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REVIEW ARTICLE

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A scoping review on the use of speech-to-text technology for adolescents with learning difficulties in secondary education

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ABSTRACT

Purpose: To identify and describe the aims, methodological approaches, and major findings of studies on the use of STT among secondary pupils (age 12–18) with learning difficulties published from January 2000 to April 2022.

Materials and method: This scoping review includes empirical studies published in peer-reviewed journals and grey literature between January 2000 and April 2022. Searches were conducted in April 2022 in three databases: ERIC, PsycINFO and Scopus. In addition, related reviews were manually screened for relevant papers.

Results: Eight peer-revied studies and five publications of grey literature were found to meet the inclusion criteria; two studies employed experimental designs, four employed quasi-experimental designs and seven employed explorative designs. Six studies described STT as an assistive technology (a compensatory aid for poor writing performance); two assessed STT as an instructional technology to determine whether it improves overall writing and related skills (e.g., reading). Results suggest that STT may increase pupils' abilities to produce texts with fewer errors, provide help with spelling and improve reading comprehension and word recognition. To date, there is a paucity of high-quality research on the use of STT among adolescents with LD.

Conclusion: The scoping review shows that very little research has been conducted on the use of STT for adolescents with learning difficulties in secondary education. Findings from the studies identified five areas of interest: writing related skills, text assessment, writing processes, accuracy of the technology, and participants' experiences. Findings indicate that writing performance among students with learning difficulties improves when using STT. Parents, teachers, and pupils report positive experiences with the technology, particularly for students with severe reading and writing difficulties.

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Speech-to-text; speech recognition; special education; assistive technology; instructional technology; writing difficulties

➤ IMPLICATIONS FOR REHABILITATION

- There is a great need for more robust research on the use of speech-to-text technology (STT) in educational settings, especially on its effect on writing skills
- Studies describe STT as either an assistive (a compensatory aid for poor writing performance) or instructional technology (aiming to improve learning in general). It is important that practitioners are aware of the different aims and possible consequences of introducing STT to learners with writing difficulties.
- STT provides both opportunities and challenges for writers with learning difficulties in secondary education. Findings indicate that writing performance among students with learning difficulties improves when using STT, yet inaccuracy of the technology was presented as one of the main challenges.
- Parents, teachers, and pupils report positive experiences with the technology, particularly for students with severe reading and writing difficulties.

Introduction

Writing is a complex activity, dependent on cognitive prerequisites, such as phonological decoding [1], efficient working memory [2,3] and knowledge of orthography, morphology and syntax [4]. Writing is also influenced by self-regulation, creativity, and self-efficacy beliefs [5,6]. Most theoretical models of writing do not consider the use of assistive technology and its impact on the writing process [7]. Instead, they tend to focus on different cognitive aspects of the writing process, including the influence of working memory, knowledge transformation and the writer's motivation and self-regulation [e.g., 8–10]. One exception is Hayes and Berninger's [11] descriptive framework of the cognitive processes involved in writing wherein transcription technology is presented as an influential element in the physical task environment. Taking this into account, pupils who display low proficiency in writing, due to poor instruction, learning disabilities, language disorders or developmental disorders [12], may benefit from the use of speech-to-text technology (STT). Notably, this may be the case for pupils with dyslexia, who due neurological deficits in the phonological component of language, experience difficulties with accurate and fluent word recognition, and poor spelling and decoding [13].

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Writing difficulties

Based on a corpus of 41 studies, including writers in primary, secondary and higher education, Newcomer and Barenbaum [14] found that struggling writers compose texts with more mechanical errors (spelling, punctuation and capitalisation), more syntax errors (subject/predicate agreement) and less fluency (fewer words, fewer sentences and less variety of words). Compared to their typically developing peers, pupils with learning disabilities did not exhibit an increase in fluency as they grew older. The studies included in their review revealed that struggling writers demonstrate less knowledge of the writing process, such as the importance of planning. These findings demonstrate that writing difficulties can be extensive and persistent [14]. Ewoldt [15] argues that, due to deficits in language and working memory that negatively impact the ability to produce quality writing, pupils with learning disabilities tend to focus on lower-level elements of writing, leading them to compose poorly organised paragraphs comprised of strings of linear ideas. According to Ewolt [15], technology can provide academic support for these pupils as it increases opportunities to focus on organisation, argumentation and how the text communicates to the reader.

Speech-to-text technology

Speech-to-text technology (STT) generates digital text from spoken language. One of the first speech recognition systems was built by scientists at AT&T Bell Laboratories in 1952 [16]. In the field of special education, studies on STT as an assistive technology for writing composition emerged in the late 1980s and 1990s [17–19]. For example, several versions of speech-to-text programs released by Dragon Systems have enabled users to produce text by speaking into a computer microphone. Other kinds of software have also been used, such as Keystone Speech master [20], Speech Texter [21], VoiceType [22] and integrated software in Apple's iPad [23]. Speech recognition technology has improved rapidly, ranging from systems that needed to be adapted for individual users to more advanced programming that builds on deep learning algorithms, providing accuracy of 90–95% in prevalent languages [24]. Technological advancement also reflects a move from "discrete recognition", which required users to include a pause between words when dictating, to systems that accept continuous speech [25], and newer technologies that provide suggestions or corrections based on contextual cues, such as previous words in the sentence.

When pupils transition from primary to secondary education, demands on their writing performance increase. Pupils in primary education are expected to have mastered the basics of grammar, orthography, and punctuation and to produce longer texts in which they focus on content, communication, and structure. Consequently, teachers may introduce assistive technologies to support students with writing difficulties. However, adoption of new approaches can be challenging for older students who have spent years developing their writing skills and habits when writing by hand or typing. Thus, research on STT requires consideration of students' and teachers' willingness to adopt STT in secondary education (age 12–18) and the ease with which it can be applied in this context [26]. In addition, there is a need for research that considers which students are most likely to benefit from STT, under what circumstances, and how any potential benefits may occur.

Assistive and instructional technology for writing

Peterson-Karlan, Hourcade, and Parette [27] define assistive technology as having a compensatory function to support pupils who struggle to write and to provide scaffolding for basic writing skills. This technology is not intended to replace writing-as-process instruction or become the student's only tool for producing texts. It is considered a support in certain areas of the writing process, especially in drafting, editing, and revising [27]. Analogous to the concepts of assistive and instructional technology are Edyburn's [28] descriptions of compensation and remediation. In these terms, compensation (assistive technology) refers to efforts to compensate for a lack of writing skills and enhance the pupil's ability to plan, compose and revise text. In contrast, remediation or instructional technology aims to improve skills by enabling pupils with LD to produce more text and increase exposure to writing activities [28]. Thus, it may not be the technology itself that differs between assistive and instructional technology, but the aim or effect of implementing the approach. For example, if researchers aim to study improvement on learning in general, they consider STT an instructive technology, while if they research the implications on a specific task (for example text quality, text length or composing time), STT is more likely to be considered an assistive technology. The theoretical, empirical and practical distinctions between writing technology as an assistive or instructional technology have been largely unexplored.

MacArthur's [29] review of assistive technology for struggling writers in primary and secondary education notes that although evidence suggests that STT can be beneficial for some students, little is known about who can benefit from STT and in what contexts. In their broad review of STT in education, Shadiev et al. [30] summarised its benefits for students with disabilities, online students, non-native speakers and in collaborative learning activities and traditional classroom environments. Pennington et al. [31] present a review on how STT supports writing in primary and higher education, and Arcon et al. [32] conducted a within-subjects experimental design study on how STT can be used for second language learning in elementary education. Yet, little is known about the use of STT in secondary education or its impact on specific tasks for learners with writing difficulties, and even less is known about its general impact on learning. As we have not identified previously published reviews on struggling writers' use of STT in secondary education, it is important to explore this research gap. This is especially true with respect to assistive technology, including STT, as it is widely recommended in the IEPs of students in secondary education [27,33,34], and as an educational practice for teachers and teacher candidates in theoretical frameworks [35,36], policy documents [37,38] and instructional materials [39,40].

Purpose of the review

Several systematic reviews and meta-analyses have been conducted on studies of assistive technology for pupils with learning impairments [41–46], and reviews on assistive technology to support learners who struggle with reading and writing [47]. However, no previous literature reviews have focused on the use of STT among struggling writers in secondary education (age 12–18). As there is little existing research on this topic, we decided to conduct a scoping review. The aim of a scoping review is to systematically map evidence on a topic and identify the main concepts, theories, sources, and knowledge gaps [48]. The purpose of this study is therefore to identify and describe the aims, methodological approaches, and major findings of studies

on the use of STT among secondary pupils with learning difficulties published from January 2000 to April 2022. Based on this review, we describe research gaps in current research and make recommendations for improvement.

Methods

Literature search

This review focuses on grey literature and peer-reviewed empirical studies published in English between January 2000 and April 2022. We chose January 2000 as a starting point, as the technological advancement of continuous speech recognition was first implemented at that time [49]. Continuous speech recognition created a shift in the usability and accuracy rate of speech technology. Studies published prior to January 2000 were excluded, as they only report findings on the use of discrete word recognition software.

Searches for peer-reviewed articles were conducted in three databases in April 2022: ERIC, PsycINFO and Scopus. Review studies conducted by Pennington et al. [31], Perelmutter et al. [46] and Peterson Karlan et al. [27] were screened for relevant papers. The following search string was used for all three databases (writing OR student* OR school OR education* OR special AND education* OR writing AND disorder* OR dyslexia OR learning AND disabilit*) AND (speech AND technolog* OR speech AND to AND text OR speech-to-text OR speech AND recognition OR stt OR dictation). Search terms were selected according to the Participants, Interventions, Comparisons and Outcomes (PICO) framework [50]. Only terms describing participants (pupils, education, dyslexia, disabilities) and interventions (STT, dictation, assistive technology) were included in the search string to avoid limiting the search to specific comparison groups (disabled versus non-disabled) or outcome measures (motivation, skills, experiences).

Searches for grey literature were conducted using title and keywords searches in Google, Google Scholar, the NDLTD (Networked Digital Library of Theses and Dissertations) and ProQuest Dissertations & Theses Global. Keyword searches included combinations of the following terms, “speech recognition”, “speech-to-text”, “STT”, “dictation”, “writing”, “learning disabilities”, “dyslexia”, “writing disorder”, “writing difficulties”, “special education” and “secondary education”. We also conducted citations searches and manual searches on all included articles and related review articles [such as 27,46]. Given the broad range of possible sources, the search process for grey literature has a greater number of limitations and is likely less exhaustive than with peer-reviewed literature.

Selection criteria

Articles were included or excluded according to a set of criteria regarding (1) target population, (2) research aim and (3) whether they were original research studies. See Table 1 for an overview of inclusion and exclusion criteria.

1. Target population

Studies of learners with difficulties that directly relate to developing writing skills, such as dyslexia, dysgraphia or specific language impairment, were included. Articles describing speech recognition users from different age groups were included if the participants were secondary education pupils (ages 12–18). Studies were excluded if they only targeted "typical learners": pupils with average or above average writing proficiency. Studies of learners with intellectual impairments or physical disabilities, were also excluded; this diverse group of students may or may not have similarities with learners who primarily struggle with written language. Studies including only children in early childhood education or primary school, as well as studies on adults, were excluded. In this review, we have chosen to use the term, "learning difficulties" (LD) instead of "learning disability", as it was necessary to include studies on struggling writers who may not have a diagnosed disability, given the paucity of research within this field.

2. Research aim

Speech technology is often regarded as speech recognition (speech-to-text) and speech synthesis (text-to-speech). The aim of this scoping review is to identify research aims, areas of interest and methodological approaches of studies on speech-to-text technology for pupils with learning disabilities in secondary education. Thus, articles that include the use of either speech recognition alone or speech recognition combined with other kinds of assistive technologies (such as speech synthesis or digital voice feedback) are included. Studies on speech recognition for second language instruction (e.g., Arcon et al. [32]) and speech- and language therapy (e.g., Kitzing et al. [51]) were excluded.

3. Original studies

Theoretical papers on how to implement speech technology and position papers on the use of speech recognition in the classroom were excluded if they did not report empirical data. Meta-analyses, systematic reviews, and literature reviews on assistive technology were included in the first screening, and relevant articles found in the reviews were included in the second screening. Larger studies on the general use of assistive technology, listing speech recognition as one of several technologies, were excluded if they did not report a specific sample using STT (e.g., Flanagan et al. [52]).

Table 1. Inclusion and exclusion criteria.

Question component	Inclusion criteria	Exclusion criteria
Age	Studies including pupils aged 12–18	Studies including only pupils in kindergarten, pre-school or aged 6–11 or older than 18
Impairment	Studies including reading, writing or language impaired learners	Studies including only non-impaired learners or learners with physical or intellectual disabilities
Technology	Studies on STT or STT and other kinds of technology such as text-to-speech (TTS)	Studies not including STT, or studies were the sample using STT was not specified
Language	L1	L2
Methodological design	Quantitative. qualitative and mixed methods	Non-empirical
Year of publication	2000–2022	<2000
Intervention	Any	
Language	English	Other languages than English

Screening and eligibility

The first author used Rayyan (www.rayyan.ai), a digital platform for document reviews and data extraction, for the initial screening of titles and abstracts of 2380 articles. Thereafter, 2227 articles were excluded as they were off topic or did not meet the inclusion criteria. In a second screening for peer-reviewed articles, 79 articles that could be considered eligible based on title and abstract were read individually by the first and second author. Both authors concluded that five articles [25,53–56] met the inclusion criteria. Three additional articles [23,57,58] were identified through manual searches. The three articles were read individually by both authors and found to fulfil the inclusion criteria, resulting in a total of eight articles. Inter-coder reliability of the eight articles was 100%. The PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) Checklist [48] was used to guide the reporting of findings. An overview of the screening and selection process is presented in Figure 1. Grey literature was searched and screened individually by the first author. Only literature that reported on and met the inclusion criteria, such as empirical findings and participants within the age range, were included. Five publications of grey literature met the inclusion criteria: three reports [59–61], one dissertation [62] and a preprint article [63].

Analysis

First, the eight peer-reviewed articles meeting the inclusion criteria were coded according to study design, research aims, sampling methods, sample size and age, country, proportion of learners with and without LD, duration of the study, characteristics of the intervention and STT software. Studies were categorized based on their stated purpose and the methods of analysis reported by the author(s), as well as the extent to which they contained components of experimental designs. The four essential components of a true experimental design include (a) random selection, (b) random assignment, (c) the presence of an intervention (i.e. manipulation of the independent variable), and (d) the use of a comparison or control group [64]. As random selection is rare in instructional research [65,p.323], quasi-experimental designs were in this study required to include at least random assignment, a comparison group and an intervention. Qualitative

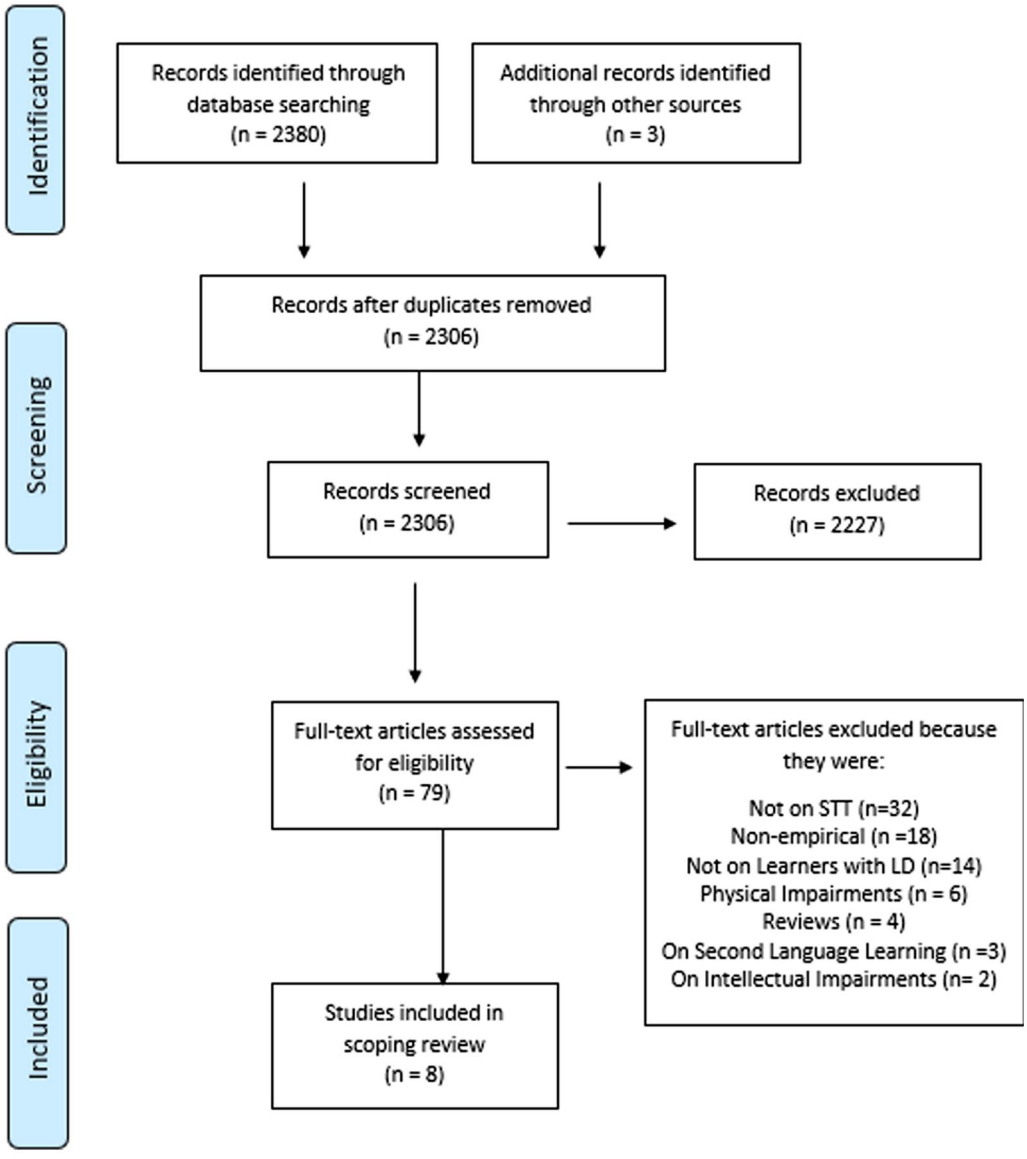

Figure 1. Flow chart of the screening process for peer-reviewed articles.

studies were determined based on the absence of quantitative measures and the clearly distinguishable purpose of developing meaning rather than testing for causal relationships [66]. An overview of study designs, sample sizes and methodological approaches is presented in Table 2 for peer-reviewed articles and Table 3 for grey literature, along with a summary of the main findings from the studies.

Secondly, we identified the primary variables investigated across the studies and derived the following areas of interest from this analysis: *writing related skills*, *text assessment*, *writing processes, accuracy of the technology, and participants' experiences*. The areas of interests are intended to capture a combination of outcome measures from experimental studies as well as explorative variables that reflect the stated aim of the studies and that were most prevalent in the studies' reported findings.

Results

Given that the quality of peer-reviewed articles has been previously established to separate grey literature from scientific publications, findings from the articles and grey literature are presented separately.

Aims and approaches

Peer-reviewed studies

Four peer-reviewed studies used quantitative approaches, two studies [53,57] filled the criteria for experimental designs and three [25,54,56] were defined as quasi-experimental approaches, as they did not conduct randomised sampling or had post-test only designs. Two studies [23,55] employed explorative designs and mixed methods approaches, while one study [58] had an explorative and qualitative approach. Information on the design, sample characteristics and software used in the included studies is presented in Table 1.

Jeffs et al. [58] Nordström et al. [23], and Ok et al. [55] conducted explorative studies based on surveys or interviews after the participants had used STT over a brief period of time. Jeffs et al. [58] sought to study characteristics, interactions, and the attitudes of parents and pupils related to their use of assistive technology. The researchers observed eight children with LD as they used a variety of assistive technologies, including STT. Afterwards, they interviewed the children and their parents to access their reflections on assistive technology's impact on literacy learning. Nordström et al. [23] examined teachers' views on the capacity of assistive technology to give learners with documented reading and writing difficulties the opportunity to assimilate ("read") and communicate ("write") text. Data comprised special education teachers' ($n = 54$) perceptions of pupils' ($n = 59$) experiences using the technology in grades 4 and 8, and upper secondary school. Ok et al. [55] examined usage patterns and perceptions of speech recognition among 95 pupils with learning disabilities (grades 4–8), while teachers and pupils participated in interviews.

Noakes et al. [56] utilized an alternating treatment, single-case design including three pupils (ages 9, 14 and 15) with written expression difficulties due to traumatic brain injuries. The study's aim was to measure STTs effect on text length, grammar, and spelling. Noakes et al. [56] compared the pupils' texts composed under two conditions, writing by hand and while using STT. Four studies [25,53,54,57] employed between-group designs. Quinlan's [54] aim was to investigate STT's effect on the writing processes of students described as "more fluent" and "less fluent" writers ($n = 41$, ages 11–14). Aiming to measure the effect on the writing process, Quinlan examined the outcome measures holistic text quality, text length, number of errors, planning time, composing time, revising time, accuracy of the technology and amount of planning words. MacArthur and Cavalier [25] examined the feasibility and validity of using speech recognition as a test accommodation. They compared STT to writing by hand and with a scribe among LD students and students without LD (NLD) in upper secondary school ($n = 31$, mean ages: LD = 14.7, NLD = 15.1).

Svensson et al. [57] explored the effects of several kinds of assistive technologies, including STT, on reading and writing related skills. The study included 149 pupils with LD in grades 4 (age 9), 8 (age 13) and upper secondary (age 16–19). An intervention group received assistive technology training while a comparison group received teaching as usual. Pre- and posttests included standardised assessments of reading and writing related skills. A survey was presented post intervention to pupils in the intervention group and their parents to assess perceived motivation. Higgins and Raskind [53] compared the effects of interventions using two types of speech recognition systems, continuous and discrete speech, and aimed to measure the remedial effects of STT on writing related skills for pupils with identified LD ($n = 52$, ages 9–18). Thus, of the eight identified studies, only two, Higgins and Raskind [53] and Svensson et al. [57], assessed changes in writing related skills after exposure to an intervention using a pre-test-posttest design and a comparison group.

Grey literature

Included grey literature comprise three reports [59–61], one dissertation [62] and a preprint article [63]. The dissertation by Mader [62] employed a quasi-experimental alternating treatments single-case design. Participants ($n = 3$, age 11, 13 and 14) composed narratives using paper and pencil and STT. The researcher collected both qualitative (semi-structured interviews) and quantitative data (self-reporting surveys, document analysis and psychometric tests) aiming to investigate the use of STT with adolescents with learning disabilities. More specifically, Mader's [62] research questions examined (1) STT's effect on the quality of student compositions, (2) the affective dimension of writing and (3) the accuracy of the technology.

The remaining four identified grey literature publications employed explorative research designs. Three of them are reports [59–61] by the governmentally funded research and development centre CALL (Communication Access Literacy and Learning) Scotland. Nisbet and Wilson [59] and Nisbet et al. [60] report from *the Introducing Speech Recognition in Schools* project that provided training and speech recognition software to forty schools. Staff from twenty-three schools (57,5%) returned evaluation forms with open-ended and closed questions reporting on 32 pupils (age 13–16) use of STT. The aim of the project was to investigate best practice in schools where STT was being used successfully, as well as to develop and evaluate training material to help other schools implement STT.

Lawson and Nisbet [61] report on the *Talking in Exams* project. The project aimed to investigate the use of STT for pupils with disabilities or additional support needs, during formal assessments. Twenty-eight schools were provided with STT software, and 70 pupils (age 10–17) participated in the trials. Teachers were asked to complete a pupil record for each learner describing underlying reasons for need of support, indications of the student's reading, writing, verbal and ICT skills, motivation to use STT, outcome of the trial and key advantages and disadvantages.

Table 2. Peer-reviewed studies included in the review.

Study	Country	Sample (LD)	Age	Approach	Design	Sampling	SR software	Methodology	Key findings
Higgins and Raskind [53]	USA	52 (52)	9–18	Experimental	Pretest-posttest, Between groups-design	Random assignment	Dragon Dictate, Dragon Naturally Speaking v1 and IBM Voice Type	Quantitative	Both intervention groups showed significant improvement in word recognition and reading comprehension.
MacArthur and Cavalier [25]	USA	31 (21)	Mean 14.7 (LD) 15.1 (NLD)	Quasi-experimental	Posttest only, between group-design	Strategic	Dragon Naturally Speaking v4	Quantitative	Dictation helped students with LD produce better quality essays. No differences in text quality found for students without LD.
Quinlan [54]	USA	41 (21)	11–14	Quasi-experimental	Posttest only, between group-design	Strategic	Dragon Naturally Speaking Professional 5	Quantitative	STT significantly increased the length and decreased the surface errors of narratives for less fluent writers. STT did not significantly improve text quality.
Jeffs et al. [58]	USA	8 (8)	9–14	Explorative	Interviews and observations	Strategic	Dragon Naturally Speaking Preferred	Qualitative	All the children in the study liked using speech-to-text software. Parents were beginning to realize that, when given the right tools, their child could be successful in reading and writing activities.
Noakes et al. [56]	USA	3 (3)	9, 14 and 15	Quasi-experimental	Alternating treatments, single-case design	Strategic	Dragon Naturally Speaking	Quantitative	All participants significantly increased total words written, words spelled correctly and correct writing sequences, compared to the handwriting control condition.
Nordström et al. [23]	Sweden	59 (59)	Grade 4, Grade 8 and upper secondary	Explorative	Cross-sectional	Strategic	iPad 2 or 3	Mixed	Students with reading difficulties could use writing apps (for example STT) in portable tablets to produce text in an applied school setting.
Ok et al. [55]	USA	95 (95)	Grades 4–8	Explorative	Cross-sectional	Strategic	iPad	Mixed	Students across grades had positive perceptions about using STT. It was especially helpful for students who struggled with spelling and supported some, but not all, students while drafting text.
Svensson et al. [57]	Sweden	149 (149)	Grade 4, Grade 8 and upper secondary	Experimental	Pretest-posttest, between groups-design	Random assignment	SayHi	Quantitative	Both the intervention and control groups improved as much in 1 year as did the normed population. However, gains did not differ between the groups directly after the intervention or at 1 year of follow-up. 50% of the students and their parents reported an increase in motivation for schoolwork after the intervention.

LD: Learning difficulties; NLD: Without learning difficulties.

Table 3. Grey literature included in the review.

Study	Country	Sample (LD1)	Age	Approach	Design	Sampling	SR software	Methodology	Key findings	Format
Nisbet and Wilson [59]	Scotland	32(32)	13–16	Explorative	Cross-sectional	Strategic	Dragon Naturally Speaking 4 or 5 and IBM ViaVoice Millennium Pro 7	Mixed	The success of introducing speech recognition in schools depends as much on school and staff resources, as on the skills of the individual student.	Report
Nisbet et al. [60]	An updated report and guide for practitioners based on the same design, approach, and sample as the report by Nisbet and Wilson [59]						Dragon Naturally Speaking Preferred Version 9	Mixed	Training sessions varied depending on the reading and ICT skills of the students. Motivation to use STT tended to be rated by the pupils as "good" or "excellent", and there was little difference between successful and unsuccessful students in relation to motivation.	Report
Mader [62]	USA	3 (3)	11, 13 and 14	Quasi-experimental	Alternating treatments, single-case design	Strategic	Dragon Naturally Speaking Preferred Version 8	Mixed	Findings suggest that STT can assist students with learning disabilities to produce better written products as they circumvent paper-pencil writing. Students are empowered to express their ideas in written form.	Dissertation
Lawson and Nisbet [61]	Scotland	39(39)	10–17	Explorative	Cross-sectional	Strategic	Dragon Naturally Speaking Pro 13	Mixed	Key advantages reported: Pupils overcome concerns about spelling, it provides independence and self-esteem, and is quicker than writing by hand or typing. Key disadvantages reported: Did not work for pupils with indistinct speech and some pupils reported that they experienced negative pressure to produce text.	Report
Levine et al. [63]	USA	120 (73)	14 - 17	Explorative	Sequential equal status mixed methods design	Strategic	Google Documents	Mixed	STT can serve as an accessible alternative mode of composition for some high school students and may be especially useful for students with writing related LDs.	Preprint

LD: Learning difficulties (or receiving special needs education).

Feedback was received from 12 schools (60%) regarding 39 (56%) of the 70 pupils.

Levine et al. [63] registered their article as a preprint (not yet peer-reviewed as of October 2022) on SSRN (Social Science Research Network). The aim of their study was to explore voluntary use of STT among general education English Language Arts (ELA) students. The study included 120 pupils (age 14–17) of which 73 (60%) attended ELA support classes. The researchers gathered quantitative data (a mid-year survey and end-of-year survey) and qualitative data (interviews and observational notes) to explore who used STT, the kinds of composition tasks pupils chose to do with STT, and pupils' and teachers' perceptions of STT. The study also compared STT compositions written with STT with similar compositions written without STT to explore potential differences in writing.

Main findings from peer-reviewed studies

Analysis of the main findings from the 8 peer-reviewed studies was organized around the five identified areas of interest described above: writing related skills, text assessment, writing processes, accuracy of the technology, and participants' experiences (see Table 4 for an overview).

Writing related skills

Two studies [53,57] addressed reading and writing skills as outcome variables. Higgins and Raskind's [53] labelled their outcome variables as reading and writing related skills (word recognition, spelling and reading comprehension) and reading related cognitive processing measures (phonological deletion, orthographic choice, semantic choice, metacognitive ability and working memory). Higgins and Raskind [53] included three groups of students with instructional programs using different technologies: continuous speech recognition, discrete speech recognition or keyboard only (contrast group). The discrete condition required students to dictate word-by-word with a pause between each word, while continuous speech recognition allowed the users to speak in full sentences. In comparison to the contrast group, both the discrete speech and continuous speech groups showed significant gains on reading comprehension and word recognition after 16 weeks, while significant gains in spelling were found only for the discrete speech condition. No significant between-group differences were found for any of the cognitive processing measures, with one exception: students provided with the discrete speech condition had significantly higher scores on the phonological deletion measure than the contrast group. There were no significant differences between the two STT conditions on any of the eight outcome measures [53].

Svensson et al. [57] employed test batteries measuring reading and writing related skills such as word recognition, reading and listening comprehension, orthographic choice, short-term memory, and fluency. The tests were conducted pre- and postintervention, and after 1 year. The intervention had a duration of 8 weeks and procedures included several kinds of assistive technologies aimed at assimilation (reading) and communication (writing) of text. Results showed that the intervention and comparison groups did not differ on any of the tests, after the intervention, or at the 1 year follow up. The study concluded that pupils receiving assistive technology as reading and writing instruction maintained the same pace of developing reading and writing related skills as did the pupils who received treatment as usual. The test battery employed in the study by Svensson et al. [57] mainly included skills related to reading, as they found it difficult to find tests that capture pupils' writing skills.

Table 4. The areas of interest in the peer-reviewed studies.

Areas of interest and study variables		Higgins and Raskind [53]	MacArthur and Cavalier [25]	Quinlan [54]	Jeffs et al. [58]	Noakes [56]	Nordström et al. [23]	Ok et al. [55]	Svensson et al. [57]
Writing related skills	Word recognition	X							X
	Spelling	X							
	Reading comprehension	X							X
	Listening comprehension								X
	Phonological deletion	X							
	Orthographic choice	X							X
	Semantic choice	X							
	Metacognitive ability	X							
	Memory	X							X
Text assessment	Holistic text quality		X	X					
	Length		X	X		X			
	Vocabulary		X			X			
	Total errors		X	X					
	Unknown words		X						
	Correct writing sequences					X			
Writing process	Planning words			X					
	Error correction			X					
	Revising time		X						
	Planning time		X						
	Composing time		X	X					
Technology	Accuracy of STT		X	X					
	Drop-out	X	X						
Experiences	Student motivation						X		X
	Student learning						X		
	Tablets as assistive technology						X		
	General opinion		X		X			X	
	Preferred modality		X						
	Strengths		X					X	
	Weaknesses		X					X	
	Frequency of use							X	
	STT's impact on writing				X			X	
	Need for support				X				

Text assessment

Three studies [25,54,56] compared pupil performance using STT to their performance using other modalities. MacArthur and Cavalier [25] and Quinlan [54] also considered the differential impact of student ability on writing performance by including LD students and NLD students. Quinlan [54] found that less fluent writers produced more words and had significantly fewer errors when using STT than when writing by hand. For more fluent writers, differences between texts written under the two conditions (STT and handwriting) were not significant. A 5-point scale measuring story development and sentence fluency (t-units) was used to assess text quality. No significant differences were found between the quality of texts under the two conditions for either group of students.

MacArthur and Cavalier [25] compared the writing of LD and NLD students under three conditions: handwriting, dictation to a scribe and STT. They used a rubric to measure holistic text quality on a 7-point scale, which included assessment of ideas/content, organisation, word choice, sentence fluency and writing conventions. For students in the LD group, the highest quality texts were produced when dictating to a scribe, while texts written with STT received significantly higher quality ratings than texts written by hand. No differences in text quality were found for the NLD group when using all three modalities. The results showed significantly fewer errors in texts written by LD pupils using STT in comparison to handwritten texts. Moreover, MacArthur and Cavalier [25] found no differences between modalities with respect to the number of errors produced by NLD pupils. Furthermore, there were no significant differences between the three modalities on text length or vocabulary use, regardless of the ability group.

Noakes et al. [56] aimed to measure STT's effect on writing for three pupils with traumatic brain injuries. The study employed three outcome variables, (1) total words written, (2) words spelled correctly and (3) correct writing sequences. All outcome variables significantly increased when the pupils used STT and were higher than the handwriting control condition.

Writing processes

MacArthur and Cavalier [25] and Quinlan [54] considered elements of the writing process, such as the amount of time students spent composing, revising, and planning with different modalities. Quinlan [46] found that average composing time was longer for STT than for handwriting across all participants. MacArthur and Cavalier [25] found no significant differences between handwriting and STT on composing time for either group of students. However, both NLD and LD students wrote significantly faster using a scribe than with handwriting or STT. MacArthur and Cavalier [25] found no differences between conditions on planning time, yet both groups of pupils spent significantly less time revising texts when writing by hand than when using STT or a scribe.

Accuracy of the technology

Two peer-reviewed studies [25,53] report on pupil dropout due to low levels of accuracy; inaccuracy of the technology was listed as the main weakness in several studies. Four of the 38 students dropped out of Higgins and Raskind's [53] continuous speech condition due to low accuracy rates; two did not complete the discrete condition because they found correction of speech recognition errors frustrating and typing more efficient. MacArthur and Cavalier [25,p.47] describe one of 21 LD students who did not complete their study because she found it "frustrating".

Both studies [25,53] employed a probe task in which the participants read passages aloud while using speech recognition, without correcting recognition errors. Mean accuracy in Quinlan's [54] study was approximately 90%, where accuracy was significantly related to age, but not to writing skill. Higgins and Raskind [53] suggest that the higher pitch of younger pupils' voices may hinder the accuracy of STT. In MacArthur and Cavalier's [25] study, 13 students showed a mean accuracy rate of 87%. Although not measured in these studies, it is assumed that the accuracy rates for a probe task using handwriting to reproduce the same passages would be close to 100% for most students. Quinlan [54] notes that some children experienced few recognition errors while others encountered several and spent considerable time and effort correcting them. Variability in functionality across individuals was highlighted across the studies included in this review.

Experiences

Five peer-reviewed studies [23,25,55,57,58] report on parents', teachers', or pupils' self-reported experiences with STT. MacArthur and Cavalier [25] collected data on pupils' opinions of using STT, including its strengths and weaknesses, and which modality they preferred; 62% expressed positive views of STT, 66% reported that they would continue using STT for future assignments and 96% said they would recommend STT to a friend. When asked to compare writing with STT to dictation to a scribe and writing by hand, 65% of the pupils in MacArthur and Cavalier's [25] study preferred using STT. Moreover, 82% agreed that STT helped them write better texts. The pupils listed, "speed, not having to write, help with spelling, [that it was] fun or 'cool', and helping to get thoughts down" as benefits of using STT [25,p.53]. All the pupils who listed "help with spelling" had a documented LD. The most frequent criticisms reported were mistakes in recognition, correction errors, and difficulties training the speech recognition system [25].

In Ok et al. [55], 50% of 7–8th grade pupils expressed that they liked using STT and 66% believed it improved their writing, yet some students reported that using STT felt like cheating and that speaking out loud in the classroom was embarrassing and distracting. In contrast, 74% of teachers in 8th grade and upper secondary reported that they believed STT improved students' ability to write [55]. The teachers described challenges such as difficulty finding a quiet place, distractions, improper use, lag time due to internet connection issues, anxiety about speaking out loud and limited teacher competency [55].

Nordström et al. [23] found that 81% of special educators believed that the intervention improved students' ability to compose texts. However, only 42% assessed the technology as having improved "traditional" reading and writing skills, and only 38% perceived writing with STT as having a positive effect on motivation. Nordström et al. [23] and Ok et al. [55] found that younger pupils were more likely to continue using STT after the intervention than older pupils.

Between 42% and 55% of pupils in Svensson et al.'s [57] study perceived that the STT-intervention positively affected motivation and independence. Analyses showed that this finding was especially valid for pupils with the most severe reading and writing difficulties. Svensson et al. [57] conducted the only longitudinal study identified, measuring pupil's attitudes one year after the intervention, finding that 65% reported that they still used the assistive technology apps after 1 year. Jeffs et al. [58] interviewed and observed parent-child dyads using assistive technology during reading and writing activities. The main findings regard the pupils and parents' changing attitudes towards literacy. The pupils

with learning disabilities had a history of avoiding reading and writing activities, and their parents described their struggle to assist them in completing literacy tasks. STT was reported as an easy approach that all the children enjoyed using. However, it was also emphasized that it was difficult to train the speech recognition system.

Moreover, parents reported that the technology provided a sense of encouragement. Yet, introducing STT required that the pupil acquire different software skills, in addition to new writing strategies of planning texts and organizing their thoughts. According to Jeffs et al. [58], one of the main benefits was that the pupils who had previously been negative towards reading and writing activities experienced pride and ownership while reading and writing with assistive technology.

Main findings from grey literature

The main findings from the grey literature vary greatly in quality, form, and genre. The three publications by Nisbet and Wilson [59], Nisbet et al. [60] and Lawson and Nisbet [61] are all presented as reports, but most of the content comprises tutorials describing how practitioners can introduce secondary pupils to STT for regular writing activities (a and b) or during formal writing assessment (c). In addition to the sections on how to dictate with STT, the reports provide results from evaluations conducted with the staff and students who took part in a project entitled CALL *Introducing Speech Recognition in Schools*. Findings presented in the reports show that the success of introducing speech recognition in schools depends as much on school and staff resources, as on the skills of the individual student. Further Nisbet and Wilson [59] found that 72% of students who were introduced to STT during the CALL-project intended to continue using the technology, while 3% were unsure and 25% reported that they did not intend to continue using STT.

Nisbet et al. [60] describe large variations in the training sessions depending on the reading and ICT skills of students. The pupils' reading skills were influential because the pupils had to read a text to train the STT technology. Nisbet et al. [60] further noted that the pupils' motivation to use STT tended to be rated "good" or "excellent", and there was little difference between successful and unsuccessful pupils in relation to motivation. Learning to use STT was described as hard work and at times frustrating, therefore pupils and students had to be prepared to put in a lot of effort to get useful results [60].

In the last report by Lawson and Nisbet [61], teachers were asked to rate how likely it was that their pupils could use STT in an exam setting. Fifty-four percent indicated "maybe", 28% said "yes", 17% said "no" and 5% did not respond. Teachers reported advantages such as the opportunity to overcome concerns about spelling, higher independence and self-esteem, and that the pupils wrote faster with STT compared to writing by hand or typing. Reported disadvantages include that STT did not work as well for pupils with indistinct speech and that some pupils did not enjoy being "put on the spot", as they experienced pressure to produce text.

