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The Compensatory Effect of Text-to-Speech Technology on Reading Comprehension and Reading Rate in Swedish Schoolchildren With Reading Disability: The Moderating Effect of Inattention and Hyperactivity Symptoms Differs by Grade Groups

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Abstract

The purpose of this study was (i) to investigate if the compensatory effect of text-to-speech (TTS) technology on reading comprehension and reading rate in schoolchildren with reading disability is influenced by problems with inattention and hyperactivity and (ii) to examine whether a potentially moderating effect of such symptoms differ between grade groups. Participants ($N = 49$) were randomized into one of the two experimental conditions: Group A listened to a text with TTS, and Group B read the text themselves. The conditions were then switched. Inattention and hyperactivity symptoms were assessed with the Strengths and Difficulties Questionnaire (SDQ). Statistical analyses were performed both on the whole group and within-grade groups (Grades 3–5 and 6–9). Using TTS technology had a positive effect on reading rate for both grade groups, and this effect was not influenced by attention-deficit/hyperactivity disorder (ADHD) symptoms. As for reading comprehension, the two groups differed both with respect to the amount of improvement seen in the TTS condition and with respect to the moderating effect of ADHD symptoms. Reading with TTS improved reading comprehension significantly in the younger group, whereas no effect on reading comprehension was found in the older group. A higher score on the SDQ ADHD Scale was associated with *less* improvement in reading comprehension in the younger group and with *greater* improvement in reading comprehension in the older group. The results indicate that symptoms of inattention and hyperactivity, as well as the child's grade level, are factors that should be taken into account when planning and introducing TTS technology.

Keywords

text-to-speech, reading disability, assistive technology, reading comprehension, reading rate, attention deficit/hyperactivity disorder

Introduction

Reading disability (RD) is characterized by difficulties with literacy development in the context of otherwise typical intellectual skills and educational opportunities (Lyon, Shaywitz, & Shaywitz, 2003). The disorder has been estimated to affect about 5–12% of schoolchildren (Shaywitz, Shaywitz, Fletcher, & Escobar, 1990), making it the most common of childhood learning disorders (Cortiella & Horowitz, 2014).

Children with RD have primary difficulties with written word recognition that is linked to a deficit in phonological processing in the majority of cases (Bishop & Snowling, 2004; Catts & Kamhi, 2005; Vellutino, Fletcher, Snowling, & Scanlon, 2004). The difficulties with written word recognition lead to slow, effortful, and often inaccurate reading, which typically has a detrimental effect on the capacity to construct meaning from what is being read (Forgrave, 2002). Impaired reading comprehension, in turn, may have a major negative impact on academic performance (Dias, Montiel, & Seabra, 2015) and is often the cause for clinical referral.

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In addition, many children with RD have problems in the neuropsychiatric domain (Boada, Willcutt, & Pennington, 2012). Most importantly, attention deficits are widespread in children with RD, and the comorbidity rate between RD and attention-deficit/hyperactivity disorder (ADHD) has been estimated to be 15–40% (Willcutt & Pennington, 2000). Inattention and/or hyperactivity problems have been shown to have an independent negative impact on reading comprehension (Miller et al., 2013) and may therefore act as moderators of the effect of intervention.

Intervention programs based on phonics have been shown to ameliorate reading accuracy in many children with RD (Edwards, 2008; Ehri, Nunes, Stahl, & Willows, 2001). However, the effect on reading fluency is somewhat less convincing, and slow and effortful reading remains a persistent trait of many affected individuals, despite considerable pedagogical efforts (Torgesen et al., 2001). For this reason, intervention also needs to encompass compensatory aids that are designed to bypass and work around the RD rather than treating it. One such compensatory aid is text-to-speech (TTS) technology that allows for digital text to be read aloud automatically with a speech synthesis. The text is read with a computer-generated voice, and the reading speed can be adjusted to fit the processing speed of the reader. TTS can be used with most digital devices, including smartphones and computers, and has become a widespread tool in Swedish schools (National Agency for Special Needs Education and Schools, 2015) as well as in many other countries (Wood, Moxley, Tighe, & Wagner, 2017). Yet, the scientific evidence for its compensatory effect on reading comprehension and reading rate in individuals with RD is not clear-cut (Wood et al., 2017).

Several studies have found positive compensatory effects of TTS on reading comprehension and/or reading rate in individuals with reading difficulties (Elkind, Black, & Murray, 1996; Elkind, Cohen, & Murray, 1993; Floyd & Judge, 2012; Lange, McPhillips, Mulhern, & Wylie, 2006). Elkind, Cohen, and Murray (1993) studied the effect of TTS on reading comprehension in 28 middle schoolchildren with RD. They found that a majority of them (70%) increased their reading comprehension when using TTS. Lange, McPhillips, Mulhern, and Wylie (2006) studied secondary-level students with reading difficulties comparing the use of different assistive softwares. Ninety-three students were separated into groups, so that 31 of them used TTS, 39 used only MS Word, and 23 of them served as controls, using no software. The results showed an increase in reading comprehension by 8% for the students using TTS, whereas no improvement was found in the other two groups. In addition, Floyd and Judge (2012) compared reading comprehension with or without TTS in six postsecondary students with learning disabilities and a reading level below average. The authors found that reading comprehension was significantly improved with TTS. In another study of 50 adult participants with RD, Elkind, Black, and Murray (1996) found a significant effect of TSS on reading rate. Using TTS also enabled the participants to sustain reading during longer periods of time.

Despite these positive results, it is clear that not all individuals with reading difficulties benefit from using TTS as a compensatory tool. For example, Schmitt, Hale, McCallum, and Mauck (2011) studied 25 children in Grades 6–8 from a remedial reading program. The results showed no significant difference in reading comprehension between reading with and without TTS. Also, in the study by Elkind et al. (1993) mentioned above, 14% of the participants actually showed a degradation of reading comprehension, and another 14% showed no improvement, when using TTS. The reason for this was not clear, but the two students with the greatest degradation of performance when using TTS had a kinesthetic motor weakness. In the study by Elkind et al. (1996) where a significant benefit was found for reading rate in the TTS condition, no effect was found for reading comprehension. Moreover, Sorrell, Bell, and McCallum (2007) found no significant effects on neither reading comprehension nor reading rate when they examined the compensatory effect of TTS in 12 elementary school (Grade 2–5) children with reading difficulties.

