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Review

Use of computer-based interventions to improve literacy skills in students with autism spectrum disorders: A systematic review

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ABSTRACT

The purpose of this review is to provide a systematic analysis of studies investigating computer-based interventions (CBI) to improve literacy skills (e.g., reading, writing, and vocabulary) in students with autism spectrum disorders (ASD). This review synthesizes intervention outcomes, appraises the certainty of evidence, and describes software features and system requirements for each CBI. Across studies, CBI's effect on literacy skills was inconsistent. Some studies reported significant results and large effect sizes and other studies reported no improvements. Given the heterogeneity of the participants and the wide variety of literacy skills targeted for instruction, it is not possible from the existing literature to determine the variables most likely to be associated with effective CBI. Future research addressing this area as well as the relative effectiveness of CBI versus person delivered literacy instruction is warranted.

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Contents

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1. Introduction

Autism spectrum disorders (ASD) are pervasive developmental disorders that include autistic disorder, Asperger syndrome and Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS; American Psychiatric Association, 2000). Many school-aged children with ASD appear unresponsive to traditional approaches (e.g., didactic and constructivist approaches) to teaching literacy skills (Lord, Rutter, & Le Couteur, 1994; Prizant, 1983; Tager-Flusberg, 1999). Regardless of whether instruction occurs in regular education classrooms or in special education/remedial classrooms with lower student–teacher ratios and specialist teachers, students with ASD often have difficulties with learning symbols and communicating academic concepts. Students with ASD also appear to have difficultly in forming appropriate relationships with teachers and other students, which might impede their academic progress (Krantz & McClannahan, 1999; Koegel, Matos-Fredeen, Lang, & Koegel, in press; Machalicek et al., 2008; Pelios, MacDuff, & Axelrod, 2003). Additionally, children with ASD may develop challenging behaviors (e.g., tantrums and aggression) that further complicate teachers' efforts to create an atmosphere conducive to academic instruction (Browder & Spooner, 2006; Fox, Dunlap, & Buschbacher, 2000; Kliewer & Biklen, 2001; Machalicek, O'Reilly, Beretvas, Sigafoos, & Lancioni, 2007).

In recent years, the number of children diagnosed with ASD has risen steeply and overwhelmed the resources of many school systems (Coo et al., 2008; Guillermo & Halterman, 2006). For example, many schools lack a sufficient number of teachers trained to teach in inclusive settings (Ganz, 2006; Lang et al., 2010; Scheuermann, Webber, Boutot, & Goodwin, 2003). Despite the challenges inherent in educating students with ASD, federal legislation mandates that all students make academic progress (Individuals with Disabilities Education Act [IDEA], 2004; No Child Left Behind Act [NCLB], 2001). Therefore, research aimed at developing efficient and effective academic instruction methods suitable in both inclusion and special education classrooms is a high priority (Machalicek et al., 2010; Matson, Sevin, Box, & Francis, 1993).

Computer-based instruction (CBI; e.g., Bosseler & Massaro, 2003; Hetzroni & Tannous, 2004) is a potentially viable approach to teaching literacy skills to students with ASD for several reasons (Powell, 1996). First, research has shown that students with ASD often respond well to teaching techniques that involve information presented visually (Bondy & Frost, 1994; Whalen et al., 2010) and, CBI presents opportunities for dynamic customizable visual displays. Second, CBI could be used to minimize the impact of social deficits inherent in ASD by reducing the quantity and complexity of student–teacher interactions. That is, students with ASD might benefit more from literacy instruction if they do not have to simultaneously engage in social interaction with the teacher. Third, research has suggested that students with ASD tend to be highly responsive to using computers, which could make academic demands delivered via computers less aversive or more palatable (Lahm, 1996). Finally, CBI can be used to individualize instruction by selecting difficulty settings appropriate for a particular student's ability level.

Although CBI offers several potential benefits to students with ASD, potential negative outcomes are also possible. For example, if students and teachers interact less when the student is using the computer then the student may have fewer opportunities to practice verbal communication, social skills, joint attention, and eye contact. The reduced opportunity for social interactions could lead to missed opportunities to develop social skills or even to a loss of social skills (e.g., Bernard-Opitz, Ross, & Tuttas, 1990). Additionally, because children with ASD may have a tendency to perseverate on computer use, CBI may result in the development or strengthening of computer-based stereotypies and/or challenging behavior maintained by computer access (e.g., Powell, 1996).

Several recent reviews have examined the effectiveness of CBI. Blischack and Schlosser (2003) conducted a review on the role of speech generating devices and talking word processing software on teaching independent spelling to children with autism. Their review revealed the importance of multi-model feedback (i.e., speech and print) in teaching spelling to learners with autism. Ramdoss et al. (2011) reviewed CBI used to improve communication in children with ASD and found CBI to be a promising practice for improving vocal and nonvocal communication. Given the need to ensure the academic progress of students with ASD, a systematic review on the use of CBI to teach literacy skills (e.g., reading, sentence construction) for students with ASD is warranted.

The purpose of this review was to provide a systematic analysis of studies in which CBI was used to teach literacy skills to students with ASD. This review describes characteristics of the included studies, evaluates intervention outcomes, and appraises the certainty of evidence. This review has three main aims: (a) to evaluate and synthesize the evidence-base, (b) to inform and guide practitioners interested in the use of CBI and, (c) to stimulate and guide future research aimed at improving literacy outcomes for students with ASD.

