hearing Research, 35* , 119-129.

Bishop, D. V., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different? *Psychological Bulletin, 130(6)* , 858-886.

Boersma, P., & Weenink, D. (2008). PRAAT software Version 5.2.10. Phonetic Sciences, University of Amsterdam.

Bowers, P. G., & Wolf, M. (1993). Theoretical links among naming speed, precise time mechanisms and orthographic skill in dyslexia. *Reading and Writing, 5* , 69-85.

Bradlow, A. R., Torretta, G. M., & Pisoni, D. B. (1996). Intelligibility of normal speech I: Global and fine-grained acoustic-phonetic talker characteristics. *Speech Communication, 20* , 255-272.

Campbell, N., & Black, A. (1997). Prosody and the selection of source units for concatenative synthesis. In J. van Santen, R. Sproat, J. Olive, & J. Hirschberg, *Progress in Speech Synthesis* (pp. 279-292). London: Springer-Verlag.

Case, R. (1985). *Intellectual Development: Birth to Adulthood.* New York: Academic Press.

Chandak, M. B., Dharaskar, R. V., & Thakre, V. M. (2010). Text to speech synthesis with prosody feature: Implementation of emotion in speech output using forward parsing. *International Journal of Computer Science and Security, 4(3)* , 352-360.

Clin, E., Wade-Woolley, L., & Heggie, L. (2009). Prosodic sensitivity and morphological awareness in children's reading. *Journal of Experimental Child Psychology, Vol 104(2)* , 197-213.

Cohen, E. A., Sevcik, R. A., Woll, M., Lovett, M. W., & Morris, R. D. (2008). Integration the PHAST and RAVE-O programs for stuggling readers. In M. R. Kuhn, & P. J. Schwanenflugel, *Fluency in the Classroom* (pp. 92-123). New York: Guilford Press.

Cohen, J., & Cohen, P. (1983). *Applied multiple Regession/Correlation Analysis for the Behavroral Sciences.* Hillsdale, NY: Lawerence Erlbaum Assoc.

Conti-Ramsden, G., & Hesketh, A. (2003). Risk markers for SLI: A study of young language-learning children. *International Journal of Language & Communication Disorders, 38* , 251-263.

Conti-Ramsden, G., Botting, N., & Faragher, B. (2001). Psycholinguistic markers for specific language impairment (SLI). *Journal of Child Psychology and Psychiatry, 42(6)* , 741-748.

Cunningham, T., & Watson, P. (2003). *If you hear a word and see a word do you know it? The effects of a text-to-speech program on both non disabled and disabled post-secondary students.* Peterborough: Trent University.

Dalton, B., & Strangman, N. (2006). Improving Struggling Readers' Comprehension Through Scaffolded Hypertexts and Other Computer-Based Literacy Programs. In M. C. McKenna, L. D. Labbo, R. D. Kieffer, & D. Reinking, *International handbook of literacy and technology (Vol 2)* (pp. 75-92). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Daneman, M., & Hannon, B. (2001). Using working memory theory to investigate the construct validity of multiple-choice reading comprehension test such as the SAT. *Journal of Experimental Psychology: General, 130* , 208-223.

David, D., Wade-Woolley, L., Kirby, J. R., & Smithrim, K. (2007). Rhythm and reading development in school-age children: A longitudinal study. *Journal of Research in Reading* , 169-183.

Dempster, F. N. (1981). Memory Span: Sources of individual and developmental differences. *Psychol Bull, 89* , 63-100.

Drager, K. D., Reichle, J., & Pinkoski, C. (2010). Synthesized speech output and children: A scoping review. *American Journal of Speech and Language Pathology, 19* , 259-273.

Duffy, S. A., & Pisoni, D. B. (1992). Comprehension of synthetic speech produced by rule: A review and theoretical interpretation. *Language and Speech* , 351-389.

Dunn, L. M., & Dunn, L. M. (1997). Peadbody Picture Vocabulary Test - 3rd edition. *PsychCorp*.

Dutoit, T. (1997). *An Introduction to Text-To-Speech Synthesis.* London: Kluwer Academic Publishers.

Edyburn, D. L. (2005). Assistive technology and students with mild disabilities: From consideration to outcome measurement. In D. K. Edyburn, K. Higgins, & R. (. Boone, *Handbook of Special Education Technology Research and Practice* (pp. 239-269). Whitefish Bay, WI: Knowledge by Design.

Eide, E., Aaron, A., Bakis, B., Cohen, P., Donovan, D., Hamza, W., et al. (2003). Recent Improvements to the IBM trainable speech synthesis system. *ICASSP, 1* , 708-711.

Elbro, C., Rasmussen, I., & Spelling, B. (1996). Teaching reading to disabled readers with language disorders: A controlled evaluation of synthetic speech feedback. *Scandinavian Journal of Psychology, 32(2)* , 140-155.

Elizabeth, J., Lambon Ralph, M. A., & Baddeley, A. D. (2004). Automatic and controlled processing in sentence recall: The role of long-term and working memory. *Journal of memory and language, 51(4)*, 623-643.

Elking, J. (1998). Computer reading machines for poor readers. *Lexia Institute*, 1-21.

Elking, J., Cohen, K., & Murray, C. (1993). Using computer-based readers to improve reading comprehension of students with Dyslexia. *Annals of Dyslexia, 43*, 238-259.

Farmer, M. E., Klein, R., & Bryson, S. E. (1992). Computer-assisted reading: Effects of whole-word feedback on fluency and comprehension in readers with severe disabilities. *Remedial and Special Education, 13(2)*, 50-60.

Farr, R., Pritchard, R., & Smitten, B. (1990). A description of what happens when an examinee takes a multiple-choice reading comprehension test. *Journal of Educational Measurment, 27*, 209-226.

Fernald, A. (1992). Human maternal vocalizations to infants as biologically relevant signals: an evolutionary perspective. In J. H. Barkow, L. Cosmides, & J. Topby (Eds.), *The Adaptive Mind: Evolutionary Psychology and the Generation of Culture* (pp. 391-428). Osford: UK: Oxford University Press.

Fisher, J., Plante, E., Vance, R., Gerken, L., & Glattkey, T. J. (2007). Do children and adults with language impairment recognize prosodic cues? *Journal of Speech and Langue, Hearing, Research, 50*, 746-758.

Fletcher, J. M. (2006). Measuring Reading Comprehension. *Scientific Studies of Reading, 10(3)*, 323-330.

Foorman, B. R., Francis, D. J., Davidson, K. C., Harm, M. W., & Griffin, J. (2004). Variability in text features in six grade 1 basal reading programs. *Scientifc Studies of Reading, 8(2)*, 167-197.

Foulke, E., & Sticht, T. (1969). Review of research on the intelligibility and comprehension of accelerated speech. *Psychological Bulletion, 72*, 50-62.

Francis, A. L., Nusbaum, H. C., & Fenn, K. (2007).). Effects of training on the acoustic-phonetic representation of synthetic speech. *Journal of Speech, Language, and Hearing Research, 50(6)*, 1445-1465.

Freedom Scientific Group. (2010). WYNN for Windows 7. St. Petersurg, FL: Freedom Scieni, Learning Group.

Gathercole, S. E. (1998). The development of memory. *The Journal of Child Psychology and Psychiatry, 39(1)*, 3-27.

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at seven years of age. *Journal of Educational Psychology, 70*, 177-194.

Gathercole, S. E., Alloway, T. P., Willis, C. S., & Adams, A. M. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93*, 265-281.

Gathercole, S., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29(3)*, 336-360.

Gathercole, S., & Baddeley, A. (1993). *Working Memroy and Language.* Hillsdale, NJ: Lawrence Erlbaum.

Good, R. H., & Kaminski, R. A. (2007). *Dynamic Indicators of Basic Early Literacy Skiils (6th ed.)*. Retrieved from Institute for the Development of Educational Achievement: http://dibels.uoregon.edu

Goodwin, C. J. (1998). *Research in Psychology: Methods and Design 2nd Edition.* New York, NY: John Wiley & Sons, Inc.

Gough, P. B., Hoover, W. A., & Peterson, C. L. (1996). Some observations on a simple view of reading. In C. Cornoldi, & J. Oakhill, *Reading comprehension difficulties: Processes and intervention* (pp. 1-13). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Gray, S. (2003). Diagnostic accuracy and test-retest reliability of nonword repetition and digit span task administered to preschool children with speoific language impariment. *Journal of Communication Disorders, 36*, 129-151.

