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Effects of ABRACADABRA Literacy Instruction on Children With Autism Spectrum Disorder

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This study explored the effects of ABRACADABRA, a free computer-assisted literacy program, on the reading accuracy and comprehension skills of children diagnosed with autism spectrum disorder (ASD). ABRACADABRA is a balanced literacy instruction program, targeting both code and meaning-based reading abilities. Twenty children with ASD, aged 5–11 years, were assigned by matched pairs to the instruction group or wait-list control group. Literacy instruction was delivered on a 1:1 basis in participants' homes over a 13-week period (26 sessions per participant). Pre and post instruction assessment using standardized measures revealed statistically significant gains in reading accuracy and comprehension for the instruction group relative to the wait-list control group, with large effect sizes. These findings indicate that children with ASD may benefit from ABRACADABRA literacy instruction.

Keywords: literacy, reading accuracy, reading comprehension, autism, ASD, ABRACADABRA

Early literacy skills provide a foundation for lifelong learning. Children who are skilled readers are more likely to experience positive academic outcomes and encounter fewer emotional and behavioral difficulties than their reading-delayed peers (Willcutt et al., 2007). These children also demonstrate greater motivation to complete academic tasks (Lyon, 1998) and are less inclined to leave school early, relative to less skilled readers (Daniel et al., 2006). In the longer term, skilled readers achieve more positive employment and economic outcomes (Roman, 2004), and exhibit greater health awareness than adults with poorer levels of reading ability (DeWalt, Berkman, Sheridan, Lohr, & Pignone, 2004). Given the potential benefits of skilled reading, there is an urgent need to establish effective literacy instruction for all children, including those with disabilities such as autism spectrum disorder (ASD).

ASD is an early onset developmental disability characterized by deficits in social communication, restricted patterns of interests, and engagement in repetitive behaviors (American Psychiatric Association, 2013). ASD is conceptualized as a spectrum disorder, meaning that these characteristics manifest heterogeneously throughout the population (Frazier et al., 2012). Global epidemiological research suggests that the median ASD prevalence rate is approximately 62/10,000 (Elsabbagh et al., 2012). ASD commonly co-occurs with difficulties in the areas of oral language (Lord, Risi, & Pickles, 2004), cognition (Chakrabarti & Fombonne, 2005), and behavior (Simonoff et al., 2008). Those more severely affected by ASD are more likely to present with associated comorbidities (Leyfer et al., 2006). The core characteristics of ASD, as well as the associated comorbid difficulties, can affect the literacy development of children within this population.

Reading and ASD

Reading is a dynamic process involving the interaction of two distinct components: decoding of text and comprehension of meaning (Gough & Tunmer, 1986). For both children without disabilities and children with ASD, these component reading abilities draw heavily on underlying cognitive and oral language skills (Jacobs & Richdale, 2013; Nation & Snowling, 2004). Given that ASD is often associated with deficits in cognition and oral language, it follows that some children with ASD are at increased risk of experiencing reading difficulties. Social-communicative deficits and behavioral difficulties may also restrict the ability of some children with ASD to adequately engage with literacy instruction, further impeding their reading development (Williams, Wright, Callaghan, & Coughlan, 2002).

In a seminal study of reading and autism, Nation and colleagues (2006) explored the reading accuracy and comprehension abilities of 41 children diagnosed with ASD (Nation, Clarke, Wright, & Williams, 2006). The researchers employed broad inclusion criteria, requiring only that participants were aged 6 to 15 years and had measureable oral language skills. Their analyses revealed that a considerable number of children exhibited difficulties in reading accuracy, with 22% of the participants completely unable to read single words and nonwords. Data from the remaining participants revealed an atypical profile of reading abilities characterized by relative strengths in reading accuracy and weaknesses in reading

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comprehension. A comparable reading profile has been observed in recent studies involving children with ASD that have employed similar inclusion criteria (e.g., Arciuli, Stevens, Trembath, & Simpson, 2013).

A study by Nation and Snowling (1997) assessed reading difficulties in children without disabilities. Their data revealed strong correlations between the component reading abilities of reading accuracy and comprehension, and among subcomponent reading abilities, such as word level reading accuracy and passage level reading accuracy. Likewise, studies involving children with ASD have reported significant correlations between component and subcomponent reading abilities (Arciuli et al., 2013; Nation et al., 2006). However, the correlations found in these studies involving children with ASD tend to be lower than those reported in studies of children without disabilities. These findings indicate that the component and subcomponent reading abilities of children with ASD may develop more autonomously by comparison with children who do not have disabilities.

An emerging body of research addresses remediation of the reading difficulties exhibited by some children with ASD. In their review, Whalon, Al Otaiba, and Delano (2009) identified 11 studies, involving a total of 61 participants, which targeted some of the key reading-related abilities as defined by the National Reading Panel (NRP; National Institute of Child Health and Human Development [NICHD], 2000). Children with ASD were shown to benefit from instruction targeting phonics (e.g., Coleman-Martin, Heller, Cihak, & Irvine, 2005), oral reading fluency (e.g., Kamps, Barbetta, Leonard, & Delquadri, 1994), vocabulary (e.g., Kamps, Leonard, Potucek, & Garrison-Harrell, 1995), and instruction in comprehension strategies (e.g., Whalon & