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Improving Reading Comprehension Using Digital Text: A Meta-Analysis of Interventions

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Abstract

Much is known about how to improve students' comprehension when reading printed text; less is known about outcomes when reading digital text. The purpose of this meta-analysis was to analyze research on the impact of digital text interventions. A comprehensive literature search resulted in 27 group intervention studies with 16,513 participants. The overall weighted mean effect size for interventions designed to provide basic access to text was small (*ES* = -.03, range -.49 to 1.18), whereas a moderate effect size was obtained for interventions that served as instructional enhancements for digital text (*ES* = .51, range -.35 to 1.57). These findings were consistent across grade level (elementary vs. secondary) and student type (with disabilities vs. without).

Comprehension, or constructing meaning from text, is the ultimate goal of reading and vitally important for student success in school and later life. Providing appropriate interventions to ensure that all students comprehend what they read is more challenging than ever before because general education classrooms consist of students with a wide range of learning needs, including students with learning disabilities (LD; Hock, Schumaker, & Deshler, 1999; Parsons, Dodman, & Burrowbridge, 2013).

An LD is a neurological disorder that affects the brain's ability to receive, process, store, and respond to information (National Center for Learning Disabilities, 2014). According to the *Diagnostic and Statistical Manual-5th Edition* (DSM-5; American Psychiatric Association

[APA], 2013), in order to be diagnosed with a specific learning disorder, a student must meet four criteria: (a) difficulty learning academic skills for at least six months despite academic intervention, (b) academic performance that is below expectation based on the student's age, (c) difficulties must be apparent in the early years or when higher-level skills are demanded in school, and (d) the learning difficulties are not due to intellectual disabilities, language differences, lack of appropriate instruction, visual or hearing impairments, psycho-social disorders, or mental disorders. In addition, LD occurs in students who have normal intelligence and may also occur in gifted students.

Due to these deficits, students with LD often have problems with several facets of academics, including reading, and may struggle with word decoding, reading fluency, and comprehension. Nevertheless, over half of this population spends 80% or more of the school day in general education settings (U.S. Department of Education [USDOE], 2012) where, especially in the upper grades, students are expected to learn independently from text. However, 33% of fourth graders and 24% of eighth graders in the United States perform below a basic level of reading indicating that they have only partial mastery of the prerequisite knowledge and skills needed to be proficient with grade-level work (National Center for Education Statistics, 2011). Additionally, many students with LD are not performing well at even the most basic reading levels (Denton, Wexler, Vaughn, & Bryan, 2008).

A body of research has shown that reading comprehension strategies can help these students understand more of what they read by helping them prevent or repair problems with comprehension they encounter while reading (see reviews by Gajria, Jitendra, Sood, & Sachs, 2007; Gersten, Fuchs, Williams, & Baker, 2001). Such strategies help students actively engage in behaviors that promote reading comprehension, such as activating background knowledge, identifying text structure, vocabulary word learning, visualizing, self-questioning, and summarizing. Effect sizes from meta-analyses of this research literature have been consistently large (see Berkeley, Scruggs, & Mastropieri, 2010; Edmonds et al., 2009; Swanson, 1999), and best practices in reading comprehension instruction have been identified. These practices include systematic instruction, use of teacher think-aloud, guided and independent practice, explicit corrective feedback, clearly stated objectives, specific teaching sequences, explicit statements about the importance of strategy use, monitoring student performance, promoting student self-questioning, encouraging appropriate attributions, and teaching for generalized use of a given strategy.

The Role of Digital Text

Increasingly, students are exposed to text in digital formats, including e-books and e-textbooks, in addition to traditional print (Kelly, McCain, & Jukes, 2009; Parker, 2010;

Schrum & Levin, 2012). As a result, it is necessary to understand how this type of text affects student comprehension. Evidence to support practices that improve reading comprehension of e-text is growing, but it is not yet as robust as the research base for reading comprehension strategies with traditional print. In general, however, technology is thought to increase possibilities for helping students, students with LD in particular, succeed with reading demands in the general education curriculum (Bryant, Bryant, & Ok, 2014). The unique nature of this format allows students to interact with curriculum content in ways that are not possible with printed text, which can ultimately support students' reading comprehension (Edyburn, 2010; Hall, Hughes, & Filbert, 2000; Marino, 2009).

Currently, various technology centers (e.g., National Center for Supported E-Text, the Accessible Instructional Materials Centers) have issued recommendations for how students can access the curriculum through the use of technology, as well as how technology enhancements can help students progress towards various standards. For example, supported e-text can be used to transform text in several ways, including embedded supports (e.g., definitions of terms, another language, embedded questions/tutorials), multiple modalities (e.g., text-to-speech, graphics, animation, sound), and links to useful resources (e.g., concept maps, note-taking tools, media to augment the main text) (Anderson-Inman & Horney, 2007; Dunleavy, Dexter, & Heinecke, 2007). Further, digital text features can be embedded that provide both basic access to text and instructional enhancements.

