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Systematic Review of Studies Addressing Computer-Assisted Instruction for Students with Visual Impairment

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Abstract

Computer-assisted instruction (CAI) gives students with visual impairment (VI) immediate access to information and enables direct collaboration with sighted educators and peers. This systematic review examined interventions addressing the impact of CAI interventions on school-age children with VI. Twenty-eight studies examined CAI interventions implemented with 339 students with VI. The CAI interventions fell into five categories: digital texts, word processors, haptic simulations, educational platforms, and serious games. Findings from this review highlight the need for: (a) addressing students' preparation or mastery for technology skills needed to participate in CAI; (b) more diverse recruitment of participants with VI; and (c) incorporating educators as implementers of CAI. Implications for practice and research are also addressed.

Keywords

assistive technology, blindness, compensatory skills, computer-assisted instruction, exceptionality, technology perspectives, visual impairment

An estimated 700,000 students with visual impairment (VI) are served in U.S. schools (Erickson et al., 2017). One of the fundamental impacts of VI on children's development is limited access to information (Wolffe, 2017). For example, Barraga and Erin (2001) note that vision provides the information individuals need for spatial awareness, incidental learning, and social motivation. Moreover, students with VI who attend general education classes face the challenge of accessing information designed to appeal primarily to visual learners (Bardin & Lewis, 2008). Indeed, most students with VI (68.2%) are served in general education classrooms (U.S. Department of Education, 2021). However, many students with VI face challenges of accessibility with regard to accessing information and instruction. Specifically, students lack the needed technology and support to access all aspects of instruction due to limited educator knowledge, teacher training, and costs of technology (Brown et al., 2013).

Researchers and educators have long touted instructional and assistive technology (AT) as a tool for increasing participation and access to information for students with VI. For example, Abner and Lahm (2002) highlighted how advances in technology at the turn of the century provided students with VI new means for writing and editing papers, conducting research, gaining access to information, and developing job skills. Students with blindness can now communicate through email, connect to the Internet, navigate educational applications, and download classwork without waiting for a transcriber to produce materials in braille. Access to this technology enables students with VI to participate more fully and meaningfully in ongoing class activities.

Computers are a form of technology that hold particular promise for addressing students' access needs within the classroom. Computer-assisted instruction (CAI) is an intervention approach whereby computers—such as desktops, laptops, or tablets—are a central component of providing students access to academic content and instruction. Examples of CAI include using a word processer application on a computer to practice writing skills (e.g., editing or spelling) or learning the braille code using an application on a tablet. One critical component in CAI interventions for students with VI is assistive software, such as screen readers or screen magnification programs. Assistive software facilitates access to information on computers or tablets by adapting media into more accessible formats (e.g., enlarged print, audio, braille). CAI has the potential to benefit students with VI in several important ways. First, CAI can provide students faster access to information. New developments in technology have

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enhanced the input and output of devices to meet a broader array of students' visual, auditory, and braille needs. Second, these technologies can increase direct collaboration with educators and peers. This can promote independence in integrated classrooms. Third, computers allow for further individualization of instruction through data-driven learning. Computers can collect and process data faster than educators and adjust instructional materials instantaneously. For example, some applications can change the sequence of activities within lessons based on each student's performance. Instruction is reordered based on student readiness and need rather than a rigid curriculum scope and sequence. Fourth, computers are integral tools used in a wide variety of potential careers. Promoting computer use throughout students' education provides opportunities to develop computer skills needed for future employment. For example, McDonnall and Crudden (2009) documented a strong relationship among AT use and the employment of individuals with VI.

To date, a systematic review of CAI for students with VI has not yet been conducted (Ferrell et al., 2014). Such a review could identify a range of technologies and strategies for carrying out this intervention approach. One of the barriers to incorporating technology into the classroom is teachers' lack of knowledge and resources (Abner & Lahm, 2002). Identifying the various ways CAI can be implemented with students may help further shape technology usage in classrooms. Moreover, a review of CAI could identify strategies for teaching students the technology skills needed to use computer devices. It is unclear how TVIs address student training in this area, as the complexity of computers may require explicit instruction on a range of skills. Additionally, a review of CAI would also inform whether interventions have been applied across the diverse instructional and support needs of students with VI. Such information would identify for whom and under which conditions CAI interventions benefit these students.

This review examined descriptive and experimental CAI studies implemented with students with VI. Our research questions are as follows: (1) What are the characteristics of the students and settings in CAI studies? (2) What are the characteristics (e.g., devices/software, training, procedures, and implementers) of CAI interventions? (3) What types of academic outcomes are addressed in CAI studies? (4) What is the impact and perceptions of CAI, as described in this literature?

Method

Inclusion Criteria

Studies included in this review were required to meet five criteria. First, studies descriptively or experimentally examined a CAI intervention. To be considered CAI, the instructional activity of an intervention had to primarily occur on the computer (e.g., learning vocabulary definitions on a tablet application; Root et al., 2017). Therefore, we did not identify interventions as CAI when devices were used merely to prompt students or as a subcomponent of an intervention. Electronic canes used during walks (Cheng, 2016) and talking calculators used with paper assessments (Bouck et al., 2011) were forms of AT excluded from this review. Second, studies examined the implementation of CAI and also collected student outcome data. This included both descriptive studies, pre-post studies, and those with a comparison condition. Studies must have satisfied the following criteria: (a) students were introduced to a new device, software, or application; and (b) studies compared changes in student performance at multiple time points or performance using another learning medium (e.g., paper text or teacher-delivered instruction). We excluded studies that only compared two computers to each other or compared variations in the features/settings of devices. Third, more than 50% of participants in studies must have been school-age elementary or secondary students (ages 5–22) identified with VI. Fourth, studies examined academic outcomes for these students. Academic outcomes included skills and activities related to a core general curriculum content area (i.e., math, science, social studies, and language arts). For example, reading speed and writing quality were considered academic outcomes because they are commonly associated with language arts standards. Fifth, studies had to be published in English in a peer-reviewed journal.