The dissertation by Mader [62] aimed to study how STT influences the quality of written composition and affect attitudes and self-perceptions towards writing. Findings suggest that STT can assist students with learning disabilities to produce better written products and it positively affects attitudes and self-perceptions towards writing. In the pre-printed article, Levine et al. [63] explored use of STT among general education English Language Arts students in two high schools. Their findings showed that STT could serve as an accessible alternative mode of composition for some high school students and were especially useful for students with writing related learning disabilities. Additionally, they saw that students with learning disabilities were more likely to use STT than other groups, and that the students preferred to use STT for drafts as opposed to revisions. A final finding from Levine et al. [63] was that older students were less likely than younger students to use STT in the classroom.

Discussion

This scoping review presents a small, yet important, collection of studies on how pupils with LD use STT in secondary education. Research on STT is clearly still in its infancy. Only eight peer-reviewed studies and five publications of grey literature met the inclusion criteria. Due to widely varying research aims, designs, and quality of studies, results are difficult to synthesise. The current review finds that existing research on STT for pupils with LD in secondary education has primarily focused on STT as an assistive technology to enable pupils to produce texts with fewer errors and more content, rather than an instructional tool aiming to improve reading and writing related skills across modalities.

STT as an instructional technology

The two studies [53,57] that assessed STT in relation to writing related skills, found significant gains on reading comprehension, word recognition and in spelling for the group using discrete speech recognition. It appears that these distinct STT approaches may have slightly unique advantages. In general, these studies suggest that STT can produce remedial effects in selected literacy skills. Lange, Mulhern, and Wylie [67] describe remedial effects as intentions to improve basic skills directly, while the compensatory effect aims to enable pupils to complete tasks on their own when using the technology. Edyburn [28] argues for a dynamic approach to determining when assistive technology can be considered either remediation or compensation. The degree of compensation must be adjusted over time and considered in relation to the learner's ability to develop writing skills and their need for support.

Higgins and Raskind [53] focus on the remedial effect of STT (as instructional technology) and did not measure its compensatory effectiveness (as assistive technology). They report that STT could potentially be used to improve reading comprehension, word recognition, and spelling among students with LD. However, we did not find any studies that considered the remedial effect of STT with respect to writing related skills for LD and NLD pupils. It is noteworthy that spelling is the only specific writing measure included in the studies of STT as an IT [53,57]. The other measures are termed *writing related* skills, such as reading proficiency and cognitive prerequisites for literacy (e.g., metacognitive ability, short-term memory). Thus, there is a significant need for more research on STT as an instructional technology with LD students, and especially on its effect on writing skills.

STT as an assistive technology

It is promising that MacArthur and Cavalier [25] and Quinlan [54] suggest that STT can be an effective assistive technology for improving writing performance among LD pupils in comparison to other modalities. However, the benefit to NLD pupils in secondary education was found to be minimal or non-existent. This is similar to the findings of Haug and Klein [68] who examined

the use of STT compared to handwriting to teach argumentative writing among 45 NLD pupils in 5th grade. No significant differences were found between the two groups with respect to either the quality of texts or pupils' perceptions of required effort. Yet, all students demonstrated gains in the variety and quality of arguments under both conditions. MacArthur and Cavalier [25] and Quinlan [54] describe improved writing performance and higher holistic text quality for pupils with LD; they report that less fluent writers displayed fewer surface errors using STT. This is in line with research in elementary school on the use of STT as an assistive technology for English language instruction [32] and as an approach to promote idea generation [58]. That younger pupils and pupils with LD have similar benefits of STT as an assistive technology, may be due to similarities among the two groups with respect to limited working memory and transcription skills that are not yet fully developed [32].

Nordström et al. [23] and Ok et al. [55] did not directly measure STT's influence on writing processes. However, these two explorative studies provide insights about how STT might be effectively implemented in classrooms as an assistive technology. Both studies [23,55] underline the importance of adequate support. For example, Ok et al. [55] suggest that environmental support, device support, and instructional support facilitate the integration of STT in everyday use. Cited environmental supports include the need for a quiet place, a comfortable environment for speaking out loud and a stable internet connection. Device support entails appropriate hardware (e.g., headphones with microphones) and software with high speech recognition accuracy. Instructional support includes the opportunity to practice verbal skills, learning to edit and providing scaffolding for writing and editing, such as checklists and prompts.

Acceptability and usability

Across the five peer-reviewed studies that examined teachers', parents', and pupils' experiences with STT [23,25,55,57,58], acceptability and perceived usability of the technology was generally high. Findings suggest that the majority of students were motivated to use STT [25,57,58] and that many pupils with LD continued using it after interventions had ended. It is further encouraging that pupils [25,55], teachers [23,55], and special educators [23] perceived STT to have a positive impact on the quality of student writing, in particular with respect to spelling.

However, not all participants in the reviewed studies preferred STT to traditional approaches. Students with more severe reading and writing difficulties [25,57] and younger students were more positive than were older students and students without difficulties [23,55]. Ok et al. [55] suggest that younger pupils may experience less frustration when adopting STT, as they more easily assimilate it into the writing process because they have not yet established other strategies to address challenges they encounter in spelling, grammar, and text production. Differences among students with respect to the perceived effectiveness and usefulness of STT indicate that while it can be a tool for promoting engagement in writing, it is not necessarily equally suited for all learners. In addition, there is little evidence from the current review to indicate that student motivation derived from STT use is transferred to writing in other modalities [23].

The challenges that study participants reported can be broadly grouped into three categories: technical, contextual, and emotional barriers. Technical challenges comprise elements that are inherent in the technology itself, such as word recognition errors, the time required to train or set up the system, and the effort needed to revise and correct mistakes that pupils do not normally make when writing by hand or on a keyboard [25,58]. Contextual factors include concerns such as teachers', pupils', and parents' lack of competency in using the tool, students' inappropriate use of the technology, and questions about when and where to use it without distracting other pupils [55,58]. Emotional difficulties include students feeling embarrassed or as though they are "cheating" when they use STT, and feelings of anxiety or frustration with the technology [25,53,55,57]. While the overall evidence gained from the current review pertaining to the acceptability and usability of STT is encouraging, it is clear that it is not yet a tool that teachers and pupils can implement without sufficient preparation, time, and ongoing support [23,58]. Since the invention of STT decades ago, the quality of the technology has improved substantially. Continued technological developments in STT may potentially resolve many of the challenges we see today. However, there remain a number of areas that require further exploration and where the current research base is insufficient.

Weaknesses in the literature

The studies included in this review employ diverse methodological approaches, which infer different claims about the knowledge that can be acquired, as well as the implications of research findings. The capacity of researchers and educators to make generalizations based on the outcomes of these studies is limited both by the extent of evidence available and the reliability and validity of this evidence. Thus, it is important to also consider the quality of the studies in this review. However, assessment of study quality is a contested issue [69,70]. Davies, Nutley and Smith [71] describe a methodological hierarchy for quantitative methods where some study designs are considered to provide more robust evidence of effectiveness than others. In traditional methodological hierarchies, high-quality secondary research is preferred to single studies, randomised experiments over quasi-experiments, and experimental research is seen as superior to observation [71].

Newman and Gough [70,p.13] present three elements to consider in critical appraisal of studies: "[1] the appropriateness of the study design in the context of the review in question, [2] the quality of the execution of the study methods and [3] the study's relevance to the review question". The studies in this review have designs that are appropriate and relevant to examine the research questions that they seek to answer, yet these designs vary in quality and differ with respect to the knowledge-claims that they can make. Particularly with respect to grey literature, the assumptions regarding quality assurance inherent in the peer-review process are per definition absent. Thus, it is not surprising that these publications tend to be less robust and of lower scientific quality.