Digital Text Features

Some digital features are intended to support student comprehension by providing access to the text in a digital format. The conversion of printed text to a digital format provides students with basic access to the text by helping students to overcome some of the barriers of paper format (Anderson-Inman & Horney, 2007). These basic access features, such as electronic format and text-to-speech, are included within a new provision of the Individuals with Disabilities Education Act (2004) that requires that "accessible instructional materials" be provided in a timely manner to students with print-related disabilities so they may successfully participate in the general education curriculum. In addition to students with visual impairments and blindness and students with physical disabilities, students with LD qualify for and may benefit from these accessible instructional materials (NCLD, 2014).

Paper text converted into a digital format allows for modifications, including enlarged font size, navigation, and text-to-speech, as well as additional supports for the perceptual needs of students who need text presented in a different format (Anderson-Inman & Horney, 2007). These supports are often utilized to provide differentiation and encourage independence for students with varying ability levels (Kennedy & Deshler, 2010). However, specifically for students with LD, text-to-speech, which enables students to hear words or phrases that are difficult to decode (Montali & Lewandowski, 1996), may be especially beneficial because many textbooks are written above students' reading level (Scruggs, Mastropieri, Berkeley, & Graetz, 2000).

In addition to allowing for basic access of text, digital features are now available that can serve as enhancements to instruction for students. Instructional enhancements are supports embedded in digital text to facilitate understanding of the text (Anderson-Inman & Horney, 2007). Often, such enhancements support student understanding of the text by purposely embedding strategies commonly found to be effective in reading research of print text, such as dictionaries, animations, videos, graphic organizers, specific strategies, and strategy supports. These supports incorporate best practices in reading comprehension research (e.g., Mastropieri, Scruggs, & Graetz, 2003) into technology-based environments.

In 2000, Hall and colleagues conducted a systematic review of computer-assisted instruction (CAI) and the impact of these supports on various reading measures, including word recognition, vocabulary, and comprehension for students with LD. The synthesis found that CAI, which consists of a computerized application that teaches students skills for reading, had positive outcomes for reading measures, including comprehension. The synthesis also found that the most effective computerized programs employed effective teaching practices such as elaborate feedback in a digital format. However, rather than evaluating supports for digital text specifically, the synthesis included digital programs for reading instruction (packaged programs) and external supports (such as Internet applications) to support reading skills.

Purpose of the Current Study

Much is known about how to improve the comprehension of students when reading printed text; however, less is known about outcomes with digital texts. Therefore, the purpose of the current investigation was to conduct a meta-analysis of the existing research on the impact of digital text interventions on students' reading comprehension. As shown in Table 1, for the purposes of the current study, these typologies have been categorized based on function, either (a) basic access to text (e.g., text-to-speech, simplified text, audio with print text); or (b) instructional enhancement (e.g., animation, dynamic visuals, embedded strategy prompts).

Specifically, the current study sought to answer the following research questions: (a) How effective are interventions designed to provide basic access to digital text for improving student reading comprehension? (b) How effective are interventions that embed instructional enhancements within digital text for improving student reading comprehension? and (c) Are there differences in the quantity and/or effectiveness of interventions for elementary and secondary students?

Table 1

Typology Categorization for the Current Study

Typology	Description	Basic Access	Instructional Enhancements
Presentational	Stagnant digital text, static images, modifiable font, navigation	X	
Translational	Digital text supported with audio and/or text-to-speech with or without dynamic highlighting; simplified text	X	
Illustrative	Digital text enhanced with sounds, video, animation, dynamic visuals		X
Summarizing	Digital text enhanced with table of contents, concept maps		X
Instructional	Digital text enhanced with prompts, questions, strategies, definitions		X

Note. Created using the typology of digital text features framework (Anderson-Inman & Horney, 2007).

Method

Procedures included a systematic search of numerous online data bases (PsycINFO, Education Full Text, Web of Science, ERIC, Education Research Complete) using the following keywords: *books (computer-, electronic-, audio-, digital-, talking/interactive-), text (electronic-, digital-), reading (comprehension, fluency), read-aloud (text-to-speech, e-readers, computer-assisted), online, supported e-text, hypertext, accommodation, students, computer-assisted instruction,* and *special education.* Ancestry searches were conducted for relevant articles and existing literature reviews (e.g., Hall et al., 2000; Lai & Berkeley, 2012; Lan, Lo, & Hsu, 2014). Finally, hand searches were conducted for the most recent year of journals where relevant articles had previously been located (e.g., *Journal of Special Education Technology*).

Inclusion and Exclusion Criteria

Initially, our research inclusion criteria were specific to interventions for students with LD; however, because of the limited number of studies focusing on students with LD, the search was expanded to include all students. Thus, participants could include students with and/or without disabilities. In addition, studies were included in the sample if (a) the study was an intervention study that utilized a group design; (b) the sample included participants who were kindergarten through 12th grade (with at least 50% of the sample within this range); (c) the study primarily investigated outcomes for reading (specifically comprehension), rather than writing or math (e.g., calculators); and (d) the study investigated technology (e.g., computers, audio/visual) for general access or enhancement of text (e.g., read-aloud, hyperlinks, embedded strategy prompts). Any e-text formats could be utilized for instruction and/or testing (i.e., accommodations) in any setting (e.g., school, home, clinic).

