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A Review of Computer-Assisted Instruction for Students With Visual Impairment

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Abstract

Computer-assisted instruction (CAI) is a critical tool for accessing information and instruction among students with visual impairment (VI). This systematic review examined eight CAI intervention studies implemented with 92 U.S. school-age children with VI. The interventions were implemented with a diverse group of students across a variety of school types (e.g., neighborhood schools, schools for the blind), grade levels, and content areas (e.g., math, reading). Although some findings were promising, the effects of CAI were inconsistent across studies. This review highlights the need for (a) additional high-quality intervention evaluations, (b) more information on the social validity of CAI interventions, and (c) evaluations of CAI among students with a wider range of needs. Implications for practice and research aimed at enhancing the use of CAI are addressed.

Keywords

computer-assisted instruction, assistive technology, instructional technology, visual impairment

Visual impairment (VI) limits students' access to information (Wolffe, 2017). Assistive technology (AT; i.e., devices or software used to increase functional capabilities) and instructional technology (i.e., devices or software that facilitate learning) are vital tools that educators can use to improve students' access to information and instruction (Kamei-Hannan et al., 2017). Computers are a particularly promising form of technology for addressing students' access needs (Abner & Lahm, 2002). Interventions that utilize computers as a central component of learning and access to classroom content are known as computer-assisted instruction (CAI) interventions. CAI can improve the lives of students with VI in several ways. First, computers can provide students an array of applications (e.g., word processors, email, the internet) to address a wide range of academic needs (e.g., Hofstetter, 2001). Second, the ability of computers to share information digitally across devices can create social opportunities for students with VI (e.g., Della Líbera & Jurberg, 2017). For example, these technologies allow students to collaborate and have interactions with sighted educators and peers. Third, computers quickly utilize data to individualize instruction (e.g., Hofstetter, 2001). For example, data-driven instruction changes the sequence of activities within lessons based on each student's performance. Finally, computers are an essential tool in the 21st century and are used in numerous careers (e.g., McDonnall & Crudden, 2009). Integrating computers into students' education increases their opportunities to develop valued skills for future employment settings.

Over the past several decades, researchers and policymakers have emphasized the importance of evaluating the impact of educational practices on students (Every Student Succeeds Act, 2015; Odom et al., 2005). Specifically, the term evidence-based practices (EBPs) refers to interventions with a body of replicated research that have experimentally demonstrated therapeutic effects for students. Identifying EBPs raises the standards for instruction and pushes educators to evaluate their practices. Current standards for identifying EBPs include the following: (a) use of an experimental design that demonstrates an independent variable's control or causal relationship on a dependent variable, (b) a sufficient number of replications within and across studies (and organizations), (c) quality research reporting, and (d) consistent positive outcomes with few to no negative effects (Cook et al., 2014). Reviews of extant literature examining the effects of interventions are critical to informing the practices of educators and shaping the field's policy. However, the field of VI has not yet established CAI as an EBP (Ferrell et al., 2014; Smith & Kelly, 2014). Moreover, an evaluation of the experimental research of CAI interventions for students with VI has not yet been conducted (Ferrell et al., 2014).

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The purpose of this review was to provide a comprehensive examination of experimental studies addressing CAI interventions for students with VI. We were guided by the following research questions:

Research Question 1: Which students were involved in CAI intervention studies?
Research Question 2: What are the characteristics of CAI interventions (e.g., settings, devices/software, dosage, implementers)?
Research Question 3: To what extent do CAI studies meet quality indicators of methodologically sound studies?
Research Question 4: What is the impact of CAI on student outcomes?

This review informs the field of VI in several important ways. First, it identifies potential technologies and approaches for delivering CAI to students with VI. A longstanding barrier to incorporating technology in the classroom is the lack of implementation knowledge and resources among teachers (Abner & Lahm, 2002). Second, it examines the effects of CAI interventions on a variety of student outcomes. Educators are called upon to use practices that have strong evidence of rigor and impact. Third, examining the quality of this collection of studies can identify key considerations for future research.

Method

Inclusion Criteria

To be included in this review, studies had to meet five criteria. First, studies implemented some form of computer-assisted instruction. CAI was defined as an intervention where computers were central to providing students instruction or access to information (Root et al., 2017). However, interventions that used devices merely to prompt students or as a subcomponent of a larger intervention were not considered CAI. For example, we excluded electronic canes used during walks (Cheng, 2016) from our definition of CAI. Second, studies had to experimentally evaluate the impact of CAI using an experimental single-case design or a group design with a comparison group. This criterion focused us on studies in which causal claims could potentially be made. Third, more than 50% of participants in studies must have been school-age students (ages 5–22 years) with a VI. Fourth, studies had to examine 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. We excluded studies that examined social or communication skills (e.g., augmented and alternative communication) because these interventions have a distinct body of literature. 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 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 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 texts" OR etext) and disability category (i.e., "visual impairment" OR "visual impairments" 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 using Google Scholar (i.e., forward search).

Screening Procedures

The search was conducted by the first author and reliability was checked by a special education doctoral student. The initial search yielded 3,521 unique article citations after removing duplicates. We screened titles and abstracts of all citations using Abstrackr (i.e., an online review-screening tool). This online software allowed us to (a) rate citations as included or excluded and (b) track multiple raters for interobserver agreement (IOA). In this phase, we retained studies that fit the inclusion criteria and questionable studies that needed further review, which resulted in 91 studies. The second rater independently screened 20% of the initial search results (n = 753 articles); there were 13 disagreements (98.3% reliability). All studies disagreed upon moved on to full-text screenings.