2. Method

This literature review involved a systematic analysis of intervention studies that focused on the use of CBI to teach literacy skills to students with ASD. Studies were included in this review based on pre-determined inclusion criteria. Each included study was analyzed and summarized in terms of (a) participant characteristics, (b) literacy skills targeted, (c) pertinent details regarding the computer hardware and software, (d) outcomes of CBI, and (e) certainty of evidence.

2.1. Search procedures

Systematic searches were conducted in four electronic databases: Education Resources Information Center (ERIC), Medline, Psychology and Behavioral Sciences Collection, and PsycINFO. The keywords fields in all four databases were searched using the Boolean terms (Autis*) or (Asperger*) or (ASD) or (PDD*), (literacy) or (read*) or (spelling) or (vocabulary) or (word) or (phon*) or (compreh*) or (sentence) or (grammar) or (math*) or (science) or (social stud*) or (art) or (music*) or (problem solving) and (computer) or (software). The search was restricted to articles written in English and published between 1990 and 2010 in peer-reviewed journals. Initially 229 studies were produced by the electronic database search. The abstracts of these 229 studies were screened according to pre-determined inclusion and exclusion criteria. Following the electronic database searches, reference sections of included studies were searched to identify additional studies for possible inclusion. Ultimately, 12 studies were included in the review.

2.2. Inclusion and exclusion criteria

In order to be included in this review, an article had to meet three criteria. First, an intervention delivered via a computer software program must have been evaluated. Second, the study had to contain at least one participant between the ages of 3 and 21 years old with a diagnosis of autism, Asperger syndrome, or PDD-NOS. Third, a study must have measured at least one dependent variable pertaining to literacy skill. For the purposes of this review, ''literacy skill'' was defined as a skill related to the decoding, comprehension, or creation of written text (e.g., reading comprehension, writing, spelling, grammar, vocabulary, pronunciation).

Studies were excluded from this review for the following three reasons. Due to immense change in the capacity and diversity of applications of computer technology over the past two decades, studies published prior to 1990 were excluded in order to focus on technology relevant to present day classroom contexts. Studies in which computers were used solely as a means to deliver reinforcers (e.g., Soares, Vannest, & Harrison, 2009) or provide video modeling (e.g., Kinney, Vedora, & Stromer, 2003; Mechling & Langone, 2000; Sansosti & Powell-Smith, 2008) were excluded. Similarly, computer programs that allowed only minimal input and control (e.g., play, stop, next) were considered video technologies, analogous to DVD players, and were excluded (e.g., Kinney et al., 2003).

2.3. Data extraction and coding

After all studies initially identified were assessed against the inclusion and exclusion criteria, included studies were summarized in terms of the following features: (a) participant characteristics, (b) literacy skills targeted, (c) details regarding the computer-based instruction, (d) intervention outcomes (including any relevant social validity or treatment acceptability data) and, (e) certainty of evidence. Various procedural aspects were also noted, including setting, experimental design, and inter-observer agreement (IOA). Finally, details regarding the computer hardware utilized and the system requirements were recorded.

Outcomes of CBI on literacy skills were summarized in several ways depending on the studies' experimental design. For studies that employed group designs or analyzed data at the group level, standardized mean difference effect sizes were estimated from *F*-statistics or repeated measures data using unbiased calculations of Hedges' g (Cooper & Hedges, 1994; Hedges & Olkin, 1985). Hedges g was chosen because it is less subject to error than other effect size calculations when used with small samples (i.e., $n < 30$; Hedges & Olkin, 1985).

For single subject design studies, the Nonoverlap of All Pairs (NAP; Parker & Vannest, 2009) was calculated from graphed data. NAP is an index of data overlap between single-subject design phases similar to Percent of Nonoverlapping data (PND; Scruggs & Castro, 1987), Percent of All Nonoverlapping Data (PAND; Parker, Hagan-Burke, & Vannest, 2007), and Percentage Exceeding Median (PEM; Ma, 2006). However, NAP equals or outperforms PND, PAND, and PEM in terms of its relationship with visual judgment, confidence interval width, and a stronger correlation R^2 (one of the leading effect sizes used in publication) (Parker & Vannest, 2009). Additionally, NAP may be more robust in terms of its resistance to influence from outliers (e.g., maximum values appearing one time during baseline). NAP is calculated by comparing every baseline (phase A) data point with every intervention (phase B) data point. In studies of treatments designed to increase behavior, a ''nonoverlapping pair'' is an ''AB'' pair in which the ''B'' point is higher than the ''A'' point. The NAP is calculated by dividing the number of comparison pairs not showing overlap by the total number of comparisons. Using the guidelines for interpretation recommended by Parker and Vannest (2009), NAP scores between 0 and .65 can be classified as ''weak effects,'' .66–.92 as ''medium effects,'' and .92–1.0 as ''strong effects.'' For more complete details on NAP calculation procedures and statistical validation see Parker and Vannest (2009).

For three studies (i.e., Basil & Reyes, 2003; Stromer, Mackay, Howell, & McVay, 1996; Williams, Wright, Callaghan, & Coughlan, 2002), quantitative summarization was not possible. Characteristics of the studies' design and the data reported did not meet the criteria for use of NAP or standardized mean difference effect sizes. Results for these studies were summarized as either "positive", "mixed", or "negative" (Machalicek et al., 2007). A classification of "positive" indicates all participants registered gains on all dependent measures. "Mixed" indicates that the participant(s) improved on some dependent measures and remained constant or declined on the others. "Mixed" was also used if some participants improved but others did not. "Negative" indicates the participants' literacy skills declined or remained constant on all dependent measures.