Although effect differences between studies may be explained by methodological differences such as, for example, the length of the text to be read and the type of TTS technology used, differences within studies are more likely to depend on within-sample individual characteristics. Several studies have shown that an individual's unaided reading comprehension and reading rate is linked to the amount of improvement seen with TTS. For example, Elkind et al. (1996) showed that the improvement in reading comprehension with TTS was larger when an individual's unaided comprehension was poorer, and when either receptive vocabulary or sentence repetition ability was better than average. As for the effect of TTS on reading rate, unaided reading rate was found to be the best predictor. More specifically, the individuals with the slowest reading rate without TTS gained most from using TTS, and the individuals with faster reading rates without TTS gained least from reading with TTS. A similar pattern was found in a study by Higgins and Raskind (1997), in which 37 postsecondary students with RD were tested on reading comprehension in one of the three conditions: (a) with TTS, (b) with a human reader, or (c) reading silently without assistance. The results showed that the effect of the TTS condition on reading comprehension was greatest for the students with the most severe reading disabilities and also that the higher the silent reading score was, the more the TTS technology interfered with the reading comprehension (even though all participants had RD). Also in the study by Sorrell et al. (2007), a trend was noted for the slower readers (i.e., the readers with the most severe reading disabilities in this study) to increase their reading rate more when using TTS, whereas the faster readers actually decreased their reading rate when using TTS.

Age or grade is another important factor since it serves as an indicator of the amount of reading instruction obtained by an individual as well as his or her cognitive, linguistic, and emotional development. However, studies examining the effect of age or grade on the compensatory effect of TTS have yielded inconsistent results. In a study of Swedish schoolchildren, Lundberg and Olofsson (1993) examined training effects of TTS and found that older children, in Grades 4, 6, and 7, benefited more from computer aided reading than did younger ones (Grades 2 and 3), as assessed by pre- and posttests of decoding skills and reading comprehension. In a meta-analysis by Buzick and Stone (2014) of different read-aloud conditions (e.g., TTS or a recording of a book by a human reader), grade was found to be a significant moderator of the effect of TTS. The effect sizes were slightly larger for elementary schoolchildren than for middle schoolchildren. In an even more recent meta-analysis, however, grade group was found to be a nonsignificant moderator of the effect of TTS (Wood et al., 2017).

Considering the cooccurrence of inattention and hyperactivity symptoms and RD (Boada et al., 2012), it appears plausible that additional interindividual variance in previous studies may be explained by individual differences in the extent to which participants had cooccurring attention/hyperactivity problems. Despite the fact that such cooccurring impairments are widespread in children with RD, not a single study has examined the influence of ADHD symptoms on the compensatory effect of TTS in children with RD. One study, however, has examined the effect of TTS on reading comprehension and reading rate in children with primary diagnosis of attention disorder. In this study, Hecker, Burns, Katz, Elkind, and Elkind (2002) examined 20 postsecondary students with diagnosed attention disorder. Reading with or without TTS was compared on reading assignments that the students were assigned to read for an English class in school. The main result from the study was that TTS increased reading rate but not reading comprehension for the participants. The participants also reported that they experienced less distractibility (mind trips) and were able to focus on reading for longer periods of time, when they used TTS.

The aim of the present study was to extend the literature on the compensatory effect of TTS on reading comprehension and reading rate in schoolchildren with RD by examining a potentially moderating effect of inattention and hyperactivity symptoms. Moreover, we aimed at investigating whether or not the compensatory effect of using TTS and/or a potentially moderating effect of ADHD symptoms differs by grade groups. Based on the study by Hecker et al. (2002), we hypothesized that a higher degree of ADHD symptoms should be associated with a relatively larger improvement in reading rate but not in reading comprehension. Because previous research on the effect of grade has yielded inconsistent results, and because grade was not taken into account in the Hecker et al.'s (2002) study, we had no a priori hypothesis about possible differences between grade groups. Finally, we investigated whether the children who participated in the study preferred reading with or without TTS.

Method

Participants

All individuals from Grades 3 to 9 in elementary school, referred by school nurses or family doctors to a speech-language pathology clinic in Central Sweden for reading assessment, were invited to join the study. This procedure resulted in inviting 60 individuals, all of whom chose to participate. Since the focus of the present study was schoolchildren with RD, only children who met the criteria for this diagnosis were included in the analyses. Criteria for diagnosis included a history of impaired reading and writing development, current functional impairment, as well as results from the reading and writing assessment. All of the included participants scored a maximum stanine value of 3 ($M = 1.89$, $SD = 0.67$) on a combined reading score. The combined reading score was composed of four different standardized reading tests that are commonly used for reading assessment in Sweden. The tests measure decoding of single words (Elwér, Fridolfsson, Samuelsson, & Wiklund, 2009; Jacobson, 2014; Johansson, 2004), single nonwords (Elwér et al., 2009; Johansson, 2004), and sentences (Jacobson, 2014).

Ten children were excluded from the analyses because they did not meet the clinical diagnostic criteria of RD. In addition, one participant was excluded because he was unable to complete the experiment. Thus, the final set of participants included for data analysis consisted of 49 children (26 boys and 23 girls, aged from 8:9 years of age to 16:1 years of age, with a mean age of 12:0 years).

Information about current problems with inattention and/or hyperactivity was obtained through the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1999; Smedje, Broman, Hetta, & von Knorring, 1999) filled in by the caregiver of each child. The SDQ consists of a total of 25 items divided into five subscales focusing on hyperactivity and inattention, emotional problems, conduct problems, peer problems, and prosocial behavior. A total stress score is calculated based on the first four scales. Scores on each subscale can range from 0 to 10, with higher scores indicating more severe problems for the first four scales. For the prosocial scale, the pattern is reversed and higher scores indicate more prosocial behavior. The hyperactivity and inattention scale of the SDQ includes items about the extent to which the child is restless or overactive, is constantly fidgeting or squirming, is easily distracted and inattentive, and whether the child thinks before acting. The scale has been shown to be a valid tool for identification of ADHD in children and adolescents (Algorta, Dodd, Stringaris, & Youngstrom, 2016).