Grdo-Salant, S., Fitzgibbons, P. J., & Friedman, S. A. (2007). Recognition of Time-Compressed and Natural Speech With Selective Temporal Enhancements by Young and Elderly Listeners. *Journal of Speech, Language, and Hearing Research, 50(5)*, 1181-1193.

Greene, B. G., Logan, J. S., & Pisoni, D. B. (1986). Perception of synthetic speech produced atomatically by rule: Intelligibility of eight text-to-speech systems. *Behavior research methods, Instruments & Computers, 18(2)*, 100-107.

Greenspan, S. L., Nusbaum, H. C., & Pisoni, D. B. (1988). Perceptual learning of synthetic speech produced by rule. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 14*, 421-433.

Handley, Z. (2009). Is text-to-speech synthesis ready for use in computer-assisted language learning? *Speech Communication (51)*, 906-919.

Harrington, J., & Cassidy, S. (1999). *Techniques in Speech Acoustics*. Boston: Kluwer.

Harwood, K. (1955). Listenability and rate of presentation. *Speech Monographs, 22*, 57-59.

Henry, L. A. (1994). The relationship between speech rate and memory span in children. *International Journal of Behavioral Development, 17(1)*, 37-56.

Hiebert, E. H. (2002). Standards, assessments, and text difficulty. In A. E. Farstrup, & S. J. Sauels, *What Research has to say about Reading Instrution* (pp. 337-391). Newark, DE: International Reading Association.

Higginbotham, D. J., Drazek, A. L., Kowarsky, K., Scally, C., & Segal, E. (1994). Discourse comprehension of synthetic speech delivered at normal and slow presentation rates. *Augmentative and Alternative Communication, 10*, 191-202.

Higgins, E. L., & Raskind, M. H. (1997). The comprensatory effectivenss of optical character reconition/speech synthesis on the reading comprehension of post-secondary students with learning disabilities. *Learing Disabilities: A mutidisciplinary Journal, 8*, 76-87.

Hill, R. L., & Murray, W. S. (200). Commas and spaces: effects of punctuation on eye movements and sentence parsing. In A. Kennedy, R. Radach, & D. (. Heller, *Reading as a Perceptaul Process* (pp. 565-589). Amsterdam: Elsevier.

Hirotani, M., Frazier, L., & Rayner, K. (2006). Punctuation and intonation effects on clause and sentence wrap-p: Evdence from eye movements. *Journal of Memory and Language, 54*, 425-443.

Hoover, J., Reichle, J., van Tassell, D., & Cole, D. (1987). The intelligibility of synthesized speech: Echo II versus votrax. *Journal of Speech and Hearing Research, 30*, 425-431.

Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and Writing, 2(2)* , 127-160.

Hux, K., Woods, M., Mercure, M., Vitko, C., & Scharf, S. (1998). Synthetic and natural speech processing by persons with or without aphasia: An investigation of attention allocation. *Journal of Medical Speech-Language Pathology, 6* .

Jilka, M., Syrdal, A. K., Conkie, A. D., & Kapilow, D. A. (2003). *Effects on TTS quality of methods of realizing natural prosodic variations.* Research Update from the AT&T Labs Research.

Jusczyk, P. W., Houston, D. M., & Newsome, M. (1999). The beginnings of word segmentation in English-learning infants. *Cognitive Psychology, 39(3-4)*, 159-207.

Jusczyk, P. W., Houston, D. M., & Newsome, M. (1999). *The beginnings of word segmentation in enhlish-learning infants.* 159-207: Cognitive Psychology, 39(3-4).

Just, M., & Carpenter, P. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*, 122-149.

Kelley, J. F. (1983). *An empirical methodology for writing user-friendly natural language computer applications.* 26-41: AMC Transactions of Office Information Systems, 2(1).

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30*, 580-602.

Kintsch, W., & van Dijk, T. (1978). Toward a model of text comprehension and production. *Psychological Review, 85*, 363-394.

Kirby, J. R. (2007). Reading comprehension: Its nature and development. In Encyclopedia of Language and Literacy Development. *Canadian Language and Literacy Research Network* , www.literacyencyclopedia.ca.

Kitzen, K. (2001). Prosodic sensitivity, morphological ability, and reading ability in young adults with and without childhood histories of reading difficulty. *issertation Abstracts International Section A: Humanities and Social Sciences*, 62(2-A), 460.