Certainty of evidence was evaluated by considering the results in light of the research design and other methodological details (Schlosser & Sigafoos, 2007). The certainty of evidence for each study was rated as either "suggestive", "preponderant", or "conclusive". This classification system was adapted from the descriptions provided by Smith (1981) and Simeonsson and Bailey (1991). The lowest level of certainty is classified as suggestive evidence. Studies within this category may have utilized AB or intervention only designs, but did not involve a true experimental design (e.g., group design with random assignment, multiple baseline, or ABAB). The second level of certainty was classified as preponderant evidence. Studies within this level contained the following five qualities. First, studies in this category utilized an experimental design. For single subject designs this also required demonstration of experimental control (e.g., divergence in data paths within an alternating treatment design). Second, adequate interobserver agreement (IOA) and treatment fidelity measures were reported (i.e., a minimum of 20% of sessions with 80% or higher agreement or reliability). Third, dependent variables were operationally defined. Fourth, sufficient detail to enable replication was provided. The fifth quality of studies at the preponderant level was that they were in some way limited in their ability to control for alternative explanations for treatment effects. For example, if concurrent interventions (e.g., CBI and teacher implemented discrete trial training) were targeting the same or related dependent variables and no design feature controlled for the influence of the non-CBI on the literacy dependent variable, the study may be classified at the preponderant level. The highest level of certainty was classified as conclusive. Within this level, studies had all the attributes of the preponderant level, but also provided at least some control for alternative explanations for treatment gains (e.g., a multiple baseline across participants in which the introduction of the CBI was staggered and concurrent interventions were held constant or a group design with appropriate blinding and randomization).

2.4. Reliability of search procedures and inter-rater agreement

In order to ensure the accuracy of the systematic search, two authors independently conducted the database and reference list searches. Of the 229 articles initially identified by the database search, 17 studies appeared relevant and were considered for inclusion. Reference list searches produced no additional articles. The two authors collaboratively assessed the 17 relevant studies and concluded that 12 met the criteria for inclusion.

After the list of included studies was agreed upon, the first and third author extracted information to develop an initial summary of the 12 included studies. The accuracy of these summaries was independently checked by one of the remaining co-authors using a checklist that included the initial summary of the study and five questions regarding various details of the study. Specifically, (a) is this an accurate description of the participants? (b) Is this an accurate description of the literacy skills being targeted? (c) Is this an accurate summary of the CBI? (d) Is this an accurate description of the results? (e) Is this an accurate summary of the certainty of evidence? Co-authors were asked to read the study and the summary and then complete the checklist. In cases where the summary was not considered accurate, the co-authors were asked to edit the summary to improve its accuracy. This process was continued until co-authors were in 100% agreement regarding the accuracy of the summaries. The resulting summaries were then used to create Table 1. This approach was intended to ensure accuracy in the summary of studies and to provide a measure of inter-rater agreement on data extraction and analysis. There were 60 items on which there could be agreement or disagreement (i.e., 12 studies with 5 questions per study). Initial agreement was obtained on 53 items (88%) and then corrected until 100%.

3. Results

Table 1 summarizes: (a) participant characteristics, (b) literacy skills targeted, (c) details of the CBI, (d) outcomes, and (e) certainty of evidence for the 12 studies identified that involved the use of CBI to teach literacy skills to students with ASD.

3.1. Participant characteristics

These 12 studies included a total of 94 participants. Individual studies' samples ranged in size from 1 to 22 ($M = 8$). Fifty participants were male (53%), 14 were female (15%), and the sex of the remaining 30 (32%) was not reported. Participants ranged in age from 3 to 21 years old ($M = 9.6$ years). All participants had a diagnosis of autism. Based on the descriptions given by the authors of the included studies, the majority of participants would best be described as having mild to moderate autism symptoms. Two studies included participants with severe autism symptoms (Bosseler & Massaro, 2003; Moore & Calvart, 2000).

Table 1
Summaries and analysis of included studies.

Citation	Participant characteristics	Literacy skill(s) targeted	Computer-based intervention	Outcomes and certainty of evidence
Basil and Reyes (2003)	1 male and 1 female; with mild to moderate autism; 8 and 14 years old	Sentence construction, reading of letters, syllables, words, and sentences, and reading comprehension	*Software*: Delta Messages (Nelson & Heimann, 1995) *Hardware*: Macintosh computer *Procedures*: Software presented a cartoon with animation and, participants constructed a sentence describing the cartoon by selecting the appropriate words. Software provided feedback in animations and digitized speech. Teachers were present during CBI and provided on-going guidance and verbal feedback *Time*: 30 min per session, 2 sessions per week for 3 months, totaling 24 sessions and 12 h *Setting*: Special education classroom	*Results*: No results obtained for male participant. Mixed results reported for female participant; gains observed in sentence construction, reading of letters, and reading comprehension. No change observed in reading syllables, words, and sentences *Certainty*: Suggestive, pre-experimental design and no control for concurrent academic instruction
Bosseler and Massaro (2003)	7 males and 1 female; with mild to moderate autism; 7–12 years old ($M = 10$ years)	Receptive identification of pictures and vocabulary words	*Software*: Baldi/Timo (Animated Speech Corp., 2010) *Hardware*: 600 MGz PC with 128 RAM *Procedure*: CBI progressed in difficulty ultimately requiring speech from participants. Software delivered digital smiling or frowning face as feedback for target behavior *Time*: 10–40 min per session, 2 sessions per week, for 6 months *Setting*: School-based program for children with autism	*Results*: Experiment 1: Number of vocabulary words increased ($\delta_{RM} = 0.710$); Experiment 2: Number of vocabulary words increased ($\delta_{RM} = 2.884$) *Certainty*: Conclusive; although TF was not measured, the 2nd experiment served the same function as TF by providing evidence that gains were due to CBI. The second experiment also provided a control for alternative explanations for treatment gains
Coleman-Martin et al. (2005)	1 female; with mild to moderate autism; 12 years old	Receptive identification of vocabulary words	*Software*: Microsoft PowerPoint (Microsoft, 2010) *Hardware*: NR *Procedure*: Three conditions compared: CBI only, CBI + teacher instruction, and teacher instruction only. CBI involved student engagement with PowerPoint slides. Initial slides displayed a target word and prompted the student to say the word while the computer also pronounced the word. Subsequent slides involved presentation of words by phonemes. Final slides returned to the whole word. Feedback included colorful pictures and audio praise (i.e., "excellent!"). *Time*: NR *Setting*: Self-contained classroom for students with autism	*Results*: Number of vocabulary words increased ($NAP = 100\%$). Person implemented instruction also associated with a NAP value of 100% *Certainty*: Suggestive; the design utilized was an ABACAD, in which "A" was baseline, "B" teacher instruction, "C" Teacher + CBI, and "D," CBI only. Therefore, the effect of CBI was not replicated for the participant with autism and the sequencing of conditions may have influenced results
Heimann et al. (1995)	A total of 30 children were assigned to 1 of 3 groups based upon diagnosis. The autism group included 9 males and 2 females; with mild to moderate autism; 7–14 years old ($M = 9$ years)	Reading of letters, words, and sentences, sentence imitation, verbal expression, and phonological awareness	*Software*: The Alpha program (Nelson & Prinz, 1991) *Hardware*: Apple IIGS microcomputer with 128K RAM and a printer & Sony videodisc player *Procedure*: Software delivered specialized curriculum of 4 modules and 112 lessons. Participants progressed through the program as test scores indicated mastery of each level. Software provided visual and audio stimuli as feedback *Time*: Sessions were 32 min ($SD = 12.6$ min). On average, children with autism received 25.6 sessions ($SD = 7.5$ sessions) across 16.9 weeks ($SD = 5.7$ weeks) *Setting*: Schools and daycares in Sweden	*Results*: For the autism group, reading letters, words, and sentences improved ($\delta_{RM} = 0.663$), sentence imitation improved ($\delta_{RM} = 0.428$), verbal expression improved ($\delta_{RM} = 0.446$), and phonological awareness improved ($\delta_{RM} = 0.164$) *Certainty*: Preponderant; group assignment was not random and teachers did not administer outcome measures to participants who they believed would be too difficult to test. This likely biased data towards positive results

Hetzroni and Shalem (2005)	3 males and 3 females; with mild to moderate autism; 10–13 years old (M = 11 years)	Identification and matching of words to pictures	*Software*: Designed by researchers using C++ programming language *Hardware*: IBM PC *Procedure*: Program implemented a 7 step gradual fading procedure that progressed from a picture of a food item (e.g., bag of chips) with a written and graphic label to only the written word. Smiley face graphics were used as feedback. Following CBI training, students matched written text to food items in the classroom as a means to request *Setting*: School computer room and classroom *Time*: 8–11 sessions (M = 9 sessions), session length NR	*Results*: Correct matches between text and food items improved for all participants (M NAP = 90.3%, values ranged from 79% to 97.9%); results maintained overtime *Certainty*: Conclusive; although TF was NR, the researcher observed all intervention sessions to ensure computer program ran as designed
Massaro and Bosseler (2006)	4 males and 1 female; with mild to moderate autism; 8–13 years old (M = 10 years)	Receptive identification of pictures and vocabulary words	*Software*: Baldi/Timo *Hardware*: Toshiba Satellite laptop with 1 GHZ Pentium 3 and 512 MB memory *Procedure*: Program provided 5 exercises (pre-test, presentation, recognition, elicitation, and post-test). The software presented each novel item, prompted the student to select parts of items with the mouse and verbally name or state their function. Software provided audio praise and a happy or sad face as feedback *Setting*: School program for children with autism *Time*: 14 sessions, 30 min per session	*Results*: The overall average of correct receptive responses pooled across lessons increased ($\delta_{F\text{-}test}$ = 3.694). Animated talking head plus synthesized voice resulted in more correct responses than the voice alone *Certainty*: Suggestive; the data was collapsed and analyzed across participants precluding detailed analysis
Moore and Calvart (2000)	12 males and 2 females, with mild to severe autism; 3–6 years old	Identification of vocabulary words	*Software*: A researcher developed program created for the study *Hardware*: NR *Procedure*: Program gave digitized voice commands (e.g., "touch the ladybug") and provided animations, praise, and interesting sounds contingent upon correct responses *Time*: CBI took place over a 2 day period, but duration of sessions was NR *Setting*: Specialized school for children with autism	*Results*: Number of words correctly identified increased ($\delta_{F\text{-}test}$ = 1.651) *Certainty*: Preponderant; details regarding the type of hardware and piloted software developed for this study were not provided in sufficient detail to enable replication
Stromer et al. (1996)	1 male; with moderate autism and profound hearing loss; 21 years old	Matching of pictures to printed words, anagram spelling, writing words for pictures, and delayed word construction	*Software*: Researcher developed program *Hardware*: Macintosh desktop computer with touch screen *Procedures*: Software provided tasks for either matching pictures with words or matching words with pictures. Correct responses reinforced with flashing display and tokens, which were exchanged for soda after session *Settings*: Quiet room *Time*: 20 min per session; 3–6 sessions/week; total number of sessions = 83	*Results*: Positive; subject improved with regard to all academic skills measured *Certainty*: Conclusive

Table 1 (*Continued*)

Citation	Participant characteristics	Literacy skill(s) targeted	Computer-based intervention	Outcomes and certainty of evidence
Tjus et al. (1998)	10 males and 3 females; with mild to moderate autism; 4–11 years old (M = 9 years)	Reading accuracy and speed, phonological awareness, and sentence identification	*Software*: Delta Messages *Hardware*: Color Macintosh computer with 8 MB RAM *Procedures*: Software guided children to construct sentences. Lesson plans customized for each student. Program covered noun–verb–noun sequences, prepositions, conjunctions, and adjectives. Software provided multi-channel feedback. *Time*: 15–30 min/sessions; M = 15.2 training sessions, 3–4 months of intervention *Setting* = NR	*Results*: Gains observed on reading accuracy (δ_{RM} = 1.031), reading speed (δ_{RM} = 1.374) and phonological awareness (δ_{RM} = 0.777). No gains observed on sentence identification. Size of gains on dependent variables appeared to be correlated with nonverbal mental level and receptive language (observation not statistically tested) *Certainty*: Suggestive; researchers employed a quasi-experimental design which involved pre- and post-tests for a single group
Whalen et al. (2010)	47 students (22 in treatment group, 25 in control group); with mild to moderate autism; 3–6 years old	Receptive language, expressive vocabulary, and "academic/cognitive skills"	*Software*: Teach Town Basic *Hardware*: NR *Procedures*: Software gave verbal instructions and guided students in problem solving activities. Problems were posed and students selected a response from 3 to 8 choices. Feedback was organized according to principles of ABA. *Time*: 20 min of computer use and 20 min of non-computer activity each school day for 3 months *Settings*: Classroom	*Results*: Preschool age students in treatment group made larger gains than those in control group on receptive language measure ($\delta_{F\text{-}test}$ = 0.962). All other between group comparisons were insignificant. Students in treatment group who mastered at least one lesson improved on "academic/cognitive skills" ($\delta_{F\text{-}test}$ = 3.320). Students in treatment group who did not master a lesson reported to have lower developmental levels (observation not statistically tested) *Certainty*: Preponderant; seven students in treatment group did not master a lesson and thus did not complete a post-test. Exclusion of students from measurement positively biased results
Williams et al. (2002)	8 children; with mild to moderate autism; sex NR, 3–5 years old (M = 4 years)	Reading words and time on task	*Software*: Researcher developed program made with Illuminatus Version 4.0, Paintshop Pro and a "simple wave editor" *Hardware*: Desktop PC *Procedures*: Software narrates a story as students click to turn pages, hear sounds, and play games. Positive cheering sound offered as feedback *Settings*: Quiet room *Time*: 15 min/session, 5 sessions/week, study lasted 10 weeks	*Results*: Negative with regard to reading words; students did not read substantially more words following CBI. Positive with regard to time on task; students spent more time on task during CBI than during book learning sessions *Certainty*: Preponderant; study is limited in its ability to control for alternative explanations and details provided on CBI were insufficient for replication
Yamamoto and Miya (1999)	3 males; with mild to moderate autism; 6–11 years old (M = 8 years)	Sentence construction, particle choice, and verbal production of constructed sentences	*Software*: Researcher developed program *Hardware*: Macintosh (Quadra800) and bus mouse *Procedures*: Software showed picture of a person doing an action and modeled description of picture with three words. Students then practiced selecting descriptive words for pictures from word bank. Fanfare sound used as positive feedback. Additionally, every 9 trials, the researcher provided student verbal praise, physical touch, and a "small prize" or "desirable card" *Settings*: Quiet room *Time*: Students had prior computer training, 20 min/session, 1 session/week; total number of weeks NR	*Results*: All students improved substantially on percent correct of untrained stimuli for sentence construction (M NAP = 100%), particle choice (M NAP = 100%), and verbal production tasks (M NAP = 100%) *Certainty*: Conclusive

Note: CBI = computer-based instruction; M = mean; δ_{RM} = standardized mean difference effect size, estimated from repeated measures data using the unbiased calculation of Hedges' g; TF = treatment fidelity; NR = not reported; NAP = Nonoverlap of All Pairs statistic; $\delta_{F\text{-}test}$ = standardized mean difference effect size, estimated from F-test results using the unbiased calculation of Hedges' g; ABA = applied behavior analysis.

3.2. Hardware and software programs

In nine studies, the hardware requirements for software programs were described in detail. Of these, eight studies utilized desktop computers and one study used a laptop (Massaro & Bosseler, 2006). The processors and memory required were well below the current capabilities of common store bought computers (i.e., less than 2 GHz of processing speed and less than 500 MB of RAM). Hardware used for input included keyboards, mice, and touch screens.

Eight studies described the software utilized. Six of these studies made use of commercially available programs specially designed for instruction including, Baldi/Timo (Bosseler & Massaro, 2003; Massaro & Bosseler, 2006), Delta Messages (Basil & Reyes, 2003; Tjus, Heimann, & Nelson, 1998), Alpha program (Heimann, Nelson, Tjus, & Gillberg, 1995) and Teach Town: Basics (Whalen et al., 2010). The other two studies made use of multi-media presentation software (i.e., MS PowerPoint and Illuminatus). In the studies involving multimedia presentation software, the researchers created interactive presentations using the various tools and templates built into the programs (Coleman-Martin, Heller, Cihak, & Irvine, 2005; Williams et al., 2002). Table 2 provides a summary of each software program's capabilities, availability, price at the time this review was submitted, minimum hardware requirements, and citations for product information.