Studies were excluded if they (a) were adaptive in nature (e.g., Braille readers, switches, video captioning; Anderson-Inman, Terrazas-Arellanes, & Slabin, 2009); (b) included a specific instructional program targeting basic reading skills (e.g., Chambers, Slavin, & Madden, 2011; Coyne, Pisha, Dalton, Zeph, & Smith, 2012); (c) were online or utilized online tools independent from text (e.g., Clay, Zorfass, Brann, Kotula, & Smolkowski, 2009; Hsin-Yuan, 2010); or did not use connected text (e.g., Jong & Bus, 2004). In addition, studies were excluded if they only contained measures of vocabulary (e.g., Korat, 2010; Verhallen & Bus, 2010). Studies were also excluded if they were not peer reviewed (e.g., reports, dissertations, masters theses), if they were written in a language other than English, and/or if they were published prior to 2000 (because technology prior to this date is now considered outdated). We also excluded studies where the students who are English learners were the primary target (i.e., greater than 50% of the sample). Finally, we excluded studies that did not provide sufficient data to calculate a standardized mean-difference effect size (e.g., Shamir, Korat, & Shlafer, 2011).

Coding Conventions

A two-part coding manual was created. Part I captured information about basic article characteristics, characteristics of the sample, and the intervention. Basic article information included authors of the study, journal name, and year of publication. Characteristics of the sample included (a) student age in years; (b) gender (number of males and females); (c) grade level (elementary = K to 6^{th}, secondary = 7^{th} to 12^{th}); (d) disability status (student with disability or general education) and type of disability; (e) ethnicity; (f) socio-economic status; (g) IQ; and (h) student achievement information. Characteristic of the intervention included (a) digital text form (audio book, digital text); (b) digital text features (e.g., text-to-speech, hyperlinks, reading strategies, animation); (c) type of text (narrative, expository, combination); (d) level of text (grade level, instructional level); (e) academic content area (language arts, content area); and (f) number of sessions (1, 2-5, or >5).

Part II of the coding manual captured information related to the rigor of the research methodology, including (a) location of the study; (b) description of interventionist; (c) type of samples (dependent, independent); (d) number of measures; (e) quality of the measures (one measure of a single construct; two or more measures of the same construct; two or more measures of multiple related constructs); (f) inclusion of vocabulary measure; (g) scope of the measures (immediate criterion referenced, norm-referenced, generalization, maintenance); (h) fidelity of implementation (interventionist and technology use as intended); (i) feedback to students; and (j) statistical significance of findings. Effect sizes were calculated using the following formula:

$$g \cong d\left(1 - \frac{3}{4(n_1 + n_2) - 9}\right)$$

For each study, interventions were determined to be targeting accessibility of text, support of instruction, or both (due to multiple conditions). For each study, only one effect size was calculated for comparisons that evaluated basic access to text, and one effect size was calculated for comparisons that evaluated instructional supports. These categories were not combined in the final analysis. In instances where multiple measures of comprehension were included, effect sizes were averaged, resulting in one effect size for the target comparison. Each calculation was computed by two trained researchers and reconciled to 100%.

Procedures. Coding conventions were established for each variable, and two doctoral students were trained to complete all coding. For Part I coding conventions, a third doctoral student was trained to complete reliability of coding conventions for 30% of research studies. Reliability with Coder 1 = 93.02% (range = 88.37% to 97.67%) and with Coder 2 = 94.32% (range = 90.70% to 100%). For Part II coding conventions, the two primary coders coded all items and reconciled discrepancies to 100% agreement.

Results

Characteristics of the Data Set

The final sample consisted of 27 group studies published in 25 articles from 2001 to 2013 in 25 peer-reviewed journals. The number of studies increased over time with an average of 1.3 studies per year in 2000 through 2006 (range = 0 to 3), and an average of 2.6 studies per year in 2007 through 2013 (range = 1 to 4). A majority (88%) of studies were conducted in the United States.

The data set included 16,513 participants. Slightly more studies were conducted at the elementary level (56%) than the secondary level (44%). Characteristics of the participants cannot be reliably reported because basic study descriptors were reported in a limited number of studies: age (52%), ethnicity (44%), socio-economic status (30%), and IQ (7%). In addition, some sort of achievement level of students was reported in only 63% of studies. Further, a description of the interventionist was provided in only 37% of studies. Because basic study descriptors were so limited, analyses based on these participant characteristics was not possible.

Ten studies (37%) included students with LD in the sample (4 included students with other disabilities); the remaining studies contained students who were typically developing or at risk (including students identified in studies as "struggling readers"). Other disabilities included in study samples were as follows: emotional disorder (ED), speech/language disorder (S/LD), intellectual disability (ID), autism, other health impairment (OHI; only attention deficit hyperactivity disorder was specified), hearing impairment (HI), and orthopedic impairment (OI). Table 2 presents a more detailed description of sample criteria reported in studies with students with LD.

Table 2

Participant Selection Criteria Reported in Studies

Study	Participant Disability	Classification Criteria
Boyle et al. (2003)	LD, ED, OHI, ADHD	Students were identified with a disability and received specialized accommodations for secondary history content on their IEP.
Crawford et al. (2004)	LD, OHI, ED, TBI, VI, ID, autism, S/LD	Majority of students in special education were identified with a learning disability, and all students with IEPs were partially or fully included in the general education classroom.
Dolan et al. (2005)	LD	Students had active IEPs, and were partially or fully included in general education classes.
Flowers et al. (2011)	LD, ID, OHI, other disability (not specified)	Students were identified with a disability and eligible for read-aloud accommodation on state assessments.
Kim et al. (2006)	LD, ID, OHI	Students were legally identified as having a disability.
Ko et al. (2011)	LD	Participants were identified by the local education agent in southern Taiwan as students with learning disabilities who also had difficulty reading.
Laitusis (2010)	LD	Classification criteria not specified.
Srivastava et al. (2012)	LD	Students receiving special education services during the data collection phase.
Twyman et al. (2006)	LD	Identified with learning disabilities in reading and writing and also had IEPs that included goals for reading and writing.

Note. LD = learning disability; ED = emotional disability; OHI = other health impairment; ADHD = attention deficit hyperactivity disorder; TBI = traumatic brain injury; VI = visual impairment; ID = intellectual disability; S/LD = speech/language disorder.

Intervention characteristics. Ten studies included interventions targeting basic access to text – 6 at the elementary level (see Table 3) and 4 at the secondary level (see Table 4). Eighteen studies targeted instructional supports – 10 at the elementary level (see Table 5) and 8 at the secondary level (see Table 6). One of the studies (Ertem, 2010) included both a basic skills intervention and an instructional support intervention.

The forms of digital text investigated included e-text (67%), e-books (22%), or audiobooks used with print text (11%). Most studies reported the type of text that was used in the intervention: expository text (41%), narrative text (22%), or a combination of narrative and expository text (22%), but four (15%) did not report type of text. Most studies utilized grade-level text (74%), 22% utilized instructional-level text, and 4% did not report the level of text used. Two thirds of the studies involved language arts materials; the remaining third utilized materials for science or social studies. Duration of study length varied: 1 session (41%), 2 to 5 sessions (22%), >5 sessions (30%), and unreported length (7%).

Table 3

Studies Investigating Comprehension Outcomes From Basic Access to Digital Text at the Elementary Level

Study (Year)	Sample *(N)*	Grades	Intervention & Comparison	Typology & Digital Text Features	Text Type	Measures	Effect Size [CI]
Crawford et al. (2004)	338 (47 LD; 3 ID; 13 S/LD; 1 ED; 8 OHI; 1 HI)[a]	4-5	I: Audio plus print text (testing) C: Print text	*Translational*: audio (through video) test administration	NR	• Comprehension Test (MC)	.29* [.08, .51]
Dundar et al. (2012)	20	5	I: e-text (static) C: Print text	No features (stagnant digital text)	Exp.	• Comprehension Test (open ended)	.29** [-.59, 1.17]
Ertem (2010)	77	4	I: e-book C: Print book	*Presentational:* Text-to-speech	Nar.	• Retell	.27* [-.28, .81]
Jeong (2012)	56	6	I: e-book (static) C: Print book	No features (stagnant digital text)	NR	• Comprehension Test (MC)	-.43** [-.80, -.06]
Laitusis (2010)	2,028 (903 LD)[a]	4-8	I: Audio plus print text (testing) C: Print text	*Translational*: audio (CD-ROM) test administration	NR	• Gates-McGinitie Reading Test (GMRT)	.30** [.18, .43]
Sorrel et al. (2007)	12 (4 LD)[a] (8 SR)	2-5	I: e-text C: e-text (static)	*Translational:* text-to-speech	Both	• Accelerated Reader Quizzes	-.30 [-1.1, .51]

Note. LD = learning disability; ED = emotional disability; OHI = other health impairment; S/LD = speech/language disorder; HI = hearing impairment; ID = intellectual disability; SR = struggling reader; Nar. = narrative); Exp. = expository); NR = not reported.
[a]special education data not disaggregated in results.
*mixed findings. **statistically significant findings.

Table 4

Studies Investigating Comprehension Outcomes From Basic Access to Digital Text at the Secondary Level

Study (Year)	Sample *(N)*	Grades	Intervention & Comparison	Typology & Digital Text Features	Text Type	Measures	Effect Size [CI]
Boyle et al. (2003)	67 (43 LD; 8 OHI; 6 ED; 4 ID; 1 SLD; 1 OI; 1 autism)	9-12	I: Audio plus print textbook C: Print textbook	*Translational*: audio (CD-ROM)	Exp.	• Comprehension Tests (matching, MC)- Unit & Chapter	.87** [.22, 1.52]
Dolan et al. (2005)	9 (9 LD)	11-12	I: e-text (testing) C: Print text	*Translational:* text-to-speech test administration	Exp.	• Released NAEP Test Items	1.18 [.18, 2.18]
Flowers et al. (2011)	12,699 (all: LD, ID, OHI, or other)	7-8	I: e-text (testing) C: Print text (with adult read-aloud)	*Translational:* text-to-speech test administration	Both	• State Test for Reading	-.49**[a] [-.61, -.36]
Schmitt et al. (2011)	25 (25 SR)	6-8	I: e-text C: e-text (static)	*Translational*: text-to-speech	NR	• Comprehension Test (MC)	.23 [-.32, 0.79]

Note. LD = learning disability; ED = emotional disability; OHI = other health impairment; SLD = speech/language disorder; OI = orthopedic impairment; ID = intellectual disability; SR = struggling reader; Nar. = narrative; Exp. = expository; NR = not reported.
[a]Comparable ES resulted when using subset of scores used in propensity selection for secondary analysis (ES = -.495).
*Mixed findings. **Statistically significant findings.

Table 5

Studies Investigating Instructional Enhancements for Comprehension of Digital Text at the Elementary Level

Study (Year)	Sample *(N)*	Grade	Intervention & Comparison	Typology & Digital Text Features	Text Type	Measures	Effect Size [CI]
Dalton et al. (2011)	106	5	I: UDL multimedia e-text (vocab + comprehension) C: UDL multimedia e-text (vocab only)	*Translational:* text-to-speech *Instructional*: vocabulary & comprehension strategy training	Nar.	• Gates-McGinitie Reading Test (GMRT) • ICON	.51* [.03, 1.00]
Doty et al. (2001)	39	2	I: e-book (interactive story book) C: Print book	*Instructional:* definitions & pronunciations *Illustrative:* interactive illustrations	Nar.	• Retell • Comprehension Test (item type NR)	.52*[c] [-.14, 1.17]
Study (Year)	Sample *(N)*	Grade	Intervention & Comparison	Typology & Digital Text Features	Text Type	Measures	Effect Size [CI]

Table 5 (continued)

Ertem (2010)	77	4	I: e-book C: Print book	*Illustrative:* cued interactive animation, sounds & music	Nar.	• Retell	.87**[b] [.30, 1.45]
Grimshaw et al. (2007) Study 1	51	5[a]	I: e-book C: Print book	*Translational:* narration *Instructional:* hyperlinked dictionary	Nar.	• Comprehension Test (MC, open-ended)	-.35** [-.95, .25]
Grimshaw et al. (2007) Study 2	81	5[a]	I: e-book C: Print book	*Illustrative:* animation	Nar.	• Comprehension Test (MC, open-ended)	.21** [-.33, .74]
Kim (2013)	141	4-5	I: Multimedia e-text (with person or robot avatar) C: Paper text	*Instructional:* comprehension strategy training via virtual agents	Exp.	• Comprehension Test (open-ended)	1.32**[c] [.83, 1.81]
Ko et al. (2011)	30 (30 LD)	5-6	I: UDL multimedia e-text C: e-text (static)	*Instructional:* comp. aids *Translational:* optional text-to-speech, voice, images, & video clips *Summarizing:* concept maps	Exp.	• Comprehension Test (MC)	1.57** [.99, 2.15]
Pearman (2008)	54 (20 SR)	2	I: e-book C: Print book	*Translational:* pronunciations, optional audio narration *Instructional*: definitions *Illustrative:* images, sound effects	Exp.	• Retell	.58* [.19, .96]
Sung et al. (2008)	130 (64 SR)	6	I: Multimedia e-text (reading strategy training via avatar) C: Print text (self study strategy)	*Instructional:* comprehension strategy training via virtual agent *Translational:* optional text-to-speech, highlighting *Summarizing:* concept maps	Both	• Expository Text Comprehension Test (ETCT) • Narrative Text Comprehension Test (NTCT)	.38* [-.11, .86]
Trushell et al. (2005)	30	4	I: e-book (animation) C: e-book (no animation)	*Translational:* audio narration *Illustrative:* cued animation	Nar.	• Comprehension Test (MC) • Retell	-.14**[c] [-.91, .63]

Note. LD = learning disability; SR = struggling reader; Nar. = narrative text; Exp. = expository text; CI = confidence interval; NR = not reported.; UDL = universal design for learning.
[a]Estimated grade based on reported student age; [b]this study contained an e-text and a narration (no animation) condition; comparison to print book was *ES* = .27; [c]effect size differed greatly by measure.
*Mixed findings. **Statistically significant findings.

Table 6

Studies Investigating Instructional Enhancements for Comprehension of Digital Text at the Secondary Level