Only two studies [53,57] employed experimental designs with randomised sampling, pretests, posttests, and comparison groups. One study [56] conducted pre- and posttests and employed a single case design with alternating treatments. Two studies [25,54] tested pupils only after the intervention and had two groups (LD pupils and NLD pupils) using different writing modalities. Three studies [23,55,58] labelled their designs as explorative, which is an approach that does not allow the researcher to draw robust conclusions about the effectiveness of using STT. Instead, the aim of these studies was to explore parents', teachers', and pupils' experiences with introducing STT to reading and writing activities in secondary education.

In summary, we find that both the quantity and the quality of research investigating the use of STT among adolescents with LD is currently insufficient to make strong recommendations for

educational practice. This is in line with claims by Haug and Klein [68], and Peterson-Karlan [49] who argue that STT may not yet be considered an evidence-based writing approach as there are not enough high-quality studies. Nonetheless, based on the findings of this review, we can suggest indications as to what is needed in future research and propose tentative recommendations for practice.

Recommendations for research and practice

Based on this review, it is evident that the use of STT provides opportunities and challenges for writers with learning difficulties in secondary education. While only eight peer-reviewed articles and five publications of grey literature were identified, the findings are generally promising. The results suggest that STT may increase a pupil's ability to produce texts with fewer errors, provide help with spelling and improve reading comprehension and word recognition. With respect to the reported experiences of pupils, teachers, and parents; it is clear that educators need to evaluate and customise how learners adapt to STT. The degree of compensation must be adjusted over time and considered in relation to the learner's ability to develop their writing skills and their specific needs for support. Professionals must carefully evaluate the age at which struggling writers should be introduced to STT, taking into consideration that pupils appear to be more positive towards STT at an earlier age.

The distinction between using STT as primarily an assistive or instructional technology also needs to be further explored and is, to date, poorly accounted for in the literature. Evidence indicates that NLD students are not negatively impacted by using STT and may even receive specific benefits. Thus, further investigation of STT implementation among different groups of students in the same classroom is warranted. It is possible that students would be more willing to adopt STT if it were introduced as a writing approach in a full class setting including both LD and NLD students. Nonetheless, findings highlight the need for support in all phases of implementation of STT in secondary education and emphasize the importance of collaboration between school and home regarding technology and writing strategies.

Limitations

Findings should be considered in light of the limitations of the current study. This scoping review only includes studies on struggling writers in secondary education published from January 2000 to April 2022. The period could have been extended to include earlier studies on STT, as well as older and younger users, to show that both effect studies and explorative studies have been conducted on STT in primary and higher education for several decades [19,68]. However, in the last 20 years, the technology has changed dramatically, and we determined that studies using older versions of software, very different methodologies, and widely diverse student groups (with substantial variations in learning objectives) would be too expansive and limit the reliability and quality of the current review.

In addition, we chose to separate the process of writing from the process of reading. While these processes are intertwined, they are different. We sought to isolate one kind of assistive technology from other technologies to analyse specific aspects of writing related skills rather than to describe a variety of digital writing activities in the secondary classroom. This is a further challenge in the current review, as it was difficult to isolate the effects of using STT alone, given that many of the studies used STT in combination with other approaches. Students often use spell-check, digital mind maps, text-to-speech (speech synthesis) and other kinds of assistive technologies in addition to STT, engaging in a range of compensatory tools for writing *and* reading activities. Future reviews may benefit from including examinations of the implementation, user experiences, and effects of these and other technologies in combination, as well as their differential effects on both writing and reading outcomes.

Conclusion

With only eight peer-reviewed studies included in this scoping review, it is evident that there is a need for more robust research on the use of STT in secondary education before a systematic review can provide further insights into its effects on writing related skills and performance for struggling writers. There is a significant need for more international research, as all the identified studies were conducted in just three countries: Sweden, the United States and Scotland. The accuracy of the technology varies between different languages; thus, accuracy is an important variable when assessing pupil's texts and experiences of using STT in education. In the current era of rapidly developing educational technology, research is needed to discover how STT influences struggling adolescent writers in educational settings as the quality of the technology improves and STT is acknowledged as another legitimate tool for writing.

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References

[1] Rack J, Hulme C, Snowling M, et al. The role of phonology in young children learning to read words: the direct-mapping hypothesis. J Exp Child Psychol. 1994;57(1):42–71.
[2] Berninger VW, Amtmann D. Preventing written expression disabilities through early and continuing assessment and intervention for handwriting and/or spelling problems: research into practice. In Swanson HL, Harris KR, Graham S, editors. Handbook of learning disabilities. New York (NY). Guilford Press; 2003. p. 345–363.
[3] Hayes JR, Chenoweth NA. Is working memory involved in the transcribing and editing of texts? Written Commun. 2006;23(2):135–149.
[4] Berninger VW, Abbott RD, Nagy W, et al. Growth in phonological, orthographic, and morphological awareness in grades 1 to 6. J Psycholinguist Res. 2010;39(2):141–163.
[5] Graham S, Harris KR, Mason L. Improving the writing performance, knowledge, and self-efficacy of struggling young writers: the effects of self-regulated strategy development. Contemp Educ Psychol. 2005;30(2):207–241.
[6] Ivanič R. Discourses of writing and learning to write. Lang Educ. 2004;18(3):220–245.