We then reviewed the full text of the 91 remaining studies using the same inclusion criteria, which eliminated all but eight studies. We eliminated 30 studies that did not implement a CAI intervention, 28 studies that implemented interventions with participants who did not meet inclusion

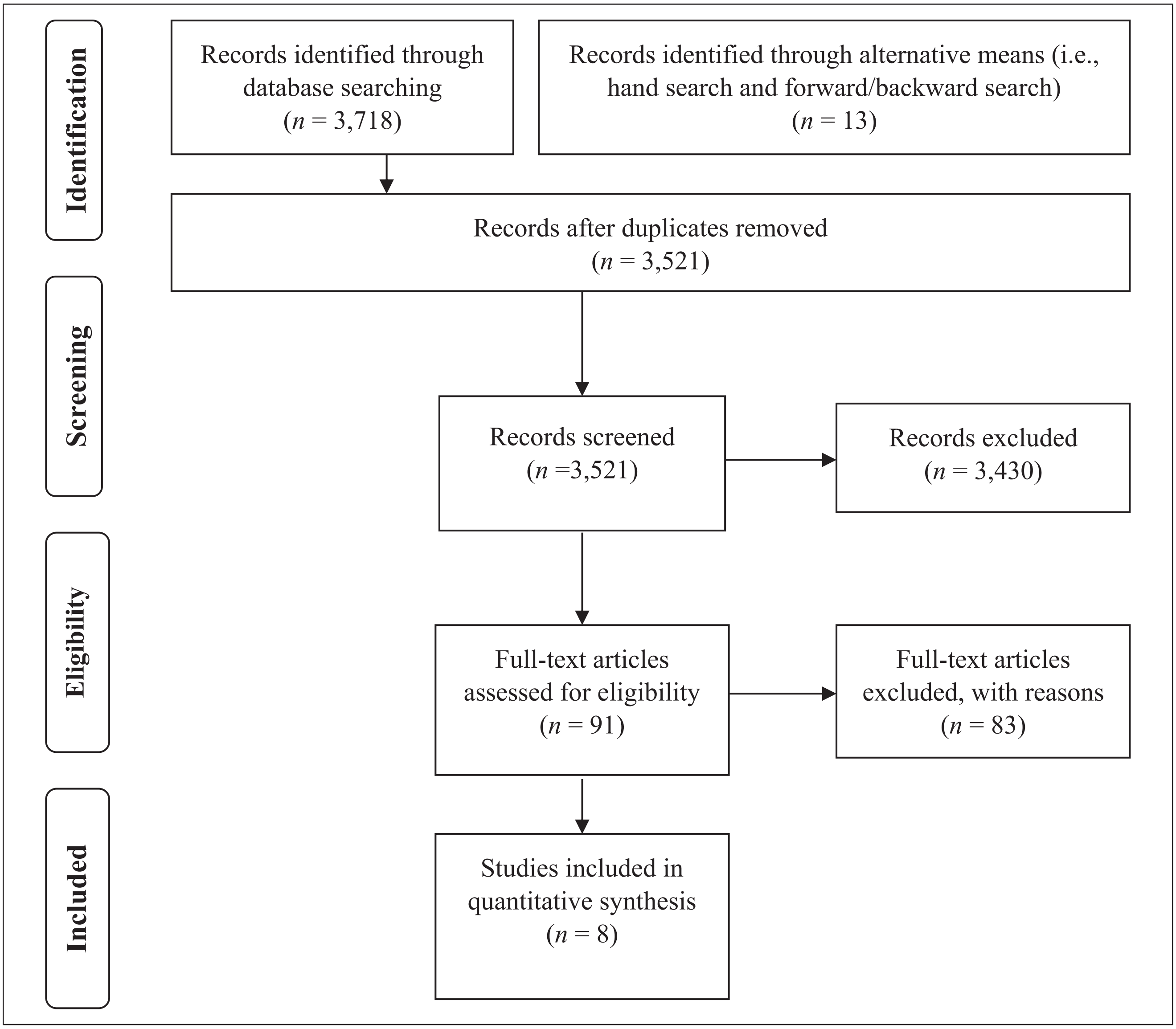

Figure 1. PRISMA diagram depicting the screening procedures used to locate and exclude studies.
Source. From Moher et al. (2009). Copyright 2009 held jointly by the authors.
Note. The chart lists the steps in the screening process and the number of studies identified or remaining after each step.

criteria (e.g., adults and college students), five studies that did not examine an academic outcome (e.g., improving eye movement, visual perspective development, visual rehabilitation), and 20 studies that did not use an experimental or quasi-experimental design. The same rater screened 20% of the 91 articles (n = 19 articles) during the full-text screening. No disagreements occurred (100% reliability).

Coding Procedures

We coded variables addressing six aspects of the studies: (a) student characteristics, (b) setting characteristics, (c) characteristics of CAI, (d) student outcomes, (e) study design, and (f) quality indicators. 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 5–22 years with a VI). When authors did not report information for a particular variable, we reported it as unknown.