Study (Year)	Sample (*N*)	Grade	Intervention & Comparison	Typology & Digital Text Features	Text Type	Measures	Effect Size [CI]
Cuevas et al. (2012)	145	10	I: e-text C: Print text	*Instructional:* comprehension aids, definitions	Both	• Gates-McGinitie Reading Test (GMRT)	.04 [-.47, .55]
Gegner et al. (2009) Study 1	122	11	I: Multimedia e-text C: e-text (static)	*Instructional:* comprehension aids, reference materials *Illustrative*: narrated descriptions, animation	Exp.	• Comprehension Test (MC)	.77** [.39, 1.15]
Gegner et al. (2009) Study 2	97	10	I: Multimedia e-text C: e-text (static)	*Instructional:* comprehension aids, reference materials *Illustrative:* narrated descriptions, animation	Exp.	• Comprehension Test (MC)	.81** [.39, 1.22]
Johnson-Glenberg (2005)	20 (20 SR)	6-7	I: Multimedia e-text C: e-text (static)	*Instructional:* comprehension strategy training *Illustrative:* 3-D interactive reading	Both	• Comprehension Test (open-ended)	.46 [-.16, 1.09]
Kim et al. (2006)	34 (28 LD; 6 ED, OHI, & S/LD)	6-8	I: Multimedia e-text C: Business as usual (print text)	*Instructional:* comprehension strategy training	Exp.	• Woodcock Reading Mastery Test- Revised (WRMT-R) • CSR Test (main idea, question)	.75** [.05, 1.45]
McNamara et al. (2006)	39	8-9	I: Multimedia e-text with avatar C: e-text (video training w/ no multimedia)	*Instructional:* comprehension strategy training, practice & feedback (via virtual agents) *Illustrative:* animated demonstrations	Exp.	• Comprehension Test (open-ended)	.40 [-.23, 1.04]
Srivastava et al. (2012)	39 (14 LD)[a]	8	I: e-text C: Print text	*Instructional:* hyperlinked vocabulary	Both	• Comprehension Test (MC, open-ended)	-.12* [-.56, .33]
Twyman et al. (2006)	24 (24 LD)	11-12	I: e-text C: Print textbook	*Translational:* simplified text, hyperlinked glossary, optional text-to-speech *Instructional:* comprehension aids *Summarizing:* hyperlinked graphic organizers	Exp.	• Concept MAZE Task	.16 [-.37, .70]

Note. LD = learning disability; SR = struggling reader; ED = emotional disability; OHI = other health impairments; S/LD = speech/language disorder; Nar. = narrative text; Exp. = expository text.
[a]Special education data not disaggregated in results.
*Mixed findings. **Statistically significant findings.

Study design characteristics. More studies consisted of independent samples (59%) than dependent samples (41%). Studies included as many as seven measures of a range of constructs (e.g., reading comprehension, vocabulary, strategy use, word recognition, fluency, eye fatigue, reading motivation, time reading, reading enjoyment); however, most studies (90%) contained one to three measures. Two studies (7%) measured comprehension with multidimensional and robust measures; seven (26%) were of moderate rigor; however, most (67%) were singular and one-dimensional. Three (11%) of these studies included a vocabulary element within the assessments of comprehension. All studies included immediate criterion- or norm-referenced measures of student performance; only one had an additional maintenance measure. Fourteen studies (50%) found statistically significant findings on all measures, seven (25%) had mixed findings, and seven (25%) did not demonstrate any statistically significant outcomes.

Of studies that included an interventionist role in facilitation of the intervention (rather than using technology alone), only a small number described fidelity procedures with (19%) or without (22%) supporting outcome data; the remaining studies did not mention fidelity at all (56%). Similar findings occurred with reporting of fidelity of student use of the technology. Only a small number (11%) both described fidelity procedures and reported supporting outcome data or reported a description of fidelity procedures without supporting outcome data (15%); the remaining studies did not mention fidelity at all (74%). One third of studies (33%) provided a description of the type of feedback or instruction provided to students while using the technology.

Basic Access of Text vs. Instructional Supports

The overall weighted mean effect size for interventions that investigated the effects of basic access technologies on comprehension was small (*ES* = -.03, range -.49 to 1.18) even after studies that compared digital text with no features to print text were removed from the analysis (*ES* = -.02). The weighted mean effect size for instructional enhancement interventions was moderate (*ES* = .51, range -.35 to 1.57). As illustrated by the confidence intervals reported in Tables 2 through 5, variability was pronounced in the majority of studies in the analysis.

Basic access studies. Further investigation revealed that the weighted mean effect size for intervention studies that investigated the impact of basic access technologies on comprehension was small at both the elementary (n = 6) and the secondary level (n = 4), *ES* = .24 and *ES* = -.39, respectively. Studies with both typically developing students (n = 4) and students with disabilities (n = 6) yielded small effect sizes (M = -.07, and M = -.02, respectively). Although caution needs to be used in interpreting these findings due to the small sample sizes (six or fewer studies), small effects seem to be robust both by grade level and type of student. While there are too few studies to aggregate findings by smaller ranges of grades, visual inspection shows that the two studies conducted at the high school level had large overall effect sizes (Boyle et al., 2003; Dolan, Hall, Banerjee, Chun, & Stangman, 2005) whereas the two studies at the middle school level had overall small effect sizes (Flowers, Do-Hoing, Lewis, & Davis, 2011; Schmitt, McCallum, & Mauck, 2011).

Extreme caution should be used when drawing conclusions from this observation both because of the very small number of studies and the large variability within study findings. To illustrate, in the study of 11th- and 12th-grade students with LD conducted by Dolan et al. (2005), the confidence interval for the large overall effect size of 1.18 ranged from .18 to 2.18. In the study of sixth, seventh, and eighth graders conducted by Schmitt et al. (2011), the confidence interval for the small overall effect size of .23 ranged from -.32 to .79. Similar variability was present in studies with students at the upper-elementary level. For example, in a study of fifth graders conducted by Dundar and Akcayir (2012), the confidence interval for the small to medium overall effect size of .29 ranged from -.59 to 1.17.