3.3. Literacy skills targeted

Across studies, a variety of dependent variables associated with literacy skills were examined (e.g., sentence construction, word construction, phonological awareness, reading, expressive and receptive language). Two studies measured the effectiveness of CBI on sentence construction (i.e., Basil & Reyes, 2003; Yamamoto & Miya, 1999). One study examined the effectiveness of CBI on word construction (Stromer et al., 1996). Two studies (i.e., Heimann et al., 1995; Tjus et al., 1998) examined the efficacy of CBI on improving phonological awareness in students with ASD. Four studies examined the role of CBI in improving reading skills in students with ASD (Basil & Reyes, 2003; Heimann et al., 1995; Tjus et al., 1998; Williams et al., 2002). Two studies (Massaro & Bosseler, 2006; Whalen et al., 2010) examined the effectiveness of CBI on receptive language and three studies (Heimann et al., 1995; Whalen et al., 2010; Yamamoto & Miya, 1999) examined the effectiveness of CBI on expressive language of students with ASD. Finally, three studies (Bosseler & Massaro, 2003; Coleman-Martin et al., 2005; Moore & Calvart, 2000), examined the effectiveness of CBI on student's vocabulary.

3.4. Outcomes

Across studies, CBI's effect on literacy dependent variables was inconsistent. Studies permitting quantitative summarization reported small, medium, large/strong, and statistically nonsignificant effects. Similarly, the studies for which only qualitative summarization was possible reported positive, mixed, and negative results. By averaging statistically significant dependent outcomes, first within and then across studies, CBI was found to have a repeated measures-derived effect size of 1.094, an *F*-statistic-derived effect size of 2.495 and a NAP of 96.8%. Confidence intervals for the effect size estimates and NAP statistics were not calculated due to the inadequate size of study samples and the resulting instability of variance estimates (Hedges & Olkin, 1985).

3.4.1. Sentence and word construction

With regard to sentence construction and sentence imitation, CBI was associated with positive results and statistically insignificant effects, respectively. Basil and Reyes (2003) observed their participant to make positive gains in sentence construction across CBI sessions. Yamamoto and Miya (1999) observed their two participants make substantial gains in sentence construction and particle choice (*M* NAP = 100%). However, Tjus et al. (1998) found statistically insignificant improvements on sentence imitation from pre- to post-test. CBI for the training of word writing and delayed word construction was associated with positive results (Stromer et al., 1996).

3.4.2. Phonological awareness

The two studies which aimed to raise phonological awareness found CBI was associated with small to moderate effects. Heimann et al. (1995) observed participants make small gains in phonological awareness across repeated measures ($\delta_{RM} = 0.164$). Tjus et al. (1998) recorded moderate effects for their participants ($\delta_{RM} = 0.777$).

3.4.3. Reading

With regard to reading, CBI was associated with both negative and positive results and moderate and large effects. Williams et al. (2002) found their group of participants did not read substantially more words following CBI. Similarly, Basil and Reyes (2003) observed their participant did not improve on reading syllables, words, or text. However, Basil and Reyes (2003) found their participant did improve on reading letters and reading comprehension. Heimann et al. (1995) assessed participants' reading of letters, words, and sentences, and recorded moderate gains on a cumulative measure ($\delta_{RM} = 0.663$). Tjus et al. (1998) measured participants' reading accuracy and reading speed, and observed large gains on both ($\delta_{RM} = 1.031$ and $\delta_{RM} = 1.374$, respectively).

Table 2
Summary of software capabilities, availability, approximate price, and system requirements.

Software	Capabilities	Availability and price	Minimum system requirements	Citations
Alpha program	Student selects words or makes sentences and the computer then displays the words/sentences, animated color graphics, gives audible speech output, and American Sign Language translation	Discontinued by the manufacturer; price not available	Designed for use with Apple IIe & Apple IIGS	AbleData (2006)
Baldi/Timo	Realistic animated talking head models craniofacial movements of actual speech and produces synthesized speech	Available as "Timo" from Animated Speech Corporation (ASC); 1 user less than $100; 5 users less than US $250; Timo Lesson Creator $250	600 MHz CPU, 128 MB RAM, 16 bit or better color monitor, Sound Blaster or compatible 16-bit sound card, speaker or headphones, microphone (optional for some sections), CD-ROM drive, 300 MB disk space	ASC (2005)
Delta Messages	The student constructs sentences of increasing complexity. The program consists of 10 lessons and includes 70 words allowing for the construction of approximately 200 unique sentences. Delta Messages creators state that "software is not an alternative to traditional instruction but should be used to complement" traditional instruction. Additionally, Delta Messages is designed for the student and teacher to interact with the program together	25$ (includes shipping)	Macintosh system 6.02 or later, 68040/33 MHz, 4 MB RAM, 12 MB hard drive space, 256 color monitor, 2× CD-ROM drive Windows version is in production	Nelson and Heimann (1995) Delta Messages (2010)
PowerPoint	Presentation software; prerecorded sounds (e.g., speech), animations, and text can be embedded within slides	Available from Microsoft; ranges in price less than $200	500 MHz CPU, 256 MB RAM, 1024 × 576 color resolution monitor, graphics card with 64 MB video memory, 1.5 GB disk space	Microsoft (2010)
Teach Town: Basics	CAI program designed to deliver lessons for students developmentally aged 2–7; program curriculum involves six learning domains (i.e., language development, social and emotional skills, adaptive skills, cognitive skills, language arts, and mathematics)	Pricing is based on the total number of students and the amount of time the product is used. For example, 1–9 students using the software for 1 month is $40	TTB is a subscription service and it requires use of internet for every session; PC with 600 MHz clock speed and 256 MB RAM (512 RAM recommended), Windows XP with 1 GB available disc space and internet connection; older systems may work but not officially supported; Macintosh is not supported	Teach Town Basics (2010)
Illuminatus	Multi-media authoring tool that allows users to combine words, pictures, video, animation, and sound to create an interactive multi-media presentation	Version 4.0 is no longer available from Digital Workshop Software. The new product replacing it is Opus Creator and is $145	*Minimum*: Windows 98/ME/2000/XP/NT4 (with service pack), Pentium II, Monitor and graphics of 16 bit color at 88 × 600, 512 MB RAM, 250 MB hard drive space, sound card, mouse, CD Rom *Recommended*: Direct X v3, Windows Media Player, Quicktime v$, 2 GHz processor, Windows 7, 2 GB RAM, 1 GB free disk space, 32 bit color graphic at 1280 × 1024	Digital Workshop (2010)
Paint Shop Pro	Photo editing software that allows users to manage, adjust and edit digital photos	Multiple versions of differing complexity and capability exist ranging in price from less than $10 to over $100	Compatible with Windows 7, Vista and XP; 1.5 GHz processor, 1 GB of RAM, 3 GB of free disc space; minimum display resolution needs to be 24 bits; internet connection required for online features	Corel (2010)
Wave Editor	Digital audio editing software	Free download available: http://www.wave-editor.com/	Compatible with Windows 2000, XP, 2003 and Vista	Wave Editor (2010)