Participant characteristics for the two grade groups are shown in Table 1. The groups did not differ significantly with respect to reading skill, broader language skills, nor in any of the SDQ scales. As seen in the table, two of the children in the older group had an ADHD diagnosis. In addition, two of the children in the younger group and one child in the older group had been referred for an ADHD assessment.

Data for the SDQ scores for the sample as a whole are shown in Table 2. Since Swedish normative data are lacking for the age-group of the present study, our data were compared to British normative data for 11- to 15-year-old children. In line with previous studies (Willcutt & Pennington, 2000), the comparisons indicate an elevated prevalence of inattention and/or hyperactivity symptoms in our sample.

Table 1. Participant Characteristics.

Participant characteristics	Younger Group (Grades 3–5) (n = 31) M (SD)	Older Group (Grades 6–9) (n = 18) M (SD)	t	p (Two-Sided)
Sex (boys/girls)	17/14	9/9		
School year (number of children)	3 = 5 4 = 8 5 = 18	6 = 8 7 = 5 8 = 0 9 = 5		
Age in years	10.96 (0.88)	13.79 (1.38)		
ADHD diagnosis	0	2		
Referred for ADHD assessment	2	1		
Reading skill (stanine)	1.77 (0.57)	2.10 (0.79)	1.72	.092
Broader language skill				
Receptive grammatical skill (TROG-2; percentile)	39.8 (21.7)	36.1 (20.7)	−0.60	.553
Expressive vocabulary (BNT; stanine)	4.6 (1.9)	4.1 (1.5)	−1.01	.317
SDQ scores				
Total scale score	10.2 (7.3)	10.0 (5.5)	−0.08	.935
Hyperactivity/ inattention scale	4.3 (2.5)	4.8 (2.4)	0.49	.629
Emotional problems scale	2.3 (2.5)	2.4 (1.9)	0.22	.824
Behavioral/conduct scale	1.6 (1.9)	1.3 (1.2)	−0.58	.567
Peer problems scale	1.9 (2.3)	1.5 (2.3)	0.55	.584
Prosocial behavior scale	8.3 (1.7)	8.1 (2.1)	−0.37	.713

Note. p Value from a two-sided t test. Reading skill: a combined score (stanine) of word decoding, nonword decoding, and sentence chains (in Swedish). Language skill: receptive grammatical skill (test for reception of grammar [TROG]-2; Bishop, 2003) and expressive vocabulary (Boston naming test [BNT]; Kaplan, Goodglass, Weintraub, & Goodglass, 1983). All the reading and language tests are in Swedish. M = mean; SD = standard deviation, t = t value; ADHD = attention-deficit/hyperactivity disorder; SDQ = Strengths and Difficulties Questionnaire.

Table 2. Data for the Strengths and Difficulties Questionnaire (SDQ) Scores for the Sample as a Whole Compared to British 11–15-Year Olds.

SDQ scores	Our Sample	British Sample	t	p (Two-Sided)
Total scale score	10.1 (6.6)	8.2 (5.8)	2.18	*.029*
Hyperactivity/inattention scale	4.5 (2.4)	3.2 (2.6)	3.34	*<.001*
Emotional problems scale	2.3 (2.3)	1.9 (2.0)	1.33	.183
Behavioral/conduct scale	1.5 (1.7)	1.5 (1.7)	0.00	1.000
Peer problems scale	1.8 (2.3)	1.5 (1.7)	1.17	.241
Prosocial behavior scale	8.2 (1.8)	8.6 (1.6)	1.67	.096

Note. Significant p values in italic letters.

Stimuli and Procedure

Participants were first randomized into one of the two experimental conditions: Group A listened to a text with TTS while simultaneously following the text with a marking and Group B read the text aloud themselves. The conditions were then switched using another text of similar complexity (Figure 1). Reading comprehension was assessed after each text with open questions that were read aloud to the participants. The time needed for each participant to complete reading the text was recorded.

Two sets of texts were used: one set for the younger participants (Grades 3–5) and one set for the older participants (Grade 6–9). The set consisted of two different texts from the computerized test Logos (Høien, 2007), which is commonly used for assessing reading difficulties in Sweden. It also has been shown to have both a high reliability and validity in detecting reading difficulties (Høien, 2007). Logos consists of different texts for younger participants (Grades 3–5) and older participants (Grades 6–9). Therefore, two sets of texts were used: one set for the younger participants (Grades 3–5) and one set for the older participants (Grades 6–9). One text in each set was the text originally used to assess reading comprehension in Logos (for the specific age-group). The second text in each set was the text that is originally used to assess listening comprehension in Logos (also for the specific age-group). This text was remodeled to have identical visual properties as the original reading comprehension text. Importantly, both texts were already of equal linguistic complexity (Høien, 2007). All texts have short answer questions.

The set for the younger participants was two fictional texts (Text 1 was a story about a football game and Text 2 was a story about a fishing trip). Both texts consisted of five text paragraphs. Reading comprehension was tested after each paragraph by three questions addressing details from the text. A correct answer was given 1 point and an incorrect answer yielded 0 point. Thus, the total score for each text was 15 points.

The set for the older participants was two factual texts (Text 1 was about bees and Text 2 was about the Cimbrians). Text 1 consisted of four text paragraphs with five questions following each paragraph, and Text 2 consisted of five text paragraphs with four questions following each paragraph. Since each correct answer was given 1 point, the total score for these texts was 20 points.

The TTS software used was TorTalk (Ghai & Olofson, 2013). As for most TTS softwares, TorTalk reads text aloud at a chosen reading rate and also has a marking that shows which word is read. Since nearly all TTS software can change the pronunciation of specific words, the words in the texts that were pronounced incorrectly were changed beforehand. When TorTalk was used, the program was applied as a “frame” on the text sections, so that it could read the text aloud.