Instructional enhancement studies. Table 7 lists the reading strategies featured in reading comprehension strategy training interventions within digital text. As illustrated, the weighted mean effect sizes of interventions with instructional enhancements at both the elementary (n = 10) and the secondary (n = 8) level suggest moderate effect (respectively, M = .58, and M = .43). The mean weighted effect size was also moderate for studies with typically developing students (n = 14, M = .52) as well as for studies that included students with disabilities (n = 4, M = .45). Moderate effects seem to be robust both by grade level and type of student. The small number of studies did not permit further analysis by upper (grades 4-6) and lower (grades K-3) elementary levels.

Finding for studies with students with LD should be interpreted with caution. Only four studies included students with LD, and findings were mixed – with two studies reporting moderate-to-large overall effect sizes: *ES* = .75 (Kim et al., 2006) and *ES* = 1.57 (Ko, Chiang, Lin, & Chen, 2011), and two reporting small overall effect sizes: *ES* = -.12 (Srivastava & Gray, 2012) and *ES* = .16 (Twyman & Tindal, 2006). As for the basic access studies, there was large variability within studies as well. For example, in the 2006 study by Kim and colleagues with 34 students with LD and other mild disabilities, the confidence interval ranged from .05 to 1.45. By comparison, in the 2006 study by Twyman and Tindal with 24 students with LD, the confidence interval ranged from -.37 to .70.

Table 7

Reading Strategies Featured in Reading Comprehension Strategy Training Interventions Within Digital Text

	Before Reading				During Reading		After Reading
	Activating Prior Knowledge	Prediction	Text Structure	Visualization	Questioning	Comprehension Monitoring	Summarizing
Dalton et al. (2011)		X		X	X	X	X
Gegner et al. (2009)	X				X		
Johnson-Glenberg (2005)				X	X		
Kim (2013)			X		X		
Kim et al. (2006)	X				X	X	X
McNamara et al. (2006)	X	X			X	X	X
Sung et al. (2008)						X	X

Discussion

The value of technology for delivering instruction has been questioned for years. As noted by Clark (1983), "media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition" (p. 457). Research is needed to support or refute this kind of claim. However, our review indicates that the research base on the use of connected digital text (whether for basic access or with instructional enhancements) is very limited, particularly for research including students with LD. Across studies reviewed in this analysis, effect sizes were small for interventions designed to help students gain basic access to digital text, and effect sizes were moderate for interventions that also included instructional enhancements. However, variability within both categories of interventions was pronounced.

Digital Features for Basic Access to Text

According to Anderson-Inman and Horney (2007), while electronic text may help students with reading difficulties to overcome substantial barriers imposed by printed materials, the usefulness of electronic text by itself is rather limited. Although only two studies (Dundar &

Akcayir, 2012; Jeong, 2012) investigated the effects of static digital text vs. print text, findings support the claim that simply putting text in a digital format for display on a computer screen does not result in improved performance (*ES* = .29 and *ES* = -.43, respectively). For example, in the study by Dundar and Akcayir (2012), the paper-based classroom textbook was converted into a digital format, which was read by the students on a tablet without any additional features or supports; the control group read the same text in a paper format. Although the text was converted into a digital format, it did not support student comprehension of the material.

Studies that included other features to support basic access, such as audio and text-to-speech, were also consistently small. In a study included within the meta-analysis (Sorrell, Bell, & McCallum, 2007), struggling readers (students reading below grade level) in the experimental group read digital text with support of text-to-speech software. When their performance was compared to that of students who read the same digital text without text-to speech, no differences in comprehension were found between the two groups.

The minimal impact of text-to-speech on student comprehension in studies included within this meta-analysis is unexpected because it is well established that decoding ability is related to reading comprehension (Fuchs, Fuchs, Hosp, & Jenkins, 2001; Goff, Pratt, & Ong, 2005). The ability to decode with automaticity frees up cognitive resources that can be allocated to text comprehension (Shinn, Good, Knuston, Tilly, & Collins, 1992), which becomes increasingly important as text increases in complexity. As such, digital text features are increasingly being used as a test accommodation, including high-stakes state assessments.

Testing accommodations are generally considered effective when a “differential boost” occurs; that is, when accommodations lead to greater score improvements for students with disabilities than for students without disabilities (Thompson, Blount, & Thurlow, 2002). Only four studies investigated the effects of digital text features for students with disabilities within testing contexts, but results were inconsistent. Specifically, two studies of audio accommodation with elementary-level students with LD (Crawford & Tindal, 2004; Laitusis, 2010) both had small to moderate effects. At the middle and high school levels, two studies investigated the effects of text-to-speech as a testing accommodation and found very small (Flowers et al., 2011) and very large effects (Dolan et al., 2005).

Although based on a very limited number of studies, these findings are consistent with mixed results reported in previous reviews of the accommodation literature for read-aloud accommodations for students with LD (e.g., Lai & Berkeley, 2012). Variability in the data indicated that the digital text features were helpful for some students, but not all. As suggested by Lai and Berkeley (2012), “until this body of research develops, IEP teams should reference evidence on the effectiveness of this accommodation for an individual student in classroom-testing situations before making a determination whether to provide it to the student in a high-stakes testing situation" (p. 167). Further, regardless of the inconclusive evidence, it is clear that more attention needs to be devoted to the quality of technology training and opportunities for sufficient student practice with technology-based tools to ensure students are ready to successfully use digital text prior to test administration.