Note: All monetary amounts are in US Dollars.

3.4.4. Receptive and expressive language

With regard to receptive language, CBI was associated with medium, large/strong, and insignificant effects. Massaro and Bosseler (2006) found students' receptive responding increased greatly following CBI ($\delta_{F\text{-}test} = 3.694$). Whalen et al. (2010) observed that preschool aged students who received CBI scored higher on a measure of receptive language ability than their peers in the control group ($\delta_{F\text{-}test} = 0.962$). However, Whalen et al. (2010) did not find a statistically significant effect for CBI for students in kindergarten and first grade on the same measure of receptive language, as compared to the control group.

Across the three studies that evaluated the effect of CBI on expression a similar range of results was reported. Heimann et al. (1995) observed participants improve moderately across repeated measures of rate of verbal expression during CBI lessons ($\delta_{RM} = 0.446$). Also, Heimann et al. (1995) found participants improved moderately in their ability to imitate sentences in preferred modes of expression (i.e., spoken language, sign language, BLISS symbols; $\delta_{RM} = 0.428$). Yamamoto and Miya (1999) found their two participants' ability to vocalize descriptive sentences for untrained picture stimuli improved substantially (*M* NAP = 100%). However, Whalen et al. (2010) recorded insignificant changes in participants' expressive vocabularies following CBI.

3.4.5. Vocabulary

Three studies measured the impact of CBI on students' vocabulary (Bosseler & Massaro, 2003; Coleman-Martin et al., 2005; Moore & Calvart, 2000). In two single group, repeated measures experiments, Bosseler and Massaro (2003) found effects of 0.710 (δ_{RM}) and 2.884 (δ_{RM}). Coleman-Martin et al. (2005) obtained a NAP of 100% for their one participant. Also, Moore and Calvert (2000) found a between groups effect of 1.651 ($\delta_{F\text{-}test}$) for CBI for vocabulary training.

3.4.6. Other academic skills

CBI for matching skills was associated with positive results and medium to strong effects. Stromer et al. (1996) demonstrated that CBI can be used to teach tasks involving matching pictures to printed words and anagram spelling to pictures. Similarly, Hetzroni and Shalem (2005) observed improvements in matching text to food items. NAP statistics for individuals ranged from 79% to 97.9% (*M* NAP = 90.3%). Williams et al. (2002) found increases in time spent on-task. Whalen et al. (2010) observed large effects for CBI with regard to "academic/cognitive skills." Students in the treatment group who mastered at least one lesson improved greatly on "academic/cognitive skills" ($\delta_{F\text{-}test} = 3.320$). The authors, however, did not define what constituted "academic/cognitive skills," nor what measurement of the variable was involved.

3.5. Certainty of evidence

The certainty of evidence for intervention effects was rated as conclusive for four studies (i.e., Bosseler & Massaro, 2003; Hetzroni & Shalem, 2005; Stromer et al., 1996; Yamamoto & Miya, 1999). Four studies were rated as providing the preponderant level of certainty (Heimann et al., 1995; Moore & Calvart, 2000; Whalen et al., 2010; Williams et al., 2002). Preponderant ratings were assigned due to studies' inability to control for alternative explanations for treatment effects and/or reporting of insufficient detail to enable replication. For the remaining four studies, the certainty of evidence for intervention effects was judged to be suggestive. Table 1 provides the specific reasons for each study's rating.

4. Discussion

Our systematic search yielded 12 studies involving the use of CBI to teach literacy skills to students with ASD. With respect to the overall scope of the existing corpus of studies, the current research base must be considered limited given the limited number of studies capable of providing a conclusive level of certainty ($n = 4$). Across studies, CBI's effect on literacy skills was inconsistent. Some studies reported significant results and large effect sizes and other studies reported no improvements. Given the wide variety of literacy skills targeted for instruction across studies and the heterogeneity of participants, it is not possible from the existing literature to provide a summative conclusion regarding the effectiveness of CBI for teaching literacy skills to students with ASD nor is it possible to identify variables associated with the effectiveness of CBI. However, several important points relevant to practitioners interested in using CBI and researchers interested in investigating CBI do emerge.