Search Procedures

We used four search techniques to identify relevant research articles. Search procedures followed PRISMA guidelines for reporting systematic reviews (see Figure 1). First, we conducted a hand search of four salient journals for all available years published: Assistive Technology, British Journal of Visual Impairment, Journal of Special Education Technology, and Journal of Visual Impairment and Blindness. Second, we searched four electronic databases: Education Full Text [ERIC], Social Science Database, ProQuest Dissertations and Theses Global, and PsycINFO. We used a combination of terms for instructional technology (i.e., "computer-assisted instruction" OR computer* OR laptop* OR tablet* OR microcomputer* OR software* OR tablet* OR touchscreen* OR "refreshable braille" OR "personal digital assistant*" OR "digital text" OR"digital textbook" OR "digital textbooks" OR "digital text" OR etext) and disability category (i.e., "visual impairment" OR "visual impairment"OR "visually impaired" OR blind* OR deafblind* OR "low vision" OR "visually handicapped"). Third, we reviewed the references of all identified articles (i.e., backward search). Fourth, we examined studies citing each of the identified articles (i.e., forward search).

Screening Procedures

The initial search yielded 3521 article citations across the four databases. We screened titles and abstracts of all citations

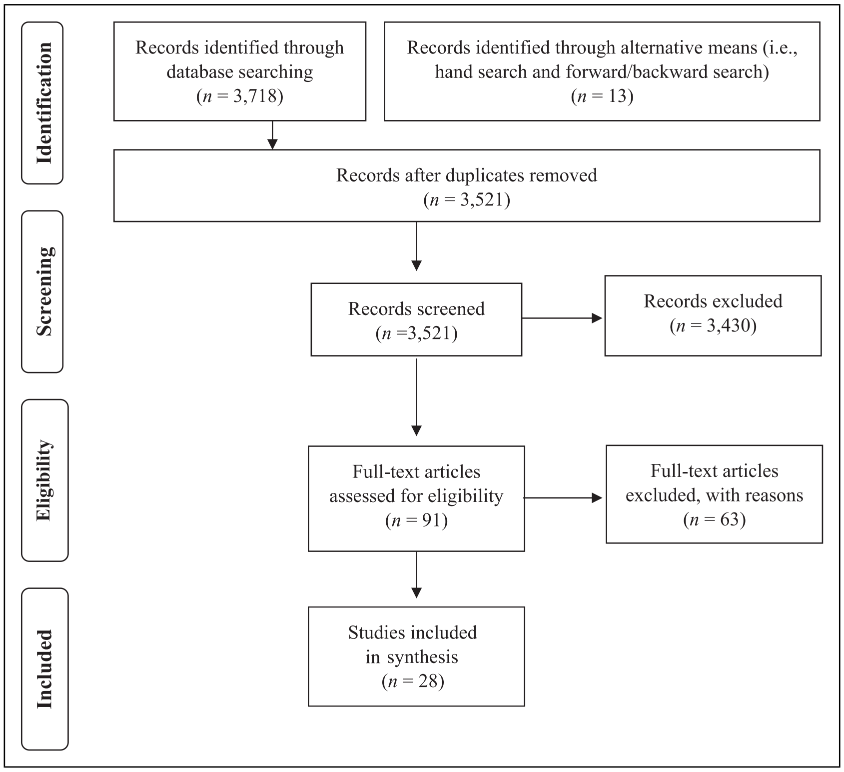

Figure 1. PRISMA diagram depicting the screening procedures used to locate and exclude studies. Source from Moher et al. (2009). Copyright held jointly by the authors. *Note.* The chart lists the steps in the screening process and the number of studies identified or remaining after each step.

using Abstrackr (i.e., an online review-screening tool). This online software allowed us to rate citations as included or excluded, tracking multiple raters for inter-observer agreement (IOA). In this phase, we retained articles that fit the inclusion criteria and questionable articles that needed further review, which resulted in 91 articles. We then reviewed the full text of the remaining articles using the same inclusion criteria, which resulted in 26 articles. Finally, we applied forward and backward search techniques, which resulted in two additional articles for a total of 28. A doctoral student in special education served as a second rater. She independently screened 20% of the initial search results (n = 743 articles). Raters had 13 disagreements (98.3% reliability). All studies disagreed upon moved on to full-text screenings. The same rater screened 20% of the remaining 91 articles (n = 19 articles) during the full-text screening. No disagreements occurred during the full-text screening (100% reliability).

Coding Procedures

We coded variables addressing five aspects of the studies: (a) student characteristics, (b) setting characteristics, (c) characteristics of CAI, (d) student outcomes, and (e) study design. For a summary of codes, see Table 1. If some students in a study did not meet the inclusion criteria, we only coded information for students who met the inclusion criteria (i.e., students ages 5 to 22 with a VI). For severity of visual impairment, we coded students based on the federal definitions for VI when acuities were provided (Varma et al., 2004). Otherwise, we used labels provided by the authors. When authors did not report information related to a particular variable, we reported the variable as unknown.

Setting Characteristics

For instructional settings, we defined pullout spaces as rooms where only adults and the student were present. Core content classrooms were defined as classes that focused on delivering content related math, science, social studies, or language arts. Self-contained classrooms were defined as classrooms where a special educator was the primary educator.