Klatt, D. (1987). Review of text-to-speech conversion for English. *Journal of the Acoustrical Society of America, 82*, 737-793.

Klein, D., & Manning, C. D. (2003). Accurate unlexicelized parsing. *Teh Association for Computational Lingustics*, 423-430.

Klein, D., & Manning, C. D. (2003). Fast exact inference with a factored model of natural language parsing. *Advance in Neural Information Processing Systems, 16*, 3-10.

Koul, R. K., & Hanners, J. (1997). Word identification and sentence verification of two synthetic speech systems by individuals with intellectual disabilites. *Augmentative and Alternative Communication, 13*, 99-107.

Koul, R. (2003). Synthetic speech perception in indiviudals with and without disabilites. *Augmentative and Alternative Communication, 19(1)*, 49-58.

Koul, R., & Clapsaddle, K. C. (2006). Effects of repeated listening experiences on the perception of synthetic speech by individuals with mild-to-moderate intellectual disabilites. *Augmentative and Alternative Communication, 22(2)*, 112-122.

Kuhl, P. K. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience, 83(5)*, 831-843.

Kurzweil Educational Systems. (2006). Kurzweil 3000 v8.0. Bedford MA: Kurzweil Educational Systems.

Lennon, C., & Burdick, H. (2010). *The Lexile Framework As An Approach for Reading Measurement and Success*. Retrieved September 05, 2008, from Lexile: http://www.lexile.com/research

Leonard, L. B. (1998). *Children with Specific Language Impairment.* Cambridge, MA: MIT Press.

Leong, C. K. (1995). Effects on on-line reading and simultancous DECtalk auding in helping belowaverage and ppor readers comprehend and summarize text. *Learning Disability Quarterly, 18(2)*, 101-116.

Levinson, S. E., Olive, J. R., & Tschingi, J. S. (1993). Speech synthesis in telecommunications. *Institute of Electrical and Electronics Engineers Communications Magazine, 3(11)*, 46-53.

Lindfield, K. C., Wingfield, A., & Goodglass, H. (1999). The contribution of prosody to spoken word recognition. *Applied Psycholinguistics, 20(3)*, 395-405.

Lindfield, K. C., Wingfield, A., & Goodglass, H. (1999). The role of prosody in the mental lexicon, 20(3). *Brain and Language. Special Issue: Mental Lexicon, 68(1-2)*, 312-317.

Lindfield, K., Wingfield, A., & Goodglass, H. (1999). The role of prosody in the mental lexicon. *Brain and Language, 68*, 312-317.

Lundberg, I., & Olofsson, A. (1993). Can computer speech support reading comprehension? *Computers in Human Behavior. Special Issue: Swedish research on learning and instruction with computers, 9(2-3)*, 283-293.

Marcus, M. P., Santorini, B., & Marcinkiewicz, M. A. (1993). Building a large annotated corpus of English: the Penn Treebank. *Computational Linguistics, 19*, 1-22.

Marics, M. A., & Williges, B. H. (1988). The intelligibility of synthesized speech in data inquiry systems. *Human Factors, 30*, 719-732.

Markwardt, F. C. (1997). *Peadbody Indiviudal Achievement Test-Revised.* New York, NY: PsychCorp.

McGivern, R. F., Berka, C., Languis, M. L., & Chapman, S. (1991). Detection of deficits in temporal pattern discrimination using the Seashore Rhythm Test in young children with reading impairments.*Journal of Learning Disabilities, 24(1)*, 58-62.

McNamara, D. S. (2007). *Reading Comprehension Strategies: Theories, interventions, and Technologies.* New York, NY: Erlbaum.

Mechelhi, A., Crinion, J. T., Long, S., Friston, K. J., Lambon Ralph, M. A., Patterson, K., et al. (2005). Dissociating reading processes on the basis of neuronal interactions. *Jounal of Cognitive Neuroscience, 17(11)*, 1753-1765.

Medler, D., Medler, D. A., Desai, R., Conant, L. L., & Liebenthal, E. (2005). Some neurophysiological constraints on models of word naming. *Neuroimage, 27(3)*, 677-693.

Microsoft. (1998). *Mary TTS Voice.* Mountain View, CA: Microsoft Research.