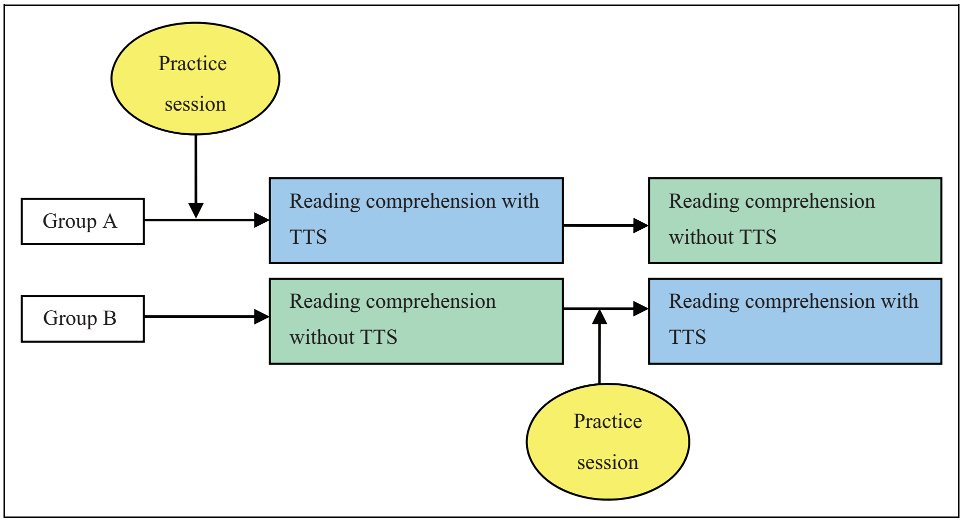

Figure 1. The procedure of the randomized crossover design. The participants completed a reading comprehension test with text-to-speech (TTS; group A) or without TTS (group B). Then, the conditions were switched. Before the reading comprehension that involved listening to the text with speech synthesis, the participants were given a practice session.

The texts were presented on a computer screen. In the condition that involved TTS, the participants read the texts with TTS using a headset with a microphone. The participants answered the reading comprehension questions verbally in the microphone. Before starting the experiment, it was made sure that the participants heard the speech from the headset and that the microphone recorded their responses properly. Reading rate was operationalized as the time (in seconds) that the participants needed to read the texts (not for answering the questions). Reading comprehension of each text was operationalized as percent correct responses to the questions that followed the paragraphs.

Prior to using the TTS, participants were trained on how to use the TTS software in a practice session. In this practice session, the participants read another text with TTS. This text was set up in the same way as the experimental texts (in sections), but it did not have any questions after each section. Participants were instructed on how to change the reading rate of the TTS software and encouraged to try out different reading rates during the practice session. They were then asked to choose a reading rate that they found comfortable. This individually chosen rate was used when the participant took on the experimental task using TTS. The same voice was used for all the participants (the Swedish female voice "Alva"). The practice session took approximately 5–10 min, and each of the test sessions (with and without the TTS software) took about 10–15 min to finish (depending on the reading rate). Therefore, for each participant, the practice session and the two test sessions took about 25–40 min in total.

After completing the two test sessions, the participants were asked "Now you have read two texts, one with a speech synthesizer and one without a speech synthesizer. What did you think was easier, reading the text with the speech synthesizer or reading the text yourself?" They were also asked if they had previous experience of using TTS prior to this test. Previous experience was operationalized as using any speech synthesizer on a weekly basis during their schoolwork or in their everyday life in the last year.

Ethical Considerations

The study followed the declaration of Helsinki. Before deciding to join the study, all participants and their accompanying caregivers were given both oral and written information about the aim and purpose of the study. They were informed that participation was voluntary and that withdrawal from the study was allowed at any time. Both the oral and the written information also clarified that all the data were coded and therefore anonymous. The participants and the caregivers also made a written consent to join the study.

Data Analysis

The study was designed as a randomized controlled crossover experiment. The dependent variables were first tested for normality with a Shapiro–Wilk's test where the data were considered normally distributed if $p > .05$. Nonparametric tests were used when the variables were not normally distributed. Version 13 of the data analysis software system, Dell Statistica (2015), was used for all data analyses.

Results

The Compensatory Effect of TTS on Reading Comprehension and Reading Rate

Compensatory effect of TTS on reading comprehension. In order to examine the effect of TTS on reading comprehension, we performed a repeated measures analysis with reading comprehension in percent in Condition A and Condition B as the dependent variables. Since these variables were positively

Table 3. Results From the Main Analysis of the Compensatory Effect of Text-to-Speech (TTS) on Reading Comprehension.

Participants	Reading Comprehension Without TTS (Correct Scores, %)	Reading Comprehension With TTS (Correct Scores, %)		
	M (*SD*)	*M* (*SD*)	*Z*	*p* (*Two-Sided*)
Whole group	62.4 (23.1)	70.3 (24.5)	2.6	*.009*
Younger group	70.1 (21.4)	81.6 (17.7)	2.91	*.004*
Older group	49.1 (20.3)	50.83 (22.5)	0.06	.995

Note. Mean (*M*), standard deviation (*SD*), *Z* value (*t*), and *p* value from a two-sided *t* test. Significant *p* values in italic letters.

Table 4. Results From the Main Analysis of the Compensatory Effect of Text-to-Speech (TTS) on Reading Rate.

Participants	Reading Rate Without TTS (in s)	Reading Rate With TTS (in s)		
	M (*SD*)	*M* (*SD*)	*Z*	*p* (Two-Sided)
Whole group	405 (208)	170 (40)	6.09	*<.0001*
Younger group	368 (137)	172 (45)	4.86	*<.001*
Older group	468 (287)	167 (31)	3.72	*<.001*

Note. Mean (*M*), standard deviation (*SD*), *Z* value (*t*), and *p* value from a two-sided *t* test. Significant *p* values in italic letters.

skewed, and thus not normally distributed (reading comprehension with TTS: $W = .921$, $p = .003$; reading comprehension without TTS: $W = .929$, $p = .006$), a Wilcoxon-matched pairs test was used.

As seen in Table 3, TTS led to a significant increase in reading comprehension in the group as a whole. However, within grade groups analyses revealed that this effect was driven largely by the effect in the younger group, whereas the effect within the older group was very small and nonsignificant.

Compensatory effect of TTS on reading rate. The reading rate data in Conditions A and B were negatively skewed (reading rate without TTS: $W = .802$, $p < .001$; with TTS: $W = .939$, $p = .013$), and a Wilcoxon-matched pairs test was used to examine the effect of TTS on reading rate.

As can be seen in Table 4, reading with TTS led to a large increase in reading rate in the group as whole. The within grade groups analyses revealed strong effects within both groups.

Relationship between reading comprehension and reading rate effects. The distribution of individual performances with respect to the difference in reading comprehension and reading rate between conditions A (without TTS) and B (with TTS) was examined in a scatterplot (Figure 2). The between-conditions difference in reading comprehension was calculated, for each individual, by subtracting the percentage of correct responses to the reading comprehension test in Condition A from the percentage of correct responses to the reading comprehension test in Condition B. Because the texts for the two grade groups were of inequal length, the reading rate data were also normalized by computing the relative difference in percent between the two conditions. This was done, for each individual, with the following formula: (reading rate in Condition A− reading rate in Condition B)/reading rate in Condition B. These between-conditions difference measures were both normally distributed (reading comprehension difference: $W = .986$, $p = .834$; reading rate difference: $W = .981$, $p = .620$).

A correlation analysis showed that there was no significant speed-accuracy trade-off effects in the group as whole ($r = -.140$, $p = .337$). This suggests that the participants did not generally increase their reading rate at the cost of comprehension. The effects were similar in the two grade groups (younger group: $r = -.221$, $p = .230$; older group: $r = -.145$, $p = .565$).

All participants decreased their reading rate when reading with TTS, and a majority (71%) increased their reading comprehension. However, 14 (29%) of the participants actually decreased their reading comprehension when using TTS compared to when reading the text themselves. These cases are demarcated with a rectangle in Figure 2 and are more carefully examined in the subsection Characteristics of Participants With Decreased Reading Comprehension With TTS.

The Effects of ADHD Symptoms on the Compensatory Effect of TTS

The relationship between ADHD symptoms and the compensatory effect of TTS on reading comprehension was examined with a regression analysis within the general linear model module in Statistica, with the between-conditions difference in reading comprehension (percent correct responses with TTS − percent correct responses without TTS) as the dependent variable. SDQ ADHD scores were included as a continuous predictor, and grade group (Grades 3–5 vs. 6–9) was included as a categorical predictor. The results are visualized in Figure 3. This analysis produced a significant main effect of grade group ($F = 9.831$, $p = .003$, $\eta^2 = .193$), in line with the results reported earlier (see section The Compensatory Effect of TTS on Reading Comprehension and Reading Rate), showing that the effect of TTS differed between the younger and older groups. There was no significant main effect of SDQ ADHD scores ($F = 0.473$, $p = .496$, $\eta^2 = .011$), indicating that, across the group as a whole, ADHD symptoms did not affect the compensatory effect of TTS. However, a significant Grade Group × SDQ ADHD Scores interaction ($F = 7.336$, $p < .0001$, $\eta^2 = .152$) showed that the effect of ADHD, on the compensatory effect of TTS, differed significantly between the two grade groups.

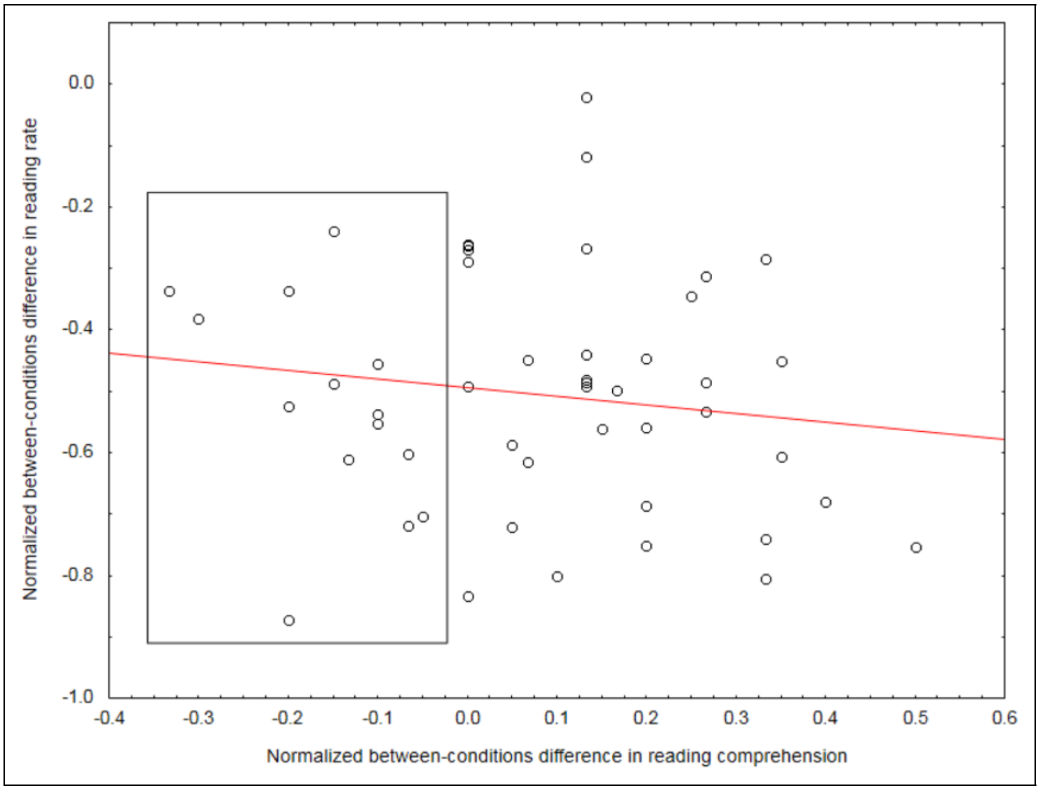

Figure 2. Scatterplot of the individual effects of text-to-speech (TTS) on reading comprehension and reading rate. Positive values on the *x*-axis stand for an increase in reading comprehension with TTS and negative values on the *x*-axis stand for a decrease in reading comprehension with TTS. Because the "speed" value is in seconds, negative values on the *y*-axis stand for an increase in reading rate with TTS, while positive values on the *y*-axis stand for a decrease in reading rate with TTS. A portion of the participants showed an increase in reading rate but a decrease in reading comprehension. This portion of participants is visualized in the rectangle of the figure.

Follow-up regression analyses on the Grade Group × SDQ ADHD Scores interaction revealed that the moderating effect of ADHD went in opposite directions in the two groups. In the younger group, there was a weak–moderate negative correlation between ADHD symptoms and the effect of TTS on reading comprehension ($r = -.320$, $p = .091$), whereas in the older group, there was a moderate positive correlation ($r = .476$, $p = .062$). That is, among the younger participants, a higher level of ADHD symptoms was associated with less improvement, or even decline in performance, when using TTS; among the older participants, by contrast, a higher level of ADHD symptoms was associated with a larger compensatory effect. The difference between the correlations was statistically significant (Fisher *r*-to-*z* transformation: $Z = 2.6$, $p = .009$). A similar regression analysis with reading rate as the dependent variable produced no significant main effects or interactions (all F values < 0.12).

Characteristics of participants with decreased reading comprehension with TTS. . In the whole group, 14 of the 49 participants (29%) had a negative reading comprehension difference score (<0), that is, their reading comprehension was poorer when they read the text with TTS compared to when reading the text themselves. The distributions within the two grade groups were 6 of the 31 in the younger group and 8 of the 18 in the older group.

In an attempt to understand what characterized this subgroup, we compared the children with negative reading comprehension difference scores (hence the "drop group"), to the children with positive scores (hence the "gain group"), with respect to SDQ ADHD and SDQ total scores, and reading comprehension without TTS. These variables were chosen based on previous reports about the impact of unaided reading comprehension without TTS for the compensatory effect of TTS (Elkind et al., 1996; Higgins & Raskind, 1997) and our interest in the effects of neuropsychiatric symptoms. From Figure 2, it was already clear that this subgroup did not differ from their peers in terms of the relative decrease in reading rate in the TTS condition. The results are shown in Table 5.

The only significant difference, in the group as a whole, was found in reading comprehension without TTS. As seen in Table 5, children who dropped in reading comprehension performance when using TTS had significantly higher reading comprehension scores compared to children who gained in performance in the condition without TTS. A similar pattern, with better reading comprehension without TTS in the drop group, was found when the analyses were performed on younger children (Grades 3–5) only. In addition, ADHD scores were higher among children who dropped in performance when

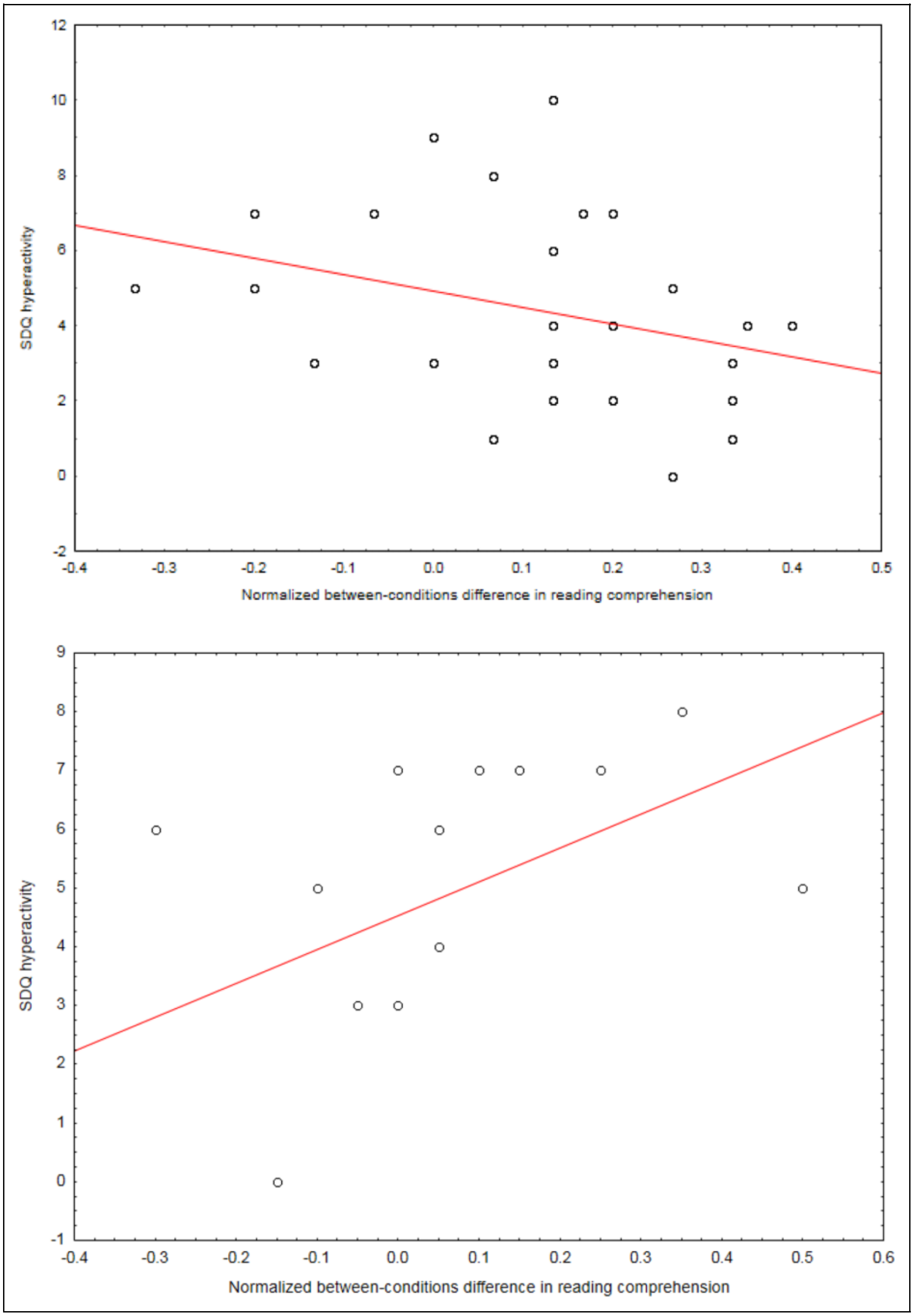

Figure 3. Regression analysis of the relationship between attention-deficit/hyperactivity disorder symptoms and the compensatory effect of text-to-speech on reading comprehension. The younger group in the upper part and the older group in the lower part of the figure.