[7] O'Rourke L, Connelly V, Barnett A, et al. Use of spellcheck in text production by college students with dyslexia. J Writing Res. 2020;12(1):35–61.
[8] Bereiter C, Scardamalia M. The psychology of written composition. Hillsdale (NJ): L. Erlbaum Associates. 1987.
[9] Zimmerman BJ, Risemberg R. Becoming a self-regulated writer: a social cognitive perspective. Contemp Educ Psychol. 1997;22(1):73–101.
[10] Alexander PA. The nature of disciplinary and domain learning: the knowledge, interest, and strategic dimensions of learning from subject-matter text. In: Hynd CR, editor. Learning from text across conceptual domains. Boca Rato (FL): Routledge; 1998. p. 263–287.
[11] Hayes JR, Berninger V. Cognitive processes in writing: a framework. In: Arfé B, editor. Writing development in children with hearing loss, dyslexia, or oral language problems: implications for assessment and instruction. New York (NY): Oxford University Press; 2014. p. 3–15.
[12] Connelly V, Dockrell J. Writing development and instruction for students with learning disabilities: using diagnostic categories to study writing difficulties. In: MacArthur CA, Graham S, Fitzgerald J, editors. Handbook of writing research. New York (NY): The Guilford Press; 2016. p. 349–363.
[13] Lyon GR, Shaywitz SE, Shaywitz BA. A definition of dyslexia. Ann Dyslexia. 2003;53(1):1–14.
[14] Newcomer PL, Barenbaum EM. The written composing ability of children with learning disabilities: a review of the literature from 1980 to 1990. J Learn Disabil. 1991;24(10): 578–593.
[15] Ewoldt KB. Productivity apps supporting higher order writing skills for secondary students with learning disabilities. Intervention School Clin. 2018;53(5):313–320.
[16] Pieraccini R, Lubensky D. Spoken language communication with machines: the long and winding road from research to business. International conference on industrial, engineering and other applications of applied intelligent systems. Springer, Berlin, Heidelberg, 2005.
[17] Brown C. Computer access in higher education for students with disabilities. Washington (DC): US Department of Education, Fund for the Improvement of Postsecondary Education; 1987.
[18] Raskind M. Assistive technology and adults with learning disabilities: a blueprint for exploration and advancement. Learn Disabil Q. 1993;16(3):185–196.
[19] Raskind MH, Higgins E. Effects of speech synthesis on the proofreading efficiency of postsecondary students with learning disabilities. Learn Disabil Q. 1995;18(2):141–158.
[20] Tang KW, Kamoua R, Sutan V, et al. Speech recognition technology for disabilities education. J Educ Technol Syst. 2004;33(2):173–184.
[21] Evmenova AS, Regan K. Supporting the writing process with technology for students with disabilities. Intervention School Clin. 2019;55(2):78–85.
[22] O'Hare EA, McTear MF. Speech recognition in the secondary school classroom: an exploratory study. Comp Educ. 1999;33(1):27–45.
[23] *Nordström T, Nilsson S, Gustafson S, et al. Assistive technology applications for students with reading difficulties: special education teachers' experiences and perceptions. Disabil Rehabil Assist Technol. 2019;14(8):798–808.
[24] Yu D, Deng L. Automatic speech recognition. A deep learning approach. London: Springer; 2016.
[25] *MacArthur CA, Cavalier AR. Dictation and speech recognition technology as test accommodations. Except Children. 2004;71(1):43–58.
[26] Orsmond GI, Cohn ES. The distinctive features of a feasibility study: objectives and guiding questions. OTJR. 2015; 35(3):169–177.
[27] Peterson-Karlan G, Hourcade JJ, Parette P. A review of assistive technology and writing skills for students with physical and educational disabilities. Phys Disabil Educ Relat Serv. 2008;26(2):13–32.
[28] Edyburn DL. Assistive technology and mild disabilities. Spec Educ Technol Pract. 2006;8(4):18–28.
[29] MacArthur CA. Reflections on research on writing and technology for struggling writers. Learn Disabil Res Pract. 2009; 24(2):93–103.
[30] Shadiev R, Hwang WY, Chen NS, et al. Review of speech-to-text recognition technology for enhancing learning. J Educ Technol Soc. 2014;17(4):65–84.
[31] Pennington J, Ok MW, Rao K. Beyond the keyboard: a review of speech recognition technology for supporting writing in schools. Int J Educ Media Technol. 2018;12(2): 47–55.
[32] Arcon N, Klein PD, Dombroski JD. Effects of dictation, speech to text, and handwriting on the written composition of elementary school english language learners. Reading Writing Q. 2017;33(6):533–548.
[33] Berninger VW, Nagy W, Tanimoto S, et al. Computer instruction in handwriting, spelling, and composing for students with specific learning disabilities in grades 4–9. Comput Educ. 2015;81:154–168.
[34] Edyburn DL. Rethinking assistive technology. Spec Educ Technol Pract. 2003;5(4):16–23.
[35] Rose DH, Meyer A. Teaching every student in the digital age: universal design for learning. Alexandria (VA): Association for Supervision and Curriculum Development; 2002.
[36] Lenker JA, Paquet VL. A review of conceptual models for assistive technology outcomes research and practice. Assist Technol. 2003;15(1):1–15.
[37] Watkins A. Model policy for inclusive ICTs in education for persons with disabilities. Paris: UNESCO; 2014.
[38] U.S. Department of Education, Office of Educational Technology. Future ready learning: reimagining the role of technology in education. Washington (DC): U.S. Department of Education, Office of Educational Technology; 2016. http://tech.ed.gov/netp/
[39] UNESCO. ICT in Education for People with Special Needs. Specialized training course Moscow. 2006. https://iite.unesco.org/publications/3214644/.
[40] Cochrane D, Key K. Speech recognition as AT for writing. A guide for K-12 education. 2016. https://www.lwsd.org/uploaded/Website/Programs_and_Services/Special_Education_and_504/Assistive_Technology/Speech_Recognition_as_AT_for_Writing_A_Guide_for_K12.pdf.
[41] Edyburn DL. 1999 in review: a synthesis of the special education technology literature. J Spec Educ Technol. 1999; 15(1):7–18.
[42] Edyburn DL. 2000 in review: a synthesis of the special education technology literature. J Spec Educ Technol. 2001; 16(2):5–25.
[43] Edyburn DL. 2001 in review: a synthesis of the special education technology literature. J Spec Educ Technol. 2002; 17(2):5–24.

[44] Edyburn DL. 2002 in review: a synthesis of the special education technology literature. J Spec Educ Technol. 2003; 18(3):5–28.
[45] Edyburn DL. 2003 in review: a synthesis of the special education technology literature. J Spec Educ Technol. 2004; 19(4):57–80.
[46] Perelmutter B, McGregor KK, Gordon KR. Technology interventions for adolescents and adults with learning disabilities: an evidence-based systematic review and meta-analysis. Comput Educ. 2017;114:139–163.
[47] Pandya JZ, Avila J. Inequitable variations: a review of research in technology, literacy studies and special education. Literacy. 2017;51(3):123–130.
[48] Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med. 2018;169(7):467–473.
[49] Peterson-Karlan GR. Technology to support writing by students with learning and academic disabilities: recent research trends and findings. Assistive Technol Outcomes Benefits. 2011;7(1):39–62.
[50] Schardt C, Adams MB, Owens T, et al. Utilization of the PICO framework to improve searching PubMed for clinical questions. BMC Med Inform Decis Mak. 2007;7:16.
[51] Kitzing P, Maier A, Åhlander VL. Automatic speech recognition (ASR) and its use as a tool for assessment or therapy of voice, speech, and language disorders. Logoped Phoniatr Vocol. 2009;34(2):91–96.
[52] Flanagan S, Bouck EC, Richardson J. Middle school special education teachers' perceptions and use of assistive technology in literacy instruction. Assist Technol. 2013;25(1): 24–30.
[53] *Higgins EL, Raskind MH. Speaking to read: the effects of continuous vs. discrete speech recognition systems on the reading and spelling of children with learning disabilities. J Spec Educ Technol. 1999;15(1):19–30.
[54] *Quinlan T. Speech recognition technology and students with writing difficulties: improving fluency. J Educ Psychol. 2004;96(2):337–346.
[55] *Ok MW, Rao K, Pennington J, et al. Speech recognition technology for writing: usage patterns and perceptions of students with high incidence disabilities. J Spec Educ Technol. 2022;37(2):191–202.
[56] *Noakes M, Schmitt AJ, McCallum E, et al. Speech-to-text assistive technology for the written expression of students with traumatic brain injuries: a single case experimental study. Sch Psychol. 2019;34(6):656–664.
[57] *Svensson I, Nordström T, Lindeblad E, et al. Effects of assistive technology for students with reading and writing disabilities. Disabil Rehabil Assist Technol. 2021;16(2): 196–208.
[58] *Jeffs T, Behrmann M, Bannan-Ritland B. Assistive technology and literacy learning: reflections of parents and children. J Spec Educ Technol. 2005;21(1):37–44.
[59] *Nisbet P, Wilson A. Speech recognition in schools. Using ViaVoice. Call Centre. Edinburgh: The University of Edinburgh; 2002.
[60] *Nisbet P, Wilson A, Balfour F. Speech recognition in schools. Using NaturallySpeaking v 9. Call Scotland. Edinburgh: The University of Edinburgh; 2008.
[61] *Lawson S, Nisbet P. Talking in exams project report. Edinburgh: The University of Edinburgh; 2016.
[62] *Mader CL. The effects of speech recognition technology on the writing skills and attitudes of adolescents with learning disabilities [dissertation]. Morgantown (WV): West Virginia University; 2007.
[63] *Levine S, Hsieh H, Southerton E, et al. How high school students used speech-to-text as a composition tool. 2022. 55 p. SSRN: https://ssrn.com/abstract=4181906.
[64] Rumrill PD Jr, Cook BG, Wiley AL. Research in special education: designs, methods, and applications. 2020. https://eric.ed.gov/?id=ED516426
[65] Cresswell JW. Educational research: planning, conducting and evaluating quantitative and qualitative research. Essex: Pearson; 2014.
[66] Lincoln Y, Guba E. Naturalistic inquiry. Beverly Hills, CA: Sage; 1985.
[67] Lange AA, Mulhern G, Wylie J. Proofreading using an assistive software homophone tool: compensatory and remedial effects on the literacy skills of students with reading difficulties. J Learn Disabil. 2009;42(4):322–335.
[68] Haug KN, Klein PD. The effect of speech-to-text technology on learning a writing strategy. Reading Writing Q. 2018; 34(1):47–62.
[69] Waddington H, Aloe AM, Becker BJ, et al. Quasi-experimental study designs series – paper 6: risk of bias assessment. J Clin Epidemiol. 2017;89:43–52.
[70] Newman M, Gough D. Systematic reviews in educational research: methodology, perspectives and application. In Zawacki-Richter O, Kerres M, Bedenlier S, et al., editors. Systematic reviews in educational research. Wiesbaden (Germany): Springer VS; 2020. p. 3–22.
[71] Davies H, Nutley S, Smith P. Introducing evidence-based policy and practice in public service. In Davies H, Nutley S, Smith P, editors. What works? Evidence-based policy and practice in public services. Bristol: The Policy Press; 2000. p 1–1126.