Student characteristics. We coded the number of participating students meeting the inclusion criteria, along with their age, grade level, gender, race/ethnicity, severity of VI, primary learning medium, and presence of any additional disabilities based on participant descriptions provided by authors (see Table 1). We coded the severity of VI as total blindness, legal blindness, low vision, cortical VI, or other (e.g., medically

Table 1. Demographics for Included Students from Reviewed Studies.

Demographic	% (*n*)
Total number of students with visual impairments	92
Grade level	
Elementary (K–5)	7.6 (7)
Middle (6–8)	21.7 (20)
High (9–12)	6.5 (6)
Unknown/unclear	64.1 (59)
Gender	
Female	53.3 (49)
Male	46.7 (43)
Unknown/unclear	0.0 (0)
Race/ethnicity	
European American	44.6 (41)
African American	8.7 (8)
Asian American	5.4 (5)
Native or Alaskan American	0.0 (0)
Latinx	5.4 (5)
Other or multiple	2.2 (2)
Unknown/unclear	33.7 (31)
Severity of visual impairment	
Total blindness	1.1 (1)
Legal blindness	2.2 (2)
Low vision	3.3 (3)
Cortical visual impairment	0.0 (0)
Unknown/unclear	93.5 (86)
Primary learning medium	
Braille	78.3 (72)
Regular print	5.4 (5)
Large print	0.0 (0)
Audio	0.0 (0)
Alternate learning medium	0.0 (0)
Unknown/unclear	16.3 (15)

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.

diagnosed diplopia). 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. We coded students' primary learning medium as braille, regular print, large print, audio, or an alternative learning medium (e.g., tactile or picture symbols).

Setting characteristics. We coded the key characteristics of the schools and classrooms in which the interventions were delivered (see Table 2). We coded location (i.e., local public/private school, state school for the blind, or nonschool setting) and instructional setting (e.g., core content classroom, self-contained classrooms, pullout room, home, or other). We coded instructional setting as a pullout space (i.e., rooms where only adults and the student were present), core content classrooms (i.e., math, science, social studies, and language arts), self-contained classrooms (i.e., classrooms where a special educator is the primary educator), and home. We coded all other settings identified by authors' information as other.

Characteristics of CAI. We coded four characteristics of CAI: (a) the components of the interventions, (b) dosage, (c) characteristics of implementers, and (d) fidelity of implementation. First, we coded the intervention components, such as assessments used to select devices, inclusion criteria, and the types of devices or software used. We coded whether studies assessed students' needs when considering devices or formatting the device settings, along with the type of assessment used for formal assessments (i.e., a named protocol), informal assessments (i.e., a personally developed protocol), or student preference (i.e., the student chose the device or adjusted the device settings). We coded whether studies mention technology skills as an inclusion criterion when recruiting participants (i.e., yes or no). We also listed the types of devices and descriptions of software described by the authors. We coded the type of devices in each study as desktop, laptop, tablet, specialized device, or other. Specialized devices were those designed solely for students with VI (e.g., braille notetakers; Kamei-Hannan & Lawson, 2012). We also coded whether or not studies utilized specific software while providing CAI, along with a brief description of the software.

Second, we coded the duration of intervention conditions and the average lengths of intervention sessions for CAI interventions (i.e., the sessions that students used devices) and technology training (i.e., the sessions that students learned how to use devices). We coded the shortest duration of a condition within a study (i.e., a week or less, between 1 week and 1 month, between 1 and 3 months, more than 4 months) and the average amount of time spent implementing each intervention session (i.e., less than 10 min, between 10 and 29 min, between 30 and 59 min, between 60 and 90 min, or more than 90 min).

Third, we coded the roles of the person facilitating the intervention: researchers, special educators, general educators, paraprofessionals, peers, or other personnel. We also indicated whether implementers were provided training and we summarized the training they received.

Fourth, we coded whether studies reported implementation fidelity. When fidelity was reported, we coded the proportion of sessions in which fidelity was measured, as well as whether implementers met a criterion of 90% or greater fidelity of implementation.

Quality indicators. We used the Council for Exceptional Children's quality indicators to evaluate the rigor and reporting of studies (see Table 3; Cook et al., 2014). Single-case

Table 2. Description of the 8 Studies Included in the CAI Intervention Review.

Study	Students	Device	Location[a]	Intervention setting	Intervention	Student outcome	Implementers	Design	Device selection[b]
Arslantas et al. (2019)	15	Desktop	School for the blind	Computer lab	Vocabulary drill program	Vocabulary	TVIs and researcher	MP	—
Bickford & Falco (2012)	9	Braille notetaker	Both	—	Refreshable braille	Braille code	TVI	AATD	—
Bouck & Weng (2014)	3	Laptop or braille notetaker	School for the blind	Core content class	Math eText	Math performance	Researcher	AATD	Settings adjusted/ student preference
Kapperman et al. (2011)	28	Braille notetaker	Both	—	Nemeth code modules	Math code knowledge	TVI	Q	Mastery of device
Kapperman et al. (2012)	22	Braille notetaker	Both	—	Nemeth code modules	Math code knowledge	TVI	Q	—
Kamei-Hannan & Lawson (2012)	3	Braille notetaker	School for the blind	Core content class	Refreshable braille	Writing skills	Researcher	AATD	Mastery of device
McCarthy et al. (2016)	9	Desktop computers with braille displays	Both	—	Adaptive braille modules	Braille	TVI	AATD	—
McLaughlin & Kamei-Hannan (2018)	3	Tablet	—	—	Student selected audiobooks	Reading fluency	TVI	AATD	Settings adjusted/ student preference

Note. AATD = adapted alternating treatments design; MP = multiple probe; TVI = teacher of students with visual impairments; Q = quasi-experimental; — indicates information was missing from the article.
[a]Both indicates the study was conducted in local school and school(s) for the blind. [b]Device selection describes procedures used to select devices or to adjust features within the device.