using TTS, but this difference was not statistically significant. Among the older children (Grades 6–9), however, there was a significant difference in SDQ ADHD scores in addition to the difference in reading comprehension without TTS. Children who dropped in performance when using TTS had *lower* ADHD scores compared to those that gained in performance. These results confirm the correlations reported in the section The Effects of ADHD Symptoms on the Compensatory Effect of TTS; in the younger group, higher ADHD scores were associated with less benefit from using TTS, whereas in the older

Table 5. Results From the Exploratory Analyses.

	Drop Group	Gain Group		
	M (*SD*)	*M* (*SD*)	*t*	*p* (Two-Sided)
Reading comprehension without TTS (correct scores, %)	73 (19)	58 (23)	$t(47) = 2.05$	*.046*
Younger group	88 (21)	66 (8)	$t(29) = 2.63$	*.013*
Older group	60 (19)	40 (15)	$t(16) = 2.43$	*.027*
SDQ hyperactivity score	4.2 (2.4)	4.6 (2.4)	$t(47) = 0.513$	.610
Younger group	5.4 (1.7)	4.1 (2.6)	$t(29) = 1.02$	.316
Older group	3.1 (2.6)	5.7 (1.8)	$t(16) = 2.27$	*.039*

Note. Mean (*M*), standard deviation (*SD*), *t* value (*t*), and *p* value from a two-sided *t* test. Significant *p* values in italic letters. TTS = text-to-speech; SDQ = Strengths and Difficulties Questionnaire.

grade group, children with the most difficulties gained more from using TTS. As for reading comprehension, the pattern in the older group was consistent with the previous comparisons.

Preferences and Previous Experience

After completing the experiment, participants were asked whether they thought reading with or without TTS was easier and whether or not they were already accustomed to using TTS (defined as using any TTS technology on a weekly basis during their schoolwork or in their everyday life in the last year) prior to the experiment.

In the group as a whole, 75% of the children preferred reading the text with TTS, and 25% preferred reading the text themselves. The distribution of responses within the two grade groups was very similar (younger group: 76% vs. 24%; older group: 71% vs. 29%).

Ten children in the whole group reported already using TTS on a regular basis, whereas 39 children had none, or very little, previous experience. Out of the children who were already using TTS, 70% preferred reading the text with TTS, whereas 30% did not, and among those with none or little previous experience, the distribution was 82% versus 18%. Thus, children with none or little previous experience were somewhat more positive to using TTS. The participants who did not think that reading with TTS was easier explained that they either thought the voice was sounding like a robot or that the fluency of the TTS was bad.

Children's preference was a significant predictor of whether or not using TTS actually helped their performance during the experiment. Children who said they found it easier to read the text with TTS showed a relatively larger compensatory effect on reading comprehension compared to the children who did not think they were helped by the technology, $t(47) = 2.09$, $p = .042$. However, preference was not a perfectly reliable predictor: Among the children who dropped in reading comprehension when reading with TTS (the drop group) about half reported that they found it easier to read with TTS compared to reading the text themselves.

Discussion

The purpose of this study was to investigate the moderating effect of ADHD symptoms on the compensatory effect of TTS technology on reading comprehension and reading rate in schoolchildren with RD and to examine whether the compensatory effect of TTS and/or a potentially moderating effect of ADHD symptoms differ by grade groups. Based on a previous study by Hecker et al. (2002), we had hypothesized that using TTS would be relatively more beneficial for children with more severe ADHD symptoms with respect to reading rate but not with respect to reading comprehension. Our results, however, turned out differently.

Using TTS technology had a positive effect on reading rate for both grade groups, and this effect was not influenced by ADHD symptoms. As for reading comprehension, however, the two groups differed both with respect to the amount of improvement seen in the TTS condition and with respect to the moderating effect of ADHD symptoms. Reading with TTS improved reading comprehension significantly in the younger group, whereas no effect on reading comprehension was found in the older group. Moreover, a higher score on the SDQ ADHD Scale was associated with *less* improvement in reading comprehension in the younger group, whereas the opposite pattern was found in the older group, in which higher ADHD scores were associated with *greater* improvement in reading comprehension.

One possible explanation for the differences in outcome between our study and the Hecker et al.'s (2002) study may be that the participants in the Hecker et al.'s study had a primary diagnosis of attention disorder, and not of RD, whereas in our study, the participants had a clinical diagnosis of RD, and not of ADD/ADHD. In our study, ADHD symptoms were assessed by using a screening questionnaire, which—although proven to be a valid tool for identification of ADHD in children (Algorta et al., 2016)—does not compare to a full clinical assessment when it comes to reliability and validity of identifying ADHD symptoms. Future studies on this topic would benefit from including a more thorough assessment of ADHD symptoms.

As outlined in the Introduction, we had no a priori hypothesis about the effects of grade group. The results from our study indicates that gains in reading rate could possibly be grade independent, that is, both younger and older schoolchildren are likely to increase their reading rate with TTS technology. The finding that using TTS improved reading comprehension only in the younger group is not consistent with the single study of grade effects that we are aware of (Lundberg & Olofsson, 1993). In the Lundberg and Olofsson's study, the pattern was the opposite, and younger participants showed less improvement in reading comprehension, when using TTS, compared to older ones. This difference may have several causes. First, Lundberg and Olofsson examined the training effect of TTS (i.e., did the TTS technology decrease reading comprehension for the participants after the trial on other texts, without TTS?) and not the compensatory effect. Second, the young participants in the Lundberg et al.'s study were in Grades 2 and 3, whereas the participants in our young group were in Grades 3–5. Moreover, in the Lundberg and Olofsson's study, the task was to read single words, and in our study, passages of connected text was read.