First, the results of two studies suggest a relation between literacy outcomes and participants' intellectual ability prior to beginning CBI. Tjus et al. (1998) reported that participants' gains on reading and phonological awareness appeared to correlate with the percentile rank of their non-verbal mental levels, as measured with the Colored Progressive Matrices (Raven, Court, & Raven, 1984), as well as their receptive language ages, as measured with the Reynell Developmental Language Scales (Hagtvet & Lilliestølen, 1984; Reynell, 1977). Although the correlation was not assessed statistically, the mean gains observed following CBI, and at a 6-week follow up, were clearly larger for participants with relatively high percentile ranks of non-verbal mental levels and receptive language ages. In contrast to Tjus et al.'s observation, Whalen et al. (2010) found no statistically significant relation between the effects of CBI and developmental level, as measured with the Brigance Inventory of Early Development (Brigance, 2004). However, Whalen and colleagues' also noted that some students who failed to master a lesson did not use the computer program regularly due to problem behavior. This reduced usage confounded the independent variable and may have biased outcomes. Future research could attempt to control for these variables and endeavor to determine if assessments of developmental or intellectual functioning could be used to predict the effectiveness of CBI.

Second, in addition to developmental and intellectual functioning, participants' learning history involving computers and motor skills (e.g., ability to operate mouse, keyboard and touch screens) would also seem likely to influence the effectiveness of CBI. Some of the reviewed studies considered on or more of these variables and took steps to introduce the software and hardware in a systematic manner prior to beginning intervention (e.g., Bosseler & Massaro, 2003; Heimann et al., 1995; Hetzroni & Shalem, 2005; Stromer et al., 1996; Yamamoto & Miya, 1999). However, other studies did not report any form of pre-orientation. Two approaches to considering these variables prior to beginning CBI emerge from the reviewed studies. The first and simplest option is to offer CBI only to students with existing skill and preference for using computers (e.g., Moore & Calvart, 2000; Stromer et al., 1996). This could be done by observing the student when given access to a computer and/or by conducting a preference assessment in which the student can choose between traditional and CBI instruction (Canella, O'Reilly, & Lancioni, 2005). The second option is to actively teach students how to use the specific hardware and software programs prior to beginning CBI in literacy (e.g., Heimann et al., 1995). This approach requires the creation of additional goals and the implementation of additional teaching procedures. As such, the efficiency of the approach and the priority of treatment goals should be considered prior to using CBI. Although the ability to use a computer is a valuable skill, it may not be deemed a priority over making immediate progress in literacy for some students. Future research examining the relative effectiveness of CBI versus person delivered literacy instruction is warranted.

The various software packages used across studies have a wide range of features and capabilities. Most notably, the software differs in terms of customizability and usability. As pointed out by Ramdoss et al. (2011), CBI is an intervention delivery approach and not an intervention in and of itself. As such, the success of CBI depends on the extent to which the software program is able to implement effective teaching procedures (e.g., prompting and reinforcement). Programs such as Microsoft PowerPoint permit only minimal customization options (e.g., digitized speech output, highlighting key concepts with differing font size, and the selection of individualized pictorial and verbal reinforcers to include on slides) compared to software programs designed specifically for delivering instruction to children. Alpha program, Baldi/Timo, Delta Messages, and Teach Town are all specifically designed to deliver instruction. Illuminatus, PowerPoint, PaintShop Pro, and Wave Editor are multi-purpose tools that require the teacher to design the instructional materials for the students. Regardless of the program used, practitioners must ensure that CBI contains the functional properties of effective teaching procedures (Ramdoss et al., 2011)

Previous research suggests that individuals diagnosed with ASD are primarily visual learners (Layton, 1988). Moreover, that natural speech, being an auditory modality, may not be compatible with the processing preferences of children with ASD (e.g., Hedbring, 1985; Oxman, Webster, & Konstantareas, 1978; Quill, 1997; Schuler & Baldwin, 1981). It has also been suggested that children with ASD may have difficulty obtaining information from faces and may not be reinforced by facial expressions associated with approval and happiness (Dawson et al., 2002; Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010; Merin, Young, Ozonoff, & Rogers, 2006). Massaro and Bosseler (2006) demonstrated that simultaneous presentation of visual and auditory information via CBI can be effective in promoting spoken and receptive language in some children with autism. Further, they maintained that the rate of learning was faster when students were presented instruction using an animated face. Future research could endeavor to establish the effectiveness of multi-channel feedback and animated faces on the rate of learning and acquisition.

Previous researchers have expressed concerns that the use of CBI with students with ASD may reduce opportunities for social interaction and could potentially lead to a loss of social skills (Bernard-Opitz et al., 1990). This issue was addressed in two of the reviewed studies. Basil and Reyes (2003) suggested that the gains observed in literacy skills in their study can be attributed to the positive interactions that the students had with their teachers while receiving CBI. Similarly, Heimann et al. (1995) maintained that teacher–child dialogue during CBI contributed to student gain in overall verbal scores. However, these assertions were not directly supported within any of the included studies and this concern warrants future research.

Overall, this review suggests that the use of CBI to improve the literacy skills of children with ASD is a promising practice. Teachers using CBI should carefully consider the preferences and existing abilities of students and the customizability of the software when deciding to use CBI and selecting a software program. Future research related to the relative efficacy of CBI versus person implemented instruction is warranted as well as research directed towards identifying student characteristics useful in predicting the effectiveness of CBI.

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