Characteristics of Computer-Assisted Instruction

Characteristics of CAI examined codes related to five aspects of interventions: (a) components of the intervention, (b) dosage, (c) characteristics of implementers, (d) fidelity of implementation, and (e) technology training procedures. Components of the intervention, dosage, characteristics of implementers and procedural fidelity all focused on information reported for the primary CAI interventions (i.e., the sessions students used devices). We also coded similar

Table 1. Article Codes and Classifications.

Code	Classifications
Student characteristics	
Age	Truncated to the nearest year reported
Sex	Female, male
Race/ethnicity	African American, Asian, Biracial, Caucasian, Hispanic, Native American, other
Severity of visual impairment*	Total blindness, legal blindness, low vision, cortical visual impairment, other (e.g., medically diagnosed diplopia)
Primary learning medium	Braille, regular print, large print, audio, an alternative learning medium
Presence of additional disabilities	Listing of any additional disabilities reported by authors
Setting characteristics	
School type	Integrated school, state school for the blind, non-school setting
Instructional setting	Core content classroom, self-contained classrooms, pullout room, home, other
Components of the intervention	
Devices	Desktop, laptop, tablet, specialized device, other
Assistive software	Name and type of software included in the intervention
Assessment	Formal assessments, informal assessments, student preference
Inclusion criteria	Whether or not studies reported mastery of technology as an inclusion criterion
Dosage	
Intervention condition	A week or less, between 1 week and 1 month, between one and 3 months, more than 4 months
Intervention sessions	Less than 10 min, between 10 to 29 min, between 30 to 59 min, between 60 to 90 min, more than 90 min
Characteristic of implementers	
Role of interventionist	Researchers, special educators, general educators, paraprofessionals, peers, other personnel
Interventionist training	Whether or not training was reported as being provided to the interventionist
Fidelity of implementation	
Conducted fidelity measures	Whether or not fidelity measures were collected
Fidelity measures met criterion	Whether or not fidelity of implementation was reported to be 90% or greater
Technology training procedures	
Materials	Listing of materials used to conduct training
Technology skills	Listing of technology skills described by authors
Training condition	A week or less, between 1 week and 1 month, between one and 3 months, more than 4 months
Training sessions	Less than 10 min, between 10 to 29 min, between 30 to 59 min, between 60 to 90 min, more than 90 min
Role of trainer	Researchers, special educators, general educators, paraprofessionals, peers, other personnel
Trainer preparation	Whether or not studies reported technology trainers received training as a part of the study
Conducted fidelity measures	Whether or not technology training fidelity measures were collected
Fidelity measures met criterion	Whether or not technology training fidelity of implementation was reported to be 90% or greater
Role of stakeholders	Researchers, special educators, general educators, paraprofessionals, peers, or other personnel
Type of perspectives	Perceived importance of the goals, perceived feasibility of procedures, perceived positive impact on outcomes, or preference for technology
Study design	
Experimental design	Randomized-control trial, quasi-experimental group designs, single-case designs
Experimental analysis	Demonstration, comparison
Types of data	Assessments, observations, interviews, surveys

Note. *If the authors provided acuities of students, we coded students based on the federal definitions for VI (Varma et al., 2004). Otherwise, we used labels provided by the authors.

information about technology trainings when studies reported how students learned to use devices prior to the implementation of the intervention. Several coding definitions and procedures are expanded upon below.

First, we defined type of assessment as: (a) *formal assessments* as a named protocol, (b) *informal assessments* as a personally developed protocol, or (c) *student preference* as the student choosing the device or adjusted the device settings. Second, devices that were designed solely for students with VI were coded as specialized (e.g., braille notetakers; Kamei-Hannan et al., 2020). Third, we coded the shortest duration of a condition or intervention session within a study when coding dosage. Finally, when coding type of analyses used in studies, we labeled studies as comparison studies when CAI was compared to traditional instruction. Studies were labeled demonstration studies when comparing student performance before and after the intervention.

When summarizing the characteristics of CAI, we identified five categories of similar interventions: (a) digital texts (n = 6 studies; 21.4%), (b) word processors (n = 5 studies; 17.9%), (c) haptic simulations (n = 4 studies; 14.3%); (d) educational platforms (n = 10 studies; 35.7%), and (e) serious games (n = 3 studies; 10.7%). Digital texts enhanced student's interaction with a text through electronic features—such as highlighting text, adjusting contrast, changing reading speeds, or adjusting pitch—or access to refreshable braille. Enhancements allowed students to interact with text based on their visual needs to increase their reading speeds and comprehension. Word processors contained standard features, such as document creation, storage, and sharing; text editing (e.g., copying, pasting, and deleting), and text formatting (e.g., font selection, bolding, underlining, or italicizing). Word processors were primarily used to complete assignments, promote independence in core content classes, or increase students' writing quality. Haptic simulations were interventions in which visual models or images were converted to another medium (e.g., tactile or auditory). Most studies converted math graphics to vibrations activated by touch or auditory feedback. For example, one haptic simulation allowed students to explore a visual image through vibrations on a tablet generated when their fingers were contacting the line (Landau et al., 2003). Educational platforms used software or applications to deliver or support large units of instruction presented in a set order or delivering lessons based on student performance on previous lessons. Software often incorporated multiple methods of instruction or ways of interacting content. For example, Arslantas et al. (2019) examined a vocabulary program that presented content in four formats: instruction (i.e., definitions and examples), practice quizzes, typing exercises, and games. Serious games were instructional games designed to present educational content rather than just entertain. For example, Sanchez and Flores (2005) developed a game called AudioMath whereby students matched flashcards.

Table 2. Student Demographics.

Demographic	% (n)
Total number of students	339
Age[a]	12.4 (21.4)
Grade level	
Elementary (K-5)	8.2% (28)
Middle (6–8)	10.9% (37)
High (9–12)	12.7% (43)
Unknown	68.1% (231)
Sex	
Female	30.7% (104)
Male	37.8% (128)
Unknown	31.6% (107)
Race/ethnicity	
European American	12.7% (43)
African American	1.8% (6)
Asian American	1.5% (5)
Native or Alaskan American	0.0% (0)
Hispanic or latino/[a]	2.7% (9)
Other or multiple	0.6% (2)
Unknown	80.8% (274)
Severity of visual impairment	
Total blindness	11.5% (39)
Legal blindness	7.1% (24)
Low vision	5.9% (20)
Cortical visual impairment	0.0% (0)
Unknown	75.5% (256)
Primary learning medium	
Braille	55.2% (187)
Regular print	8.8% (30)
Large print	5.0% (17)
Audio	0.0% (0)
Alternate learning medium	0.0% (0)
Unknown	31.0% (105)

Note. The table presents the available demographic information about students extracted from studies. Percentages are calculated relative to the total number of students. The number of students coded under a specific demographic is provided in parentheses.
[a]$M(SD)$ for 79 students.

Student Outcomes

We recorded the name of each academic-related outcomes measured for students with disabilities. As a part of our inclusion criteria, we required studies to examine the impact of AT on academic outcomes. We defined academic outcomes as skills and activities that related to one of the four main areas of the general curriculum: math, science, social studies, or language arts. For example, performance on math problems and vocabulary knowledge were academic outcomes identified in studies.

Inter-rater Reliability

We collected IOA on our coding of study characteristics for 32.1% of the included articles (n = 9). The second coder was trained by reviewing a coding manual, coding with an expert coder, and independently practice coding an article. After demonstrating more than 90% agreement, independent coding of the nine articles began. The number of possible agreements was determined by the unit of analysis relevant for each item coded. For example, the maximum number of possible agreements for demographic information was based on the number of participants in the study. If there was a discrepancy in the unit of analysis (e.g., one coder identified nine participants and the other coder identified 10), the largest possible number of agreements was used as the denominator. In

Table 3. Description of Studies.

Study	Number of Students	School type	Setting	Intervention	Student outcome	Interventionist	Device
Digital text							
Bouck et al. (2013)	3	School for the blind	Core content class	Math eText	Math performance	Researchers	AB
Bouck & Weng (2014a)	3	School for the blind	Pullout room	Speech-to-text of selected math problems	Math performance	Researchers	L
Bouck & Weng (2014b)	5	School for the blind	Core content class	Math eText	Math performance	Researchers	LBN
Bouck et al. (2016)	4	School for the blind	Core content class	Math eText	Math graphic recognition	Researchers & paraeducator	AB
Frankel et al. (2017)	21	Integrated schools & school for the blind	—	Speech-to-text of selected math problems	Math performance	TVI	D
McLaughlin & Kamei-Hannan (2018)	3	—	—	Student selected audiobooks	Reading fluency	TVI	T
Word processors							
Beevers & Halliman (1990)	1	Integrated school	Self-contained classroom	Braille and audio word processing	Writing skills	Researchers	D
Bickford & Falco (2012)	9	Integrated schools & school for the blind	—	Refreshable Braille access to content	Braille code	TVI	BN
Cooper & Nichols (2007)	17	Integrated schools	Core content class	Hybrid braillewriter/ computer	Reading level	TVI	E BD
Farnsworth & Luckner (2008)	1	Integrated schools	Core content class	Refreshable Braille access to content	Classroom engagement	Researcher	BN
Kamei-Hannan & Lawson (2012)	3	School for the blind	Core content class	Refreshable Braille access to content	Writing skills	Researchers	BN
Haptic simulations							
Hahn et al. (2019)	17	Non-school setting	—	Haptic presentation of graphics	Math graphic recognition	Researchers	T
Jones et al. (2014)	15	Integrated school	Pullout room	Haptic simulation of science material	Science concepts	Researchers	C
Landau et al. (2003)	6	—	—	Haptic presentation of graphics	Math graphic recognition	Researchers	T
Rovira & Gapenne (2009)	3	Integrated schools & school for the blind	—	Haptic presentation of graphics	Math graphic recognition	Researchers	D T
Educational platforms							
Arslantas et al. (2019)	15	School for the blind	Computer lab	Vocabulary drill program	Vocabulary	Collaboration of TVIs and researchers	D
Beal & Rosenblum (2018)	29	Integrated school	—	Mathematics modules	Math performance	TVI	T
Beal et al. (2011)	14	Integrated schools & school for the blind	—	Math drill program	Math performance	Researchers	—

(continued)

Table 3. (continued)

Study	Number of Students	School type	Setting	Intervention	Student outcome	Interventionist	Device
Beal & Shaw (2009)	11	Integrated school	—	Mathematics drill program	Math performance	Researchers	D
Kamei-Hannan et al. (2020)	52	Integrated schools & school for the blind	—	Braille modules	Braille	TVI	T
Kapperman et al. (2011)	28	Integrated schools & school for the blind	—	Nemeth code modules	Math code knowledge	TVI	BN
Kapperman et al. (2012)	22	Integrated schools & school for the blind	—	Nemeth code modules	Math code knowledge	TVI	BN
McCarthy et al. (2016)	9	Integrated schools & school for the blind	—	Adaptive Braille Modules	Braille	TVI	D BD
Mioduser et al. (2000)	1	—	—	Adaptive vocabulary modules	Spelling	Researchers	—
Sanford (1984)	10	Integrated schools & school for the blind	—	Technology modules	Technology use	Researcher	D BD
Serious games							
Radecki et al. (2020)	6	—	—	Haptic presentation of graphics	Graphic orientation	Researchers	—
Sanchez & Elias (2007)	7	School for the blind	—	Instructional game for science content	IQ	Special educator	D
Sanchez & Flores (2005)	10	School for the blind	—	Instructional game for math content	Math performance	Special educator	D

Note. AB = audiobook player; C = custom device; D = desktop; E = embosser BD = braille display; BN = braille notetaker; T = Tablet. Missing information is denoted with a dash.

addressing disagreements, we reviewed the original article to reach a consensus on the final code. IOA averaged 91.6% (range 83.5%–97.1%) across studies. For each category, IOA averaged 96.7% for student characteristics items, 87.0% for setting items, 91.4% for characteristics of interventions, 94.0% for study design items, and 88.5% for outcome items.