Mirenda, P., & Beukelman, D. (1990). A comparison of intelligibility among natural speech and seven speech synthesizers with listeners from three age groups. *Augmentative and Alternative Communication, 6*, 61-68.

Mirenda, P., & Beukelman, D. R. (1987). A comparison of speech synthesis intelligibility with listeners from thre age groups. *Augmentative and Alternative Communication, 3*, 120-128.

Mitterer, H., & Blomert, L. (2003). Coping with phonological assimilation in speech perception: Evidence for early comprensation. *Perception & Psychophysics, 65(6)*, 956-969.

Montali, J., & Lewandowski, L. (1996). Bimodal reading: Benefits of a talking computer for average and less skilled readers. *Journal of Learning Disabilities, 29(3)*, 271-279.

Moody, T., Joost, N., & Rodman, R. (1987). Vigilance and its role in AI technology: How smart is too smart? In G. Salvendy, S. L. Sauter, & J. J. Hurrell, *Social, Ergonomic and Stress Aspects of Work Wwith Computers* (pp. 263-270). Amsterdam: Elsevier.

Moore, D. R., Rosenberg, J. F., & Coleman, J. S. (2005). Discrimination training of phonemic contrasts enhances phonological processing in mainstream school children. *Brain and Language, 94*, 72-85.

Nakatani, L. H., & Schaffer, J. A. (1978). Hearing 'words' without words: Prosodic cues for word perception. *Journal of the Acoustical Society of America, 63*, 234-245.

Nation, K., Adams, J. W., Bowyer-Crane, C. A., & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology*, 139-158.

National Center for Education Statistics. (2001). *Assessing the Lexile Framework: Results of a Panel Meeting. Working Paper No. 2001-08.* Washington, DC: U.S. Department of Education.

National Institute of Child Health and Human Development. (2000). *Report of the National Reading Panel. Teaching Children to Read. An evidence-based assessment of the scientifc research literature on reading and its implications for reading insturction.* Washiongton, D.C.: NIC Pubilication No. 00-4769. Goverment Printing Office.

National Reading Panel. (2000). *Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction.* Washinten DC: Department of Education of the United States of America.

Nelson, H. (1948). The effect of variation of rate on the recall by radio listeners of "straight" newscasts. *Speech Monographs, 15*, 173-180.

Nelson, P., Soli, S., & Seitz, A. (2002). *Acoustical Barriers to Learning.* Melville, NY: Technical Committee on of the Acoustical Society of America.

NextUp. (2008). *TextAloud V2.285.* Clemmons, NC: NextUP.

Ontario Ministry of Education. (2004). *The individual education plan (IEP): a resource guide.* Toronto: Ontario Ministry of Education.

O'Shaughnessy, D. (2007). Modern Methods Speech Synthesis. *IEEE Circuits and Systems magazine, 1109(3)*, 6-23.

O'Shaughnessy, D. (2000). *Speech Communication: Human and Machine, 2nd ed.* New Jersey: Institute of Electrical and Electronics Engineers Communications Magazine Press.

O'Shaughnessy, D., Bardeau, L., Bernardi, D., & Archambault, D. (1988). Diphone speech synthesis. *Speech Communication, 7*, 55-65.

Pae, H. K., Wise, J. C., Cirino, P. T., Sevcik, R. A., Lovett, M. W., Wolf, M., et al. (2005). The woodcock reading mastery test impact of normative changes. *Assessment, 12(3)*, 347-367.

Panel, N. R. (2000). *Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction.* Washinten DC: Department of Education of the United States of America.

Paris, C. R., Gilson, R. D., & Thomas, M. H. (1995). Effect of synthetic voice intelligibility on speech comprehension. *Human Factors, 37(2)*, 335-340.

Pisoni, D. B., Manous, L. M., & Dedian, M. J. (1987). Comprehnsion of natural and synthetic speech: Effects of predictability on the verification of sentences controlled for intelligibility. *Computer Speech and Language, 2*, 303-320.

Pressley, M., & Harris, K. R. (2006). Cognitive strategies instruction: From basic research to classroom instruction. In P. A. Alexander, & P. H. Winne, *Handbook of Educational Psychology, (2nd ed.)* (pp. 265-286). Mahwah, NJ: Erlbaum.

Pressley, M., & Harris, K. R. (1995). *Verbal protocols of reading: The nature of constructively responsive reading.* Hillsdale, NJ: Erlbaum.