Digital Features to Enhance Instruction With Digital Text

Based on the effectiveness of reading strategies on student reading comprehension of print text (e.g., Berkeley et al., 2010; Edmonds et al., 2009; Swanson, 1999), researchers (e.g., Okolo, 2005) have logically conjectured that reading comprehension can be further supported by adding instructional enhancements to digital text such as concept maps, text-to-speech, embedded dictionaries, and alternative representations of information. Further, findings from previous research syntheses have shown positive outcomes for digital supports on the reading performance of both general education students (Lan et al., 2014) and students with LD (Hall et al., 2000). Therefore, the mixed findings in this analysis of digital text studies were surprising – especially for the studies with students with LD who presumably would be more likely to benefit from supports.

Differences in findings across syntheses may be due to differences in the target populations and the nature of the intervention reviewed. For example, Lan and colleagues (2014) included college-age students in their selection criteria. Specifically, half of the studies included in the synthesis were conducted with undergraduate students, and the researchers noted generally positive reading outcomes for this age group. However, struggling readers did not benefit from the digital instructional enhancements. In addition, this meta-analysis only included studies with digital metacognitive strategies and did not determine the impact of other digital texts features, such as text-to-speech, stagnant digital text, or animations, on comprehension. Based on the nature of the interventions selected and the inclusion of college-aged students, it is possible that digital supports are more effective for certain age groups of readers and as a teaching medium rather than a built-in digital support to facilitate comprehension.

Differences may also be related to the type of technology targeted for synthesis. A narrative review of the research found that CAI interventions with instructional enhancements resulted in positive outcomes in various reading skills for students with LD (Hall et al., 2000). However, Hall et al.'s synthesis included computer programs for reading instruction and external supports, such as Internet applications, to support reading skills, whereas the present study focused on built-in supports that impact the comprehension of digital text specifically. Interventions with instructional enhancements in this meta-analysis all incorporated digital features to aid in increasing the understanding of the text, such as digital text with built-in comprehension aids and reference materials (Gegner, Mackay, & Mayer, 2009), text-to-speech combined with comprehension strategy training (Dalton, Proctor, Uccelli, Mo, & Snow, 2011), e-books with animation and music (Ertem, 2010), virtual agents that provide comprehension support (Kim et al., 2013), and digital text with comprehension aids (Kim et al., 2006).

Given the limited number of studies and the degree of similarity among the intervention components, it is difficult to arrive at a definite explanation for the inconsistent findings; however, we speculate that they may be due, at least in part, to the demands of the text itself. For example, each of the LD studies with limited effectiveness (i.e., Srivastava & Gray, 2012; Twyman & Tindal, 2006) contained hyperlinked text. Hypertext requires making choices among multiple potential paths (Lee & Tedder, 2003), which can lead to cognitive overload, particularly for student with LD who are known to have challenges with reading comprehension caused by deficits in working memory (Backenson et al., 2015; Swanson, 1994; Swanson & Alexander, 1997). In addition, students with LD are less likely to self-regulate their learning and persist with tasks (Gersten et al., 2001), so non-linear reading tasks are likely to be more challenging for them and explicit instruction in how to approach these types of text is necessary for them students to be successful.

Although results were mixed for instructional enhancements on comprehension in the present synthesis, variability in the findings might also be explained – at least in part – by the variability of rigor in the research methodologies of the studies. The majority of the reviewed studies did not meet the quality indicators for special education research (Gersten et al., 2005; Odom et al., 2005). Quality indicators for special education technology research require assessment of both surface and quality; in other words, both the technology-based intervention itself and how well it is implemented (Gersten & Edyburn, 2007).

Studies in the current analysis were particularly lacking in description of the sample, components of the intervention (both the implementation and the characteristics of the technology itself), and fidelity of treatment (including feedback provided to students). These areas are especially important in technology research when digital features are optional to students (e.g., text-to-speech, digitized realistic narrations, dynamic highlighting, hyperlinks) because the outcome is likely directly related to frequency of use.

Implications for Research

According to Gersten and Edyburn (2007) "the use of technology in special education has been advanced on the basis of marketplace innovations and federal policy initiatives rather than on a compelling research base" (p. 3). As such, statements about the effectiveness of digital text must be made with great caution. Studies investigating the effectiveness of digital text for improving reading comprehension are of mixed quality and outcome. Further, the research base on the effectiveness of digital text (whether for basic access or with instructional enhancements) for students with LD is very limited. It is imperative that more empirical evidence be obtained that meets the quality indicators for special education technology research to support the use of digital text. However, this is a daunting task considering that technology advances generally outpace research. Compounding the issue is the fact that unlike other disciplines where knowledge accumulates over time, much of the research on technology becomes irrelevant as older technologies become obsolete. For this reason, it is particularly important for researchers to meticulously document the characteristics of the participants as well as the salient features of the intervention – to include type of text, instructional procedures, and fidelity of implementation, in addition to thorough descriptions of the digital text features utilized.

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