Results

What are the Characteristics of the Students and Settings in CAI Studies?

Student demographics are displayed in Table 2. Age and grade levels of students varied widely within and across studies, though this information was infrequently reported. Several studies involved students from multiple school levels (Beal & Rossenblum, 2018; Jones et al., 2014; Kamei-Hannan et al., 2021). However, information for participants' age and grade level were only reported for 23.3% and 31.9% of students, respectively (with only 15 students, or 4.4%, not overlapping). Of the 19.2% of students (n = 65) for whom race/ethnicity was provided, 66.2% were European American, 9.2% were African American, 7.7% were Asian American, 13.8% were Hispanic/Latino, and 3.1% were identified as multiple or other. Almost one fourth of students met the legal definition for blindness (n = 63 students; 18.6%). However, the severity of visual impairment was only reported for 24.5% of students. Students' primary learning medium was reported for 69.0% of students and indicated most students used braille (n = 187 students; 55.2%). Only 47 students (13.8%) were reported to use print media (i.e., regular or large print). Some studies indicated that students used audio as a learning medium (e.g., Bouck & Weng, 2014; Kamei-Hannan & Lawson, 2012), but no studies listed audio as a primary learning medium. 17 students (5.0%) were identified in studies as having additional disabilities, which included attention deficit disorder, intellectual disability, physical impairments, and speech-language impairment.

Descriptive summaries of each study are provided in Table 3. Locations of studies were relatively balanced between integrated schools (n = 6 studies; 21.4%), schools for the blind (n = 8 studies; 28.6%), or a combination of the two types of locations (n = 9 studies; 32.1%). One study was conducted during a summer camp for visually impaired students (Hahn et al., 2019). Location was not reported for four studies. Studies most frequently took place in classrooms related to core content (i.e., math, science, language arts, or social studies; n = 6 studies; 21.4%). Two studies (7.1%) were implemented in pullout spaces, one study was conducted in self-contained classrooms (3.5%), and one study (3.5%) was conducted in a computer lab during related arts instruction. The remaining 18 studies did not report instructional setting.

What are the Characteristics of CAI interventions?

Devices. The most common devices used were specialized devices (n = 11 studies; 39.2%), most of which were braille notetakers (n = 8 studies; 28.6%). These devices also included audiobook players and a custom-made haptic device. Desktop computers (n = 9 studies; 32.1%) and tablets (n = 5 studies; 17.9%) were also frequently used in studies. Desktops were frequently used with educational platforms (n = 3 studies) and serious games interventions (n = 2 studies). Tablets were frequently used in haptic simulations (n = 3 studies). Laptops were rarely used (n = 3 studies) and only within digital text interventions. Moreover, studies also frequently focused on the use of specific applications on devices (n = 19 studies).

The ways devices were selected or adapted varied across studies. Only one study used an assessment to select a device (Beevers & Halliman, 1990). Six studies (21.4%) adjusted device/application settings base on student preference. Two educational platform studies (7.1%) determined students' starting lessons after assessment (Kamei-Hannan et al., 2020; Mioduser et al., 2000). Three studies (10.7%) assessed student mastery of devices before implementing CAI. Device selection/adaptation was not reported in the remaining 16 studies.

Dosage

The length of interventions was reported for 18 of the studies and varied widely. Five studies lasted 1 week or less, five lasted between 1 week and 1 month, three studies lasted between 1 and 4 months, and five studies lasted longer than 4 months. Two interesting patterns were evident: (a) four of the five studies lasting less than 1 week implemented haptic simulations (Hahn et al., 2019; Jones et al., 2014; Landau et al., 2003; Rovira et al., 2009), and (b) two of the serious game studies lasted longer than 4 months (Sanchez & Elias, 2007; Sanchez & Flores, 2005).

Session lengths varied and were reported in 17 studies. One study contained sessions less than 10 min, five had 10–29 min sessions, three studies had 30 min to 1 hr sessions, two had 1 hr to 90 min sessions, and six studies had sessions lasting longer than 90 min. Two studies that implemented serious games interventions (66% of this type of intervention) and five studies that utilized desktop computers (56% of this type of intervention) reported longer intervention sessions (i.e., 60–90 min, longer than 90 min). Interventions that used braille notetakers frequently used 30–60 min sessions. Word processors and educational platforms interventions frequently used shorter intervention sessions (i.e., less than 10 min and 10–29 min).

Implementers

CAI was primarily implemented by researchers (n = 17 studies). Nine studies were implemented by TVIs, two studies by special education teachers, and one study by a paraeducator. Two studies used multiple implementers (i.e., a researcher and a TVI or paraeducator). Of the nine studies implemented by educators, only four studies described trainings for educators. Trainings provided to TVIs included: a 3-day walk-through using 2-hour sessions focused on a math educational platform, refreshable braille display, and study procedures (Beal & Rosenblum, 2018), a manufacturer demonstration on operating a Mountbatten with ongoing technical support (Cooper & Nichols, 2007), a 3-hour training session on a braille educational platform with additional professional development, technical support, and webinars (Kamei-Hannan et al., 2020), and a 1-hour online training session on using a braille educational platform and study procedures (McCarthy et al., 2016).