Psychology Software Tools, INC. (2008). E-Prime V1. Sharpsburg, PA, USA.

Ralston, J. V., Pisoni, D. B., & Mullennix, J. W. (1989). *Comprehension of synthetic speech produced by rule (Reserch on Speech Perception Progress Report No. 15).* Bloomington: Indiana University.

Ralston, J., Pisoni, D., Lively, S., Greene, B., & Mullenix, J. (1991). Comprehension of synthetic speech produced by rule: Word monitoring and sentence-by-sentence listening times. *Human Factors, 33*, 471-491.

Rapp, D. N., van den Broek, P., McMaster, K. L., Kendeou, P., & Espin, C. A. (2007). Higher-order comprehension processes in struggling readers: A perspective for research and intervention. *Scientific Studies of reading, 11(4)*, 289-312.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124(3)*, 372-422.

Rayner, K., & Pollatsek, A. (1989). *The Psychology of Reading.* Englewood Cliffs, NJ: Prentice Hall.

Rayner, K., & Slattery, T. J. (2009). Eye movements and moment-to-moment comprehension processes in reading. In R. K. Wagner, C. Schatshneider, & C. Phythian-Sence, *Beyond Decoding: The Behavioral and Biological Foundations of Reading Comprehension.* New York, NY: The Guilford Press.

Rayner, K., Kambe, G., & Duffy, S. A. (2000). The effect of clause wrap-up on eye movements during reading. *The Quarterly journal of Experimental Psychology: Human Experimental Psychology 53A*, 1061-1080.

Reynolds, M. E., & Fucci, D. (1998). Synthetic speech comprehension: A comparison of children with normal and impaired language skills. *Journal of Speech, Language and Hearing research, 41*, 458-466.

Reynolds, M. E., & Givens, J. (2001). Presentation rate in comprehension of natural and synthetic speech. *Perceptual and Montor Skills, 92*, 958-968.

Reynolds, M. E., & Jefferson, L. (1999). Natural and syntetic speech comprehension: comparison of children from two age groups. *Augmentative and Alternative Communication, 15*, 174-182.

Reynolds, M. E., Issaac-Duvall, C., & Haddox, M. L. (2002). A comparison of learning curves in natural and synthesized speech comprehension. *Journal of Speech, Language, and Hearing Research, 45(4)*, 802-811.

Reynolds, M. E., Issacs-Duvall, C., Sheward, B., & Rotter, M. (2000). Examination of the effects of listening practice on synthesized speech comprehension. *Augmentative and Alternative Communication*, 250-259.

Scherer, K. R. (1979). Non-linguistic vocal indicators of emotion an psychopathology. In C. E. Izard, *Emotions in Personality and Psychopathology* (pp. 485-529). New York: Plenum Press.

Schmidt-Nielsen, A. (1995). Intelligibility and acceptability testing for speech technology. In R. W. Bennett, A. K. Syrdal, & S. L. Greenspan, *Behaviroral Aspects of Speech Tehcnology: Theory and Application* (pp. 41-63). Boca Raton, FL: CRC.

Schroeter, J. (2005A). Text-to-Speech (TTS) synthesis. *Electrical Engineering Handdbook, 3rd Edition*, 1-13.

Schroeter, J. (2005B). Voice Modification for Applications in Speech Synthesis. *AT&T Labs - Research*, 1-20.

Schwanenflugel, P. J., Hamilton, A. M., & Kuhn, M. R. (2004). Becoming a Fluent Reader: Reading Skill and Prosodic Features in the Oral Reading of Young Readers. *Journal of Educational Psychology, 96(1)*, 119-129.

Segal-Seiden, L. (1997). Perception and spelling of strange speech sounds by Polish-Canadian

L2 speakers of English. Unpublished doctoral dissertation, University of Toronto, Ontario.

Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical Evaluationof Language Fondamentals-fourth Edition.* New York: Pearson.

Shankweiler, D., & Fowler, A. E. (2004). Questions people ask about the role of phonological processes in learning to read. *Reading and Writing, 17(5)*, 483-515.

Siegel, L. (1994). Working memory and reading: A lifespan perspective. *International Journal of Behavioral Development, 17*, 109-124.