The moderating effect of ADHD symptoms on the compensatory effect of TTS on reading comprehension differed significantly between the two grade groups, with a negative correlation in the younger group (higher ADHD scores associated with lower gains in reading comprehension) and a positive correlation in the older group (higher ADHD scores associated with larger gains in reading comprehension). To the best of our knowledge, the present study is the first to examine not only the moderating effect of ADHD symptoms on the compensatory effect of TTS in children with RD but also whether such an effect differs between grade groups. Thus, we know of no previous studies with which to compare our results. One hypothetical explanation for our findings is that they relate to difficulties with executive functions such as divided attention (i.e., processing multiple stimuli at the same time), which is a core deficit in ADHD (Pasini, Paloscia, Alessandrelli, Porfirio, & Curatolo, 2007). Because research suggests that this capacity may improve with development (Faraone, Biederman, & Mick, 2006; Shepp & Barrett, 1991), it is possible that the younger individuals with ADHD symptoms were relatively more distracted by the synthetical voice, compared to the older ones, so that it interfered with, rather than helped, reading comprehension.

Even though most participants across both grade groups gained from using TTS, 29% decreased their reading comprehension in the TTS condition. Exploratory comparisons between children with negative reading comprehension difference scores (the "drop group") and children with positive reading comprehension difference scores (the "gain group") with respect to unaided reading comprehension scores and ADHD symptoms, confirmed the findings reported in some previous studies: The children who gained in reading comprehension with TTS had significantly lower unaided reading comprehension scores, compared to children who dropped in performance (Elkind et al., 1996; Higgins & Raskind, 1997). As for ADHD symptoms, the findings confirmed the correlational analyses described above: In the younger group, children who dropped in performance in the TTS condition had higher ADHD scores compared to children who gained in performance, although this difference did not reach statistical significance. In the older group, by contrast, larger gains in performance were associated with higher ADHD scores.

One explanation for the finding that lower unaided reading comprehension scores predict larger gains when using TTS could be that if a child's reading comprehension is already relatively good, there is less room for improvement when reading with TTS, compared to if the unaided reading comprehension is very poor. Another explanation may be the regression-to-the-mean effect (Bland & Altman, 1994), which entails that individuals with extreme scores (in both directions) will tend to be less extreme in a second measurement.

Finally, the children's own preference for reading with or without TTS was examined. In the group as a whole, 75% of the children preferred reading the text with TTS and 25% preferred reading the text themselves. These results proved to be a good, but not perfect, predictor of the amount of improvement in reading comprehension. The children who said they found it easier to read the text with TTS showed a relatively larger compensatory effect on reading comprehension. However, about half of the children who dropped in reading comprehension when using TTS also said that they found it easier to read with TTS. These results show that the child's own thoughts about whether the TTS technology helped them or not, needs to be taken into consideration, and that preference often, but not always, tells if the TTS technology is helpful. Also, if a child likes using the technology, he or she will be more motivated to adhere to regular use, which may lead to training effects (e.g., Fasting & Lyster, 2005) and even larger beneficial effects.

Limitations With the Study

In addition to the lack of a full clinical assessment of ADHD symptoms discussed above, three limitations with the present study should be pointed out. The first limitation with the study was the relatively small sample size (49 participants in total). Even though this sample size is small in general, it is actually large in this specific research area. In the studies covered in the Introduction, for example, only Lange et al. studied more students (93 participants). But, regardless of this, the sample size should be taken into consideration, and all results should be interpreted with this in mind.

The second limitation is that different text genres were used in the two grade groups, with narrative texts for the younger group and factual texts for the older group. The texts for both groups came from a standard computerized test that is commonly used for assessing reading difficulties in Sweden and was considered to be the best at hand. However, previous research has shown that the predictors of reading comprehension may differ between text genres, with comprehension of narrative text being most influenced by word decoding skills, and comprehension of factual texts being best predicted by world knowledge (Best, Floyd, & Mcnamara, 2008). Thus, one possible explanation to the fact that only the younger participants showed an increase in reading comprehension in the TTS condition, in our study, may be the fact that, although the use of TTS may bypass word decoding problems, it can obviously not improve one's world knowledge. Future studies examining this topic will benefit from keeping the text genre constant across grade groups, in order to control for possible genre effects.

The third limitation concerned the voice of the TTS, the Swedish voice Alva. Almost all participants noted that they thought that the speech sounded strange and that it did not flow naturally. However, only a few of the participants stated that the strange speech or the bad flow disturbed their comprehension. What most of the participants said after listening to the text by the speech synthesizer was that it sounded a bit strange, but that it did not really matter because it helped anyway. Even though the voices of the speech synthesizers available today sound much more human like than when they were first developed, these comments from the participants implicate that developing the voices might increase the compensatory effects of TTS even further.

Suggestions for Further Research

Since the relationship between the compensatory effect of TTS and cooccurring ADHD symptoms in individuals with RD is a new field of research, there are many areas that should be more thoroughly investigated. One suggested area for further research is to study the effect of ADHD symptoms more closely by including (i) one group of participants with both RD and ADHD, (ii) one group with RD only, (iii) one group with ADHD only, and (iv) one group of typically developing controls. In addition, the relative contribution of inattention and hyperactivity symptoms should be more carefully examined.

Another suggestion for further research is to study older schoolchildren more closely. For example, can TTS enhance reading comprehension also in older schoolchildren if they receive more practice with using the technology, or with other types of texts?

Finally, it would be informative to use a qualitative approach to study the opinions of children using TTS technology; what do they like about it, and what technical or methodological improvements do they think could help enhance the compensatory effects and encourage continued use of the technology?

Conclusions

The results of the present study show that using TTS increases reading rate or increases both reading rate and reading comprehension for most children with RD. Although further research is needed to confirm and refine the findings of the present study, the results also indicate that symptoms of inattention and hyperactivity, as well as the child's grade level, are factors that should be taken into account when planning and introducing TTS technology in clinical and pedagogical settings.

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