Technology Training

Eleven studies reported teaching students to operate the CAI technology. Nine of these studies provided students with a single-session training led by a researcher (n = 6 studies), an educator (n = 1 study), or using a device tutorial (n = 2 studies). In single-session trainings, students were given technology demonstrations and opportunities for guided practice. These single-session orientations focused on the layout of the device (n = 1 study), features/settings (n = 8 studies), and navigation commands (n = 3 studies). Only two studies reported the length of single-session trainings; both lasted 30–59 min. Single-session trainings were primarily present in digital book (n = 5 studies) and educational platform (n = 3 studies) interventions. Two studies provided multiple technology training sessions provided by a TVI (McLaughlin & Kamei-Hannan, 2018) or AT specialist (Kamei-Hannan & Lawson, 2012). In multi-session trainings, students were also provided technology demonstrations and opportunities for guided practice for digital texts (McLaughlin & Kamei-Hannan, 2018) or a word processor (Kamei-Hannan & Lawson, 2012). However, students also learned specific technology skills such as downloading digital texts, using bookmarks, orientation to virtual menus, and editing text. Length of training sessions ranged from 10 to 30 min to 50-min sessions. The frequency of trainings ranged from 2 to 3 times per week, while the duration ranged from 4 to 6 weeks. Kamei-Hannan and Lawson (2012) integrated a curriculum with lessons and practice activities into assignments from the general education classrooms.

What Academic Outcomes are Addressed in CAI Studies?

Studies examined a wide range of academic skills. Fifteen studies examined math outcomes, eight examined outcomes related to English and language arts (ELA), and one study examined science outcomes. Studies that examined math outcomes involved educational platforms (n = 7 studies), digital texts (n = 4 studies), haptic simulations (n = 2 studies), and serious game interventions (n = 1 study). These studies measured students' performance on math problems, tactile graphic recognition, and knowledge of the Nemeth code. For example, participants in Beal and colleagues (2011) worked on a web-based program using speech-to-text access to improve their accuracy in completing math problems ranging from simple addition problems to adding and subtracting problems with unlike denominators. Studies that examined ELA outcomes involved word processing (n = 4 studies) and educational platform (n = 3 studies) interventions and measured writing skills (e.g., speed, accuracy, and editing behaviors; n = 2 studies), braille knowledge (n = 2 studies), reading level (n = 1 study), reading fluency (n = 1 study), spelling accuracy (n = 1 study), and vocabulary gains (n = 1 study). Jones et al. (2014) examined performance on an assessment of thermal energy, pressure, and random motion concepts using a haptic feedback intervention.

What is the Impact and Perceptions of CAI?

Studies used multiple forms of data collection. Methods of data collection included quantitative measures of student learning (n = 25 studies), field notes (n = 12 studies), interviews (n = 15 studies), and surveys (n = 2 studies). Eight studies examined outcomes experimentally. Two studies used quasi-experimental group designs and found statistically significant student gains in knowledge of the Nemeth code (Kapperman et al., 2011; Kapperman et al., 2012). Six studies used single-case designs and visual analysis. Three of these studies showed no effect (Bickford & Falco, 2012; Bouck & Weng, 2014b; McLaughlin & Kamei-Hannan, 2018), one study demonstrated an inconsistent effect (Kamei-Hannan & Lawson, 2012), and two studies found strong effects (Arslantas et al., 2019; McCarthy et al., 2016). The remaining 20 studies used descriptive designs.

Studies examining the impact of CAI using quantitative measures indicated that many students learned new information when using devices (n = 13 studies). Studies that addressed quantitative gains in student performance examined educational platforms (n = 10 studies), haptic simulations (n = 2 studies), digital texts (n = 1 study), and word processors (n = 1 study). Some studies compared within-participant performance using CAI to traditional learning mediums. Most comparison studies indicated that students performed better (n = 8 studies) or comparably (n = 5 studies) using CAI vs. traditional mediums. However, one study indicated students performed worse in reading math problems when using digital textbooks than traditional mediums (Frankel et al., 2017). Educational platforms yielded the most consistent comparative study results. More specifically, six studies found students performed better on educational platforms than on traditional instruction (Arslantas et al., 2019; Beal & Rosenblum, 2018; Beal & Shaw, 2009; Kapperman et al., 2011; McCarthy et al., 2016; Mioduser et al., 2000). Additionally, four studies examining digital textbooks found students performed comparably on CAI and traditional (Bouck et al., 2013; Bouck & Weng, 2014b; Frankel et al., 2017; McLaughlin & Kamei-Hannan, 2018). Researchers in Bouck et al. (2016) speculated that student performance in digital text interventions was limited due to lack of direct instruction on math topics provided with digital texts. One study that examined haptic simulations found students performed better on devices (Landau et al., 2003) compared to traditional media, while another study found students performed comparably (Hahn et al., 2019).

Stakeholder Perspectives

Fifteen studies examined stakeholder perspectives regarding CAI. Thirteen studies examined the feasibility of CAI, 11 examined student preferences of media formats, six examined perceived outcomes of CAI, and two studies examined perceived classroom benefits. Studies also collected social validity from multiple sources, including students in 14 studies, TVIs in five studies, general educators in four studies, and parents in two studies.