Sisto, R., Pieroni, A., Delucis, C. (2007). Noise exposure and speech intelligibility in elementary schools in Tuscany. *19th International Congress on Acoustics*, Madrid

Skakum, E. N., Maguire, T., & Cook, D. A. (1994). Strategy choices in multiple-choice items. *Academic Medicine Supplement, 69(10)*, S7-S9.

Snowling, M. J. (2000). *Dyslexia.* Oxford: Blackwell.

Snowling, M. J. (2000). Language and literacy skills: Who is at risk and why? In D. V. Bishop, & L. B. Leonard, *Speech and language impairments in children: Causes, characteristics, intervention and outcome* (pp. 245-259). New York, NY: Psychology Press.

Snowling, M. J., & Hayiou-Thomas, M. E. (2006). The Dyslexia Spectrum: Continuities Between Reading, Speech, and Language Impairments. *Topics in Language Disorders, 26(2)*, 110-126.

Snowling, M., Chiat, S., & Hulme, C. (1991). Words, nonwords, and phonological processes: Some comments on Gathercole, Willis, Emslie, and Baddeley. *Applied Psycholinguistics, 12*, 369-373.

SourceForge.net. (2008). *Audacity V 1.2.6.* www.sourceforge.net: SourceForge.net.

Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. *Journal of Educational Psychology, 86(1)*, 24-53.

Stanovich, K. E., Siegel, L. S., & Gottardo, A. (1997). *Converging evidence for phonological and surface subtypes of reading disablity.* Journal of Educational Psychology, 89(1): 114-127.

Staub, A. (2007). The return of the repressed: A bandoned parses facilitate syntactic reanalysis. *Journal of Memory and Language, 57*, 299-323.

Stenner, A. J., Burdick, J., Sanford, E. E., & Burdick, D. (2006). How accurate are lexile text measures? *Journal of Applied Measurement, 7(3)*, 307-322.

Stokes, S. F., Wong, A. M.-Y., Fletcher, P., & Leonard, L. B. (2006). Nonword repetition and sentence repetition as clincal markers of SLI: the case of cantonese. *Journal of Speech, Language, and Hearing Research, 49*, 219-236.

Strangman, N., & Dalton, B. (2005). Using technology to support struggling readers: a review of the research. In D. Edyburn, K. Higgins, & R. Boone (eds), *Handbook of Special Education Technology Research and Practice.* Wisconsin: Knowledge by Design.

Swanson, H. L. (1999). What develops in working memory? A life span perspective. *Developmental Psychology, 35(4)*, 986-1000.

Swanson, H. L. (1999). Reading research for students with LD: A meta-analysis of intervention outcomes. *Journal of Learning Disabilites, 32* , 504-532.

Swanson, H. L., Ashbaker, M. H., & Carole, L. (1996). Learning-disabiled readers' working memory as a function of processing demands. *Journal of Experimental child Psychology, 61(3)*, 242-275.

Swanson, L. (1994). Working memory and phonological processing as predictors of children's mathematical problem solving at differnt ages. *Memory and Cognition, 32*, 648-661.

The Stanford Natural Language Processing Group. (2010). *The Stanford Natural Language Processing Group*. Retrieved March 13, 2011, from http://nlp.stanford.edu

Timmer, S. (2008). University of Toronto Reader. USA.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Rose, E., Lindamood, P., Conway, T., et al. (1999). Preventing reading failure in young children with phonological processing disabilities:

Group and individual responses to instruction. *Journal of Educational Psychology, 91(4)*, 579-593.

US technology-related assistance for indiviudals with disabilites act. (1998). *Section 3.1 Public Law 100-407.*

Van Bon, W. H., & Van Der Pijl, J. M. (1997). Effects of word length and wordlikeness on pseudoword repetition by poor and normal readers. *Applied Psycholoinguistics, 18*, 101-114.

van der Lely, H. K. (2005). Domain-specific cogntive systems: insigt from Grammatical-SLI. *Trends in Cognitive Sciences, 9*, 53-59.

Venkatagiri, H. S. (1991). Effects of rate and pitch variations on the intelligibility of synthesized speech. *Augmentative and Alternative Communication, 7*, 284-289.

venKatagiri, H. S. (2004). Segmental intelligibility of three text-to-speech synthesis methods in reverberant enviroments. *Augmentaive and Alternative Communication, 20(3)*, 150-163.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101(2)*, 192-212.