Table 3. Quality Indicators for Experimental Studies.

	Students and settings			Implementers		Procedures and fidelity					Internal validity									Dependent variables						Data analysis		
Study	1.1	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	5.3	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.1	7.2	7.3	7.4	7.5	7.6	8.1	8.2	8.3
Group design																												
Kapperman et al. (2011)		✓			✓	✓	✓				✓	✓	✓	✓	—	—	—	✓	✓	✓	✓	✓	✓	✓		✓	—	✓
Kapperman et al. (2012)					✓	✓	✓					✓		✓	—	—	—	✓		✓	✓	✓		✓		✓	—	
Single-case design																												
Arslantas et al. (2019)	✓			✓			✓				✓	✓	✓	—	✓	✓	✓	—	—	✓		✓	✓	✓	—	—	✓	—
Bickford & Falco (2012)			✓	✓		✓	✓	✓			✓	✓	✓	—	✓	✓		—	—	✓	✓	✓	✓	✓	—	—	✓	—
Bouck & Weng (2014)	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓		—	✓	✓	✓	—	—	✓		✓	✓	✓	—	—	✓	—
Kamei-Hannan & Lawson (2012)	✓	✓	✓	✓		✓	✓	✓			✓	✓		—	✓	✓		—	—	✓	✓	✓		✓	—	—	✓	—
McCarthy et al. (2016)	✓	✓	✓	✓		✓	✓				✓	✓		—	✓	✓		—	—	✓	✓	✓	✓	✓		—	✓	—
McLaughlin & Kamei-Hannan (2018)		✓	✓			✓	✓				✓	✓	✓	—	✓	✓	✓	—	—	✓		✓	✓		—	—	✓	—

Note. Columns indicate the corresponding quality indicators as outlined by the Council for Exceptional Children. For example, 1.1 refers to the description of the context and setting. Checkmarks indicate a study met a quality indicator and blank cells indicate it did not. A dash (—) denotes that the indicator is not required given a study's design. For more information about indicators, see Figure 2. Source for quality indicators: Table 1 (Cook et al., 2014).

design studies were evaluated with 22 quality indicators, and group design studies were evaluated with 24 quality indicators (see Cook et al., 2014, for details). Quality indicators focused on (a) students and settings, (b) implementers, (c) procedures and fidelity of implementation, (d) internal validity, (e) dependent measures, and (f) data analysis procedures. Each item was coded dichotomously according to whether or not the information was present in a report.

Experimental design. We identified the research designs used in each study: randomized controlled trial, quasi-experimental, or single-case design.

Student outcomes. We coded the name of the outcomes measured for students with disabilities. We defined *outcomes* as the skills and behaviors for which authors examined the impact of CAI. The outcomes had to be academic related (i.e., related to the general curriculum). We coded (a) the procedures used to collect data on these measures (e.g., partial interval recording or momentary time sampling), (b) whether studies reported operational definitions and provided examples/nonexamples, (c) the length of time maintenance data were collected, (d) the type of generalization measures that were collected (e.g., different dependent variables measured or materials used), and (e) the level of agreement data on experimental outcomes.

Social validity. We coded the social validity or stakeholder perspectives that studies collected related to the intervention. We coded the roles of all stakeholders who provided social validity: students with VI, special educators, general educators, teachers of students with visual impairments (TVIs), parents, paraprofessionals, peers, or other. We documented a brief summary of each perspective and categorized it as (a) a normative comparison (i.e., comparing participant outcomes with those of a typical population, such as students without disabilities), (b) blind raters for the importance of the results, (c) perceived importance of the goals, (d) perceived feasibility of procedures, (e) perceived positive impact on outcomes, or (f) preference of device use.

Interrater Reliability

The same special education doctoral student served as the second coder when extracting information from the articles. We collected IOA on study characteristics for 63% of the included articles (n = 5). The second coder reviewed the coding manual, was trained in coding, and independently practiced the coding. After demonstrating more than 90% agreement, we independently coded the eight articles. 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 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.

Findings

Which Students Were Involved in CAI Studies?

Student demographics are displayed in Table 1. Reported age and grade levels of students varied widely within and across studies. Middle school students made up the largest identified group with 20 students (21.7%), followed by elementary school (n = 7 students; 7.6%) and high school students (n = 6 students; 6.5%). Students' gender was relatively balanced between female (53.3%) and male (46.7%). For the students whose race/ethnicity was reported, 41 were European American, eight were African American, five were Asian, five were Latinx, and two were Other races/ethnicities. Severity of VI was only reported for six students (6.6%; three legally blind or worse and three low vision). No students were identified in studies as having additional disabilities.

Most students used braille as their primary learning medium (n = 72 students; 78.3%). Only five students (5.4%) were reported to use some form of print media (i.e., regular or large print). Some studies indicated that students used audio as a learning medium to navigate computers or listen to long texts (e.g., Bouck & Weng, 2014; Kamei-Hannan & Lawson, 2012). However, no students were identified with audio or alternative learning media as their primary learning medium.

What Are the Characteristics of CAI Interventions?

The way CAI was implemented varied across studies. Summaries of the characteristics of interventions are provided in Table 2. We examined four different characteristics of CAI interventions: (a) settings, (b) types of devices used in studies, (c) dosage of the interventions, and (d) the characteristics of the implementers of the interventions.

Settings. Locations of studies occurred primarily in schools for the blind (n = 3 studies; Arslantas et al., 2019; Bouck & Weng, 2014; Kamei-Hannan & Lawson, 2012). Four of these studies also included participants located in local and specialized schools for the blind (Bickford & Falco, 2012; Kapperman et al., 2011, 2012; McCarthy et al., 2016). Location was not reported in McLaughlin and Kamei-Hannan (2018). Bouck and Weng (2014) and Kamei-Hannan and Lawson (2012) took place in classrooms related to core content (i.e., math, science, language arts, or social studies). Bouck and Weng (2014) was implemented in a math classroom, whereas Kamei-Hannan and Lawson (2012) took place during students' social studies class. Arslantas et al. (2019) was conducted in computer labs during related arts instruction. The remaining five studies did not report the instructional setting.

Devices. The most common devices used were specialized devices (n = 5 studies; 62.5%). The specialized devices consisted solely of braille notetakers. Desktop computers (Arslantas et al., 2019; McCarthy et al., 2016), tablets (McLaughlin & Kamei-Hannan, 2018), and laptops (Bouck & Weng, 2014) were also used in studies. Moreover, studies frequently focused on the use of specific applications on devices (n = 6 studies; 75.0%). In four studies, students had access to content presented through learning modules that they completed at their own pace (Arslantas et al., 2019; Kapperman et al., 2011, 2012; McCarthy et al., 2016). Students used word processors to write and edit documents in two studies (Bickford & Falco, 2012; Kamei-Hannan & Lawson, 2012). In two studies, students accessed digital texts through devices (Bouck & Weng, 2014; McLaughlin & Kamei-Hannan, 2018).

The ways devices were selected or adapted differed across studies. No studies selected a device based on student needs identified through an assessment. Researchers in Bouck and Weng (2014) and McLaughlin and Kamei-Hannan (2018) adjusted device/application settings according to student preference. Student mastery of devices was assessed in Kapperman et al. (2011) and Kamei-Hannan and Lawson (2012) before implementing CAI. The remaining four studies did not report information on how devices were selected.

Dosage. Intervention length varied widely across studies. Two studies lasted between 1 week and 1 month (Bouck & Weng, 2014; McLaughlin & Kamei-Hannan, 2018), two studies lasted between 1 month and 4 months (Arslantas et al., 2019; Kamei-Hannan & Lawson, 2012), and three studies lasted longer than 4 months (Bickford & Falco, 2012; Kapperman et al., 2011, 2012). In McCarthy et al. (2016), the authors did not report the length of the intervention. Session lengths also varied. McLaughlin and Kamei-Hannan (2018) contained a session of less than 10 min, three studies reported session lengths of 10 to 29 min (Bouck & Weng, 2014; Kamei-Hannan & Lawson, 2012; McCarthy et al., 2016), and Bickford and Falco (2012) contained sessions lasting longer than 90 min. The remaining studies did not report the length of intervention sessions (Kapperman et al., 2011, 2012).

Implementers. CAI interventions were implemented by researchers (n = 5 studies; 62.5%) and TVIs (n = 3 studies; 37.5%). Only one study described the training provided to these implementers. In McCarthy et al. (2016), a 1-hr online training session was provided to TVIs on how to use an application with lessons for learning the braille code. TVIs were also trained on the application's features and the procedures of the study.

To What Extent Do CAI Studies Meet Quality Indicators of Methodologically Sound Studies?

A summary of the quality indicators for each of the studies in this review is provided in Table 3. Column subheadings in Table 3 indicate the corresponding quality indicators as outlined by the Council for Exceptional Children (Cook et al., 2014). Numbers in column subheadings refer to the eight categories of quality indicators: (1) context and setting, (2) participants, (3) intervention agents, (4) description of practice, (5) implementation fidelity, (6) internal validity, (7) outcome measures/dependent variables, and (8) data analysis. Each category is further broken down into indicators related to each category (e.g., 1.1, 2.1, 2.2). For definitions of each quality indicator, see Figure 2.

Two studies examined the effects of CAI using group methodology, both of which used matched-student designs (Kapperman et al., 2011, 2012). Six studies used single-case methodology to examine the effects of CAI. Three studies met internal validity quality indicators relevant to their designs (Arslantas et al., 2019; Kapperman et al., 2011; McLaughlin & Kamei-Hannan, 2018). None of the studies met all quality indicators relevant to the design. Most commonly, researchers did not report adequate fidelity measures (n = 7 studies), lacked sufficient implementer descriptions (n = 6 studies), or did not report critical features of student and setting information (n = 5 studies). Critically, four studies did not limit exposure to the intervention in comparison conditions. In Bouck and Weng (2014) and Kamei-Hannan and Lawson (2012), devices were integrated throughout daily instruction in inclusive settings. Only reading and writing probes alternated between media formats. In Kapperman et al. (2012), the intervention was not fully withdrawn from a previous study phase. In addition, the researchers did not report on differential attrition despite high overall attrition. Thus, the study lacked essential quality indicators for systematically manipulating the independent variable, limiting access to the intervention, and reporting differential attrition.

Context and setting
1.1 Describes critical features of the context or setting of the school and intervention location.
Participants
2.1 Describes relevant participant demographics (i.e., sex, age, grade, race/ethnicity, learning medium).
2.2 Describes participants' severity of visual impairment.
Intervention agent
3.1 Describes the role of the intervention agent (e.g., researcher, educator, assistive technology specialist).
3.2 Describes any specific training (e.g., frequency/duration or criterion) or qualifications (e.g., degree or license) required to implement the intervention.
Description of practice
4.1 Describes intervention procedures (sufficient for replication) or cites sources that provide this information.
4.2 Describes or cites intervention materials (e.g., technology, curriculum, visual supports) used.
Implementation fidelity
5.1 Measures (e.g., direct observation or observation checklist) and reports adequate (i.e., >90%) adherence and differentiation (across conditions) of prescribed procedures.
5.2 Assesses and reports the dosage of the intervention.
5.3 Assesses and reports implementation fidelity (a) regularly throughout the intervention conditions, and (b) by unit of analysis.
Internal validity
6.1 The researcher controls and systematically manipulates the independent variable.
6.2 Describes baseline or control/comparison conditions (e.g., setting, activity, personnel).
6.3 Participants in control/comparison- or baseline-conditions have no or extremely limited access to the treatment intervention.
6.4[a] Describes group assignment and relevant pre-treatment differences between groups.
6.5[b] The design provides at least three demonstrations of experimental effects at three different times.
6.6[b] Single-subject research designs with a baseline phase include at least three data points and establish a pattern that predicts undesirable future performance.
6.7[b] The design controls for common threats to internal validity (e.g., ambiguous temporal precedence, history, maturation, diffusion).
6.8[a] Overall attrition is low across groups (e.g., <30% in a 1-year study).
6.9[a] Differential attrition is low (e.g., ≤10%) or is statistically controlled.
Outcome measures/dependent variables
7.1 Outcomes are socially important (e.g., outcomes related to the general curriculum).
7.2 Defines and describes measurement of the dependent variables with a system that could be replicated.
7.3 All targeted measures of the outcomes are reported.
7.4 Frequency and timing of outcome measures are appropriate (e.g., sufficient baseline/intervention measures).
7.5 The reliability of data collection on outcomes (a) reports method of calculating, and (b) meets minimum standards (i.e., overall IOA > 80%).
7.6[a] The study provides adequate evidence of validity, such as content, construct, criterion, or social validity.

Figure 2. *(continued)*

Data Analysis
8.1[a] Data analysis techniques are appropriate for comparing group change.
8.2[b] Outcome data across all study phases and for each unit of analysis are graphed for visual analysis.
8.3[a] Reports one or more appropriate effect-size statistic for all relevant outcomes, or provides data from which appropriate effect sizes can be calculated.

Figure 2. Definitions of the Council for Exceptional Children's quality indicators of research.
Source. Adapted from "Council for Exceptional Children: Standards for Evidence-Based Practices in Special Education," by B. Cook, V. Buysse, J. Klingner, T. Landrum, R. McWilliam, M. Tankersley, & D. Test, 2014, *Remedial and Special Education*, *36*(4), Table 1. Adapted with permission of the Council for Exceptional Children.
[a]Item applies to group designs only. [b]Item applies to single-case designs only.

What Is the Impact of CAI on Student Outcomes?

Student outcomes. A range of academic skills were examined across CAI studies. Five studies examined outcomes related to English and language arts (ELA) and three examined math outcomes. Studies that examined math outcomes measured students' knowledge of the Nemeth code (Kapperman et al., 2011, 2012) and performance on math problems (Bouck & Weng, 2014). Studies that examined ELA outcomes measured writing skills (e.g., speed, accuracy, and editing behaviors; Bickford & Falco, 2012; Kamei-Hannan & Lawson, 2012), reading level (McLaughlin & Kamei-Hannan, 2018), reading fluency (McLaughlin & Kamei-Hannan, 2018), and spelling accuracy/vocabulary gains (Arslantas et al., 2019).

Experimental outcomes. Both group design studies found statistically significant student gains in knowledge of the Nemeth code (Kapperman et al., 2011, 2012). These studies evaluated an intervention where students learned math symbols from the Nemeth code on a BrailleNote™. In Kapperman et al. (2011), a standardized mean difference of $d = 0.49$ ($p = .02$) was found for reading of math symbols and writing math symbols ($d = 1.01$; $p < .01$). In Kapperman et al. (2012), the effect sizes were calculated from a linear contrast of growth at multiple time points. Authors found effect sizes of $\eta^2 = .16$ ($p = .01$) for math reading outcomes and $\eta^2 = 2.38$ ($p < .01$) for math writing outcomes. Caution should be used in interpreting these results, as studies implemented quasi-experimental designs and authors did not control pretreatment differences during analyses.

Five of the six single-case studies used comparative designs to examine ELA ($n = 5$ studies) or math outcomes ($n = 1$ study). Using visual analysis, inconsistent effects were found across ELA outcomes. McCarthy et al. (2016) found strong effects for using a desktop with an educational application that taught target words to students compared with using teacher-delivered instruction. McCarthy et al. (2016) was one of two studies that measured maintenance and generalization. One maintenance probe was collected within 2 weeks of the completion of the intervention. The percentage of target words was maintained for four of the five students. Pre- and posttest generalization measures indicated that students also learned new braille contractions while using the program. An inconsistent effect was found for using a specialized device to increase reflections and corrections while editing written work (Kamei-Hannan & Lawson, 2012). Bickford and Falco (2012) found no effect for a specialized device on reading and writing speeds. Likewise, no effect on reading speed was found when accessing a digital textbook on a tablet (McLaughlin & Kamei-Hannan, 2018). CAI had no effect on the accuracy of interpreting math problems or time spent solving math problems (Bouck & Weng, 2014). Finally, Arslantas et al. (2019) examined the impact of an application on students' use of semantics and spelling of vocabulary words. Baseline data included measures of student semantics and spelling when no instruction was provided. Authors found strong effects for both outcomes, where visual analysis indicated immediate and sustained changes in level across word sets and students upon implementation of the intervention. Three maintenance measures were collected at 6 weeks, 8 weeks, and 10 weeks after the intervention concluded. Outcomes maintained similar levels for both semantics and spelling of vocabulary across word sets and students. Generalization measures on vocabulary showed all students improved from 0% to 100% accuracy.

Social validity. Four studies examined the social validity of CAI (Arslantas et al., 2019; Bouck & Weng, 2014; Kamei-Hannan & Lawson, 2012; McCarthy et al., 2016). All four studies examined the feasibility of implementation, three studies examined student preferences for instructional or learning media formats (Arslantas et al., 2019; Bouck & Weng, 2014; Kamei-Hannan & Lawson, 2012), and researchers in McCarthy et al. (2016) reported perceived outcomes due to CAI. Studies also collected social validity from multiple sources. The authors collected social validity data from the students in all four studies, TVIs in two studies (Arslantas et al., 2019; McCarthy et al., 2016), and general educators in Bouck and Weng (2014). Students in Kamei-Hannan and Lawson (2012) indicated that the braille notetaker was more efficient than traditional tools. However, students also discussed the limitations of devices, such as being unable to display complete graphs and being able to write more using traditional tools. Most students preferred traditional media to the braille notetaker. TVIs in McCarthy et al. (2016) reported that after initial instruction with the device's functions, most students were able to use the device independently. In fact, across studies, adults indicated that they were able to reduce the amount of direct support in inclusive settings with CAI and that CAI could be feasibly implemented. However, some TVIs said that the materials in McCarthy et al.'s (2016) CAI were not tied into a specific curriculum. Students generally preferred the application in McCarthy et al. (2016) to traditional instruction. In Bouck and Weng (2014), most students preferred traditional media. Moreover, both students and their TVIs identified that technical issues arose while using devices. Finally, students in Arslantas et al. (2019) reported that the instant feedback their educational application provided motivated them to learn.

Discussion

Computers can provide multimedia access to information and promote engagement with academic content for students with VI. Moreover, computers can convert content across media more efficiently than many traditional means, such as transcribers. However, little is known about the impact these computers have had on the outcomes of students with VI. We reviewed all eight available studies evaluating the effects of CAI interventions among school-age children with VI. Our findings extend the knowledge base on using CAI with students with VI.

First, this review identified a number of CAI interventions for students with VI that educators might draw upon. Interventions primarily focused on braille notetakers and desktop computers used to provide students with learning modules and access to digital texts. Moreover, these CAI approaches were used to promote a wide range of outcomes for students with VI. For example, CAI developed students' vocabulary knowledge and Nemeth knowledge. Indeed, CAI seems to be flexibly individualized across a wide range of student needs. For example, some studies examined word processors that provided students with additional tools for editing and formatting to promote writing skills, whereas other interventions focused on customizing settings to increase reading speeds. Regardless, the consolidation of these strategies, along with their outcomes, provides educators information for aligning CAI strategies to student needs.

Second, there is still insufficient evidence to establish CAI as an EBP for students with VI. Current standards for group design studies require at least two randomized control trials that sufficiently control for between-group differences to be considered an EBP. A minimum of five single-case studies are needed to establish an EBP and the studies must (a) demonstrate experimental control, (b) meet acceptable methodological criteria, and (c) be conducted by at least three different research teams across multiple institutions. The eight studies we reviewed did not meet either of these criteria. Moreover, the studies yielded inconsistent effects. Specifically, group studies did not sufficiently control for between-group differences and strong demonstrations of effects were only present in two of the six single-case studies.

Despite the lack of effects found in these studies, this body of literature still yielded some promising results. For example, studies that examined gains in knowledge, such as recognition of braille symbols and vocabulary, produced greater effects than studies that examined the impact of CAI on skills, such as oral reading rate. Thus, CAI strategies may produce stronger effects for certain student outcomes. However, such findings should be interpreted with caution due to the methodological issues discussed below. Moreover, CAI did not have a countertherapeutic impact on skills such as reading speeds. Although students may not have improved these skills using CAI, studies indicated these skills might be performed comparably on devices compared with traditional media.