Student Perspectives. Eleven studies asked a total of 88 students about their preferred instructional formats or learning media. Most students preferred to use technology (n = 49; 55.7%), 12 students (13.6%) did not indicate a preference, and 27 students (30.7%) preferred using traditional methods/media. Three themes arose across studies. First, students perceived CAI provided efficient access to content in four studies (Arslantas et al., 2019; Bouck & Weng, 2014a; Bouck et al., 2016; Kamei-Hannan & Lawson, 2012). These studies indicated that CAI provided instant access to worksheets in classrooms. Traditional access to text required more time to reproduce materials in braille or large print. Of note, students in one study indicated that digital textbooks could not display some mathematical expressions (Bouck & Weng, 2014a). Three studies identified technical issues that arose while using devices (Beevers & Halliman, 1990; Bouck & Weng, 2014b; Farnsworth & Luckner, 2008). Technical issues prevented students from participating in CAI due to devices or applications not working properly. For example, issues in internet connection arose in Farnsworth and Luckner (2008), preventing students from receiving and submitting work. Finally, three studies reported instant feedback in CAI motivated students (Arslantas et al., 2019; Beal & Rosenblum, 2018; Beevers & Halliman, 1990). Students reported that they enjoyed receiving instant feedback, which made them want to complete more work. Educational platforms often provided students instant feedback on the accuracy of their answers.

Adult Perspectives. Eight studies examined the perspectives of adult stakeholders. Adults reinforced the students' themes regarding efficient access (n = 5 studies), technical issues (n = 4 studies), limitations of devices (n = 3 studies), and benefits of instant feedback ($n = 2$ studies; see *Student Perspectives*). Two additional themes arose from adult perspectives. First, adults in four studies reported increased student independence (Beal & Rosenblum, 2018; Bouck et al., 2013; Farnsworth & Luckner, 2008; McCarthy et al., 2016). Adults indicated CAI allowed them to reduce direct support in inclusive settings. Moreover, adults also indicated CAI could be feasibly implemented. Second, adults in three studies described the flexibility of devices (Bouck et al., 2013; Bouck et al., 2016; Farnsworth & Luckner, 2008). The features and device settings provided students allowed students to choose how to access content or adjust settings to meet specific needs. However, four studies also indicated that students had trouble using technology or required supervision (Bickford & Falco, 2012; Bouck & Weng, 2014b; Bouck et al., 2016; Beevers & Halliman, 1990). Educators expressed mixed support for technology—they were supportive in one study (McCarthy et al., 2016), but unsupportive in another (Bouck et al., 2016).

Discussion

The potential of CAI for facilitating educational access and participation of students with VI has been emphasized for more than two decades (Scadden, 2000). An in-depth examination of CAI studies is needed to synthesize the available research and identify key student and educator considerations for implementation. We reviewed 28 studies describing the use of CAI interventions with school-age children with VI. The findings extend the literature on CAI for students with VI in several ways.

First, this review identified a number of CAI intervention approaches that can be used with students with VI. These studies form a body of literature that can serve as a resource upon which TVIs and other educators can draw. Five categories of CAI interventions were identified: digital text, word processing, haptic simulations, educational platforms, and serious games. Across these categories, CAI was used to teach students in a multitude of ways, such as: using devices to navigate and modify access to textbooks (digital texts); providing students with new tools for editing and formatting text (word processers); providing new ways to explore graphics and visual models (haptic simulations); integrating multiple options for interacting with content, providing instant feedback, and providing more robust data-driven instruction (educational platforms); and integrating educational topics into entertaining electronic games (serious games). Moreover, these approaches were used to address a wide range of academic outcomes for students with VI, ranging from math performance to reading and writing speeds to science content knowledge. Studies focused primarily on math-related (25%) and ELA (28.6%) outcomes. Only one study examined science-related outcomes and none of the studies focused on social study-related outcomes. This suggests that research CAI is focused on a narrow application of academic subjects and these findings have limited application across academic contexts. Moreover, future research needs to explore whether there are wider applications of CAI for science- and social studies–related outcomes, especially given the visual nature of some scientific and geographic concepts.

This review also illustrates the individualization of CAI to meet specific student needs. For example, digital text studies frequently addressed students' access to math texts in integrated settings, word processing studies addressed writing skills, and haptic feedback focused on tactile perception skills. On the other hand, some intervention strategies may be applied more broadly (e.g., educational platforms and serious games). Across studies, researchers and stakeholders indicated that CAI offers many potential benefits for students with VI (e.g., increased student performance and perceived benefits, faster access to content, increased independence). However, inconsistent findings and mixed perceptions suggest more research on CAI is needed and careful consideration is needed when selecting CAI strategies.

Second, very few studies ($n = 11$) incorporated technology training in CAI interventions. Additionally, most studies ($n = 25$) did not examine students' technology skills before implementing CAI. This finding is concerning given that research has identified lack of technology skills as a contributing factor to AT abandonment among students with disabilities (Federici & Borsci, 2016). Presently, educators have few resources and limited curricula for preparing students to use AT effectively (Arthanat et al., 2017). Likewise, there is little research examining the strategies and curricula used to promoting effective device use (Campbell et al., 2006). CAI interventions often utilize complex AT devices that require many technology skills to operate. Thus, future studies should provide a stronger focus on pre-requisite technology skills of CAI and integrate technology training procedures to increase the replicability of studies.

Third, participant descriptions were very limited. The categories of age, grade, race/ethnicity, and severity of VI were unknown for almost three quarters of participants across studies. Inconsistency in participant reporting complicates meaningful discussions about which procedures are relevant or useful for which students. Educational experiences could vary across school levels and impact performance in CAI studies. For example, elementary-age students may lack sufficient exposure to technology or skills required for CAI interventions. Social pressures in middle schools and high schools might make students resist using devices that feel stigmatizing. Likewise, reporting of race/ethnicity is essential for identifying racial disparities in the impact of CAI. The limited diversity of participants' learning media in studies also suggests research examining CAI may need to expand participants' recruitment. Most participants were identified as braille readers (53.5%). However, the American Printing House for the Blind Annual Report (2019) reports that only 8.4% of students who receive federal quota funds use braille as a primary learning medium. In short, the current focus of CAI studies might only address a small portion of the population of students with VI who could benefit from CAI. The focus on braille readers may be due to the need for more intensive adaptations (e.g., refreshable braille displays, screen-reading applications, haptic feedback) than print readers. Additionally, print users' adaptations (e.g., large print keyboards, adjusting zoom, fonts, and contrast) may be more easily integrated into mainstream CAI than adaptations for braille readers. However, students with low vision also need direct instruction in compensatory skills (Corn & Koenig, 2002).

Fourth, less than one third of studies involved educators (e.g., TVI, special educator, general educator, paraprofessional, AT specialist) as implementers of CAI interventions or in the training of implementers. Moreover, the nature of educators' involvement in interventions was often poorly described. Most studies did not list supports (e.g., troubleshooting devices, navigating applications, review device commands) educators provided to students. Researchers may be underutilizing educators in technology trainings and implementing CAI. This is evidenced by some studies indicating educators were successful in implementing or supporting CAI interventions. For example, paraeducators in Bouck et al. (2016) were taught features of an application to support CAI during math instruction. Moreover, incorporating educators more in interventions may promote CAI use in natural settings and address educators' limited AT knowledge identified in research (e.g., Abner & Lahm, 2002). Likewise, educators delivered technology trainings successfully. For example, educators in Kamei-Hannan and Lawson (2012) utilized a curriculum to teach students to use word processors. Using educators to implement CAI interventions improves the social validity of CAI and increases the likelihood the intervention is adopted in schools.

Limitations

Several limitations should be considered when interpreting the results of this review. First, the definition of CAI used in this review differed somewhat from definitions used in some other reports. This review limited CAI to studies that implemented instructional activities primarily on computer devices to focus on interventions that incorporate rich interaction with computers. Other reports have adopted much broader definitions of CAI (e.g., Odom et al., 2015), which may have yielded additional or different results. Second, we only reviewed studies published in peer-reviewed journals and excluded product research or unpublished studies. The decision to include only peer-reviewed research may also leave these findings vulnerable to publication bias (Shadish et al., 2016). Third, we did not address social and communication outcomes to avoid including augmented and alternative communication technology, which has a distinct body of literature. Including these outcomes may have yielded additional CAI studies.

Implications for Research

The results of this review highlight several directions for future CAI research within the field of special education. First, future researchers should address student preparation for CAI interventions through their inclusion criteria or technology training. AT experts and researchers in Kamei-Hanna et al. (2022) identified 41 technology skills critical for proficient AT use. Students' proficiency in technology skills likely influence the potential impact of CAI. For example, proficiency in digital orientation, digital organization, knowledge of screen-access software, and knowledge of word processors are all pre-requisites skills needed to participate in the writing activities (e.g., Bickford & Falco, 2012). Research examining the strategies that develop technology skills is needed to improve participation in CAI. However, few such studies exist in special education broadly, let alone the field of VI. Future researchers should consider developing this line of research or embedding empirical examinations of AT instruction into CAI studies. Second, research needs to replicate the potential for CAI in core content classrooms. Previous reviews of CAI have highlighted the limited implementation of CAI in special education settings (Root et al., 2017). Our findings suggest that CAI may have broader applications. However, application to a limited range of outcomes suggests that research can further expand examinations of CAI across core content settings. Moreover, additional experimental research is needed to establish the effectiveness of CAI interventions in these settings. Studies should also describe the specific supports and considerations of implementing CAI in core content classrooms. Third, future studies of students with VI must provide more detailed participant information. Specifically, researchers should consider using visual acuity as a measure in their reports. Many studies reported students' primary learning medium; however, visual acuity is a more widely used measure of VI than primary learning medium. Finally, future researchers should incorporate special educators and TVIs as implementers of CAI. As discussed previously, several studies in this review illustrate the potential of educators as implementers. However, only a few studies described how educators' were trained as implementers. Future studies should better describe these training procedures, frequency, and dosage. Developing educators' AT knowledge was central in the studies that described training educators. However, future research might explore other types of training relevant to implementing CAI (e.g., developing implementation plans, AT lesson planning, troubleshooting).

Implications for Practice

Findings from this review have several important implications for special education practice. First, this review identified a breadth of approaches to CAI interventions that educators can consider implementing with students with VI. Descriptive findings illustrate some potential benefits of CAI for these students. For example, some educational platforms developed the pre-requisite AT skills students needed. Moreover, research suggests TVIs may lack confidence for providing instruction in these areas (Abner & Lahm, 2002). Thus, teachers should consider incorporating this type of CAI into practice.

However, educators should use caution when selecting CAI interventions by assessing each student's needs, making data-based decisions, and closely monitoring student progress.

Second, educators should assess the technology skills students will need to participate in CAI. Some types of CAI can be implemented quickly and with relative ease; others require substantial amounts of direct instruction before implementation in core content classrooms. For example, participants in Kamei-Hannan and Lawson (2012) received several months of instruction on devices before students participated in the word processing intervention. Informal assessments are needed to determine appropriate type of CAI interventions for students. Additionally, formal assessments of technology skills need to be developed to identify the pre-requisite needs of students for participating in these CAI interventions.

Third, these studies indicate that educators can implement CAI with proper training and support. School administrators should provide educators with in-service training to increase their AT knowledge and improve AT instruction they may have missed in preparation programs (Smith et al., 2011). Likewise, this review can serve as a resource to teacher preparation programs creating opportunities for students to practice implementing CAI in practicum placements. Such opportunities would allow future educators to become more fluent in providing AT instruction.

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