Wagner, R., Torgesen, J., & Rashotte, C. (1999). *Commprehensive Test of Phonological Processing (CTOPP).* New York: NY: Pearson.

Walpole, S., Hayes, L., & Robnolt, V. (2006). Matching second graders to text: The utility of a group-administered comprehension measure. *Reading Research and Instruction, 46*, 1-22.

Wang, M., & Geva, E. (2003). Spelling acquisition of novel English phonems in chinese children. *Reading and Writing: An Interdisciplinary Journal, 16*, 325-348.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101(2)* , 192-212.

Wagner, R., Torgesen, J., & Rashotte, C. (1999). *Commprehensive Test of Phonological Processing (CTOPP).* New York: NY: Pearson.

Whalley, K., & Hansen, J. (2006). The role of prosodic sensitivity in children's reading development. *Journal of Research in Reading, 29(3)*, 288-303.

Wise, B. W., & Olson, R. K. (1995). Computer-based phonological awareness and reading instruction. *Annals of Dyslexia, 45*, 99-122.

Wood, C. (2006). *Sensitivity to speech rhythm and the decelopment of reading: Thrends in cognitive psychology research.* New York, NY: Nova Science.

Wood, C., & Terrell, C. (1998). Poor readers' ability to deetect speech rhythm and perceive rapid speech. *British Jounral of Developmental Psychology, 16*, 397-413.

Wood, C., & Terrell, C. (1998). Pre-school phonological awarenss and subsequent literacy development. *Educational Psychology, 18(3)*, 253-274.

Woodcock. (1987). *Woodcock Reading Mastery Test - Revised-Normative Update.* New York: NY: PsychCorp.

Woodcock, R. W. (1991). *Woodcock Language Proficiency Battery - Revised.* New York: NY: Nelson.

Woodcock, R. W. (1998). *Woodcock Reading Master Test-Revised/Normative Update.* Circle Pines, MN: American Guidance Service.

WordCalc.com. (2010). *Syllable Counter & Word Count*. Retrieved March 13, 2010, from www.wordcalc.com

Appendices

Appendix A

Do to copyright restrictions; the comprehension passages cannot be presented.

Appendix B

TTS Study Passage Comprehension Form

ID# _____ Date: _____

Voice: ☐ Lot TTS | ☐ High TTS

Reading Condition

Condition	Number		Condition	Number	
Phrase Pause | Slow			Random Pause | Fast		
Phrase Pause | Medium			No Pause | Slow		
Phrase Pause | Fast			No Pause | Medium		
Random Pause | Slow			No Pause | Fast		
Random Pause | Medium					

Speed Condition

Voice	Slow	Medium	Fast
Low TTS (Mary)	-3	-1	1
High TTS (Cristal)	-2	0	2

Order	Passage #	Pause	Speed	Q1	Q2	Q3	Q4	Q5
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								

Text-To-Speech Survey

User ID _____ Date: _____
Voice Used _____

How did you lie the computer reading to you:

	Worst Best						Worst Best				
No Pause	1	2	3	4	5	Slow reading sped	1	2	3	4	5
Random Pause	1	2	3	4	5	Medium reading speed	1	2	3	4	5
Phrase Pause	1	2	3	4	5	Fast reading speed	1	2	3	4	5

General Questions

□ Yes | □ No

Have you ever had a computer read to you before

If yes, how often do you have a computer read to you

All the time	Most of the time	Often	Seldom	Never

If you have a computer read to you, what do you ask it to read:

□ Reading school work
□ Stories for pleasure reading
□ Newspaper
□ Magazines
□ Work that you wrote on the computer
□ Instruction manuals
□ Web sites

Please tell me how much you agree or disagree with the following statements:

	Strongly	Agree	Disagree
I like when I have a story read to me.	1	2	3
I enjoyed the voice that has read to me.	1	2	3
I found that when the program read faster, I did not comprehend what was being read.	1	2	3
I understand better when I had the program read to me.	1	2	3
The program made it easier for me to read.	1	2	3
I found that when the program paused, I understood better	1	2	3
I like that the program highlighted words.	1	2	3
I would use a program like this in the future to aid in my reading.	1	2	3
I found myself frustrated when the program read to me.	1	2	3
Highlighting of words helped me focus on the words.	1	2	3
I did not understand the voice that read to me.	1	2	3