Third, several methodological issues were present in these studies. Particularly concerning were issues related to internal validity, which included a lack of fidelity of implementation measures, uncontrolled pretreatment differences between groups, high levels of attrition, not limiting access to treatment in control conditions, and insufficient data. Issues with internal validity temper some of the promising effects. More than half of the studies did not report fidelity of implementation, which would have helped clarify the relationship between the interventions and outcome measures. Moreover, group design studies did not establish group comparability, even after high levels of attrition. Group comparability is fundamental to evaluating the impact of interventions on outcomes. Likewise, several single-case design studies did not limit exposure to the intervention across conditions (e.g., Bouck & Weng, 2014; Kamei-Hannan & Lawson, 2012). Mixed findings across single-case studies may have been affected by exposure to treatment across conditions. Thus, it is difficult to determine the true effectiveness of these interventions. Future studies should explain procedures for limiting carryover of intervention effects (e.g., limited access to technology in comparison conditions), as done in two studies in this review (i.e., Bickford & Falco, 2012; McLaughlin & Kamei-Hannan, 2018).

Methodological features related to the external validity of studies could also be improved. Specifically, half of the studies lacked measures of social validity. Although CAI carries practical benefits for accessing information and instruction, examining the social importance of intervention goals, procedures, and outcomes from the perspectives of participating students, parents, and/or teachers provides critical information about information. For example, stakeholders' views on acceptability and feasibility provide crucial information for promoting the adoption of interventions and scaling up their use in classrooms. Moreover, stakeholders' feedback on interventions can further improve interventions to become more practical and readily implemented by school personnel.

Limitations

Several limitations should be considered when interpreting the findings of this review. First, the definition of CAI focused on studies that utilized instructional activities taking place primarily on computer devices. Other reports have utilized broader definitions of CAI that may have yielded more results (e.g., Odom et al., 2015). The purpose in narrowing the definition was to focus on interventions that incorporate rich interaction with computers rather than interventions that utilize computers as a simple prompting device (e.g., haptic canes, bug in the ear). Second, we only reviewed studies published in peer-reviewed journals and did not include unpublished research or dissertations. The decision to include only peer-reviewed research may also leave these findings vulnerable to publication bias (Shadish et al., 2016). Third, we applied quality indicators published by the Council for Exceptional Children in 2014 (Cook et al., 2014) to evaluate the methodological quality of studies published prior to 2014. Reporting standards have changed over time. Caution should be used when assessing the methodological quality of past publications with updated standards. Fourth, we did not include social and communication outcomes in this review. These skills often include technology related to a distinct body in augmented and alternative communication.

Implications for Research

This review highlights several directions for future CAI research involving students with VI. First, more rigorous experimental research is needed. The field of VI has struggled to identify EBPs (Ferrell et al., 2014). However, several CAI studies produced promising experimental findings, suggesting that additional research could help establish CAI as an EBP. Second, future research should improve the methodological quality of studies. Mixed findings and poor methodological quality across studies limited experimental findings. For example, only one of eight experimental studies reported implementation fidelity measures. Incorporating implementation fidelity measures could help clarify active ingredients or the level of precision implementers need to obtain positive results. Third, future researchers should seek to improve the generalizability and social validity of CAI studies. Seeking the feedback of CAI interventions and incorporating educators in the implementation of interventions would improve the social validity of CAI. This may make CAI more likely to be adopted by educators by prompting stakeholders to recognize the importance of technology among these students.

Implications for Practice

Our findings have important implications for practitioners who support students with VI. First, this review identified several CAI approaches for educators to use with their students. Moreover, some forms of CAI found promising effects attributed to CAI. However, there is insufficient evidence to classify CAI as an EBP for this population. Thus, educators should use caution when selecting CAI interventions by assessing each student's needs, making data-based decisions, and closely monitoring student's progress.

Second, educators should consider the individual needs of students when implementing CAI. CAI interventions can take many forms that can and should be adapted to meet the individualized needs of a student with VI. This flexibility allows CAI to be implemented with a diverse set of students and outcomes in a variety of contexts. However, consideration must be given to the varying time requirements across CAI strategies. For example, the intensive procedures used in Kamei-Hannan and Lawson (2012) may be difficult for itinerant teachers to implement due to the time constraints associated with this service model (Wolffe et al., 2002). Indeed, many of these interventions were implemented in schools for the blind. Still, these interventions are a promising way of incorporating multiple expanded core curriculum skills (Lohmeier et al., 2009) into a single intervention. Thus, CAI has promise as an instructional strategy across service models, although implementation across models may be different.

Third, interventions also lack a level of specificity to guide educators with limited knowledge regarding technology. Thus, educators will likely need additional training to implement CAI effectively. School administrations should seek out professional development opportunities for CAI to promote AT and instructional technology application in school systems. Some ways, administrators can provide or promote AT professional development.

Conclusion

Computers play a critical role in the educational experiences of students with VI. This review examined experimental research to identify the devices and procedures used within CAI, the student outcomes that have been addressed, and the quality and outcomes of these studies. Several studies demonstrated promising effects for CAI on student outcomes. Moving forward, high-quality intervention evaluations are needed, particularly ones that recruit a more diverse population of students with VI and enhance the social validity of these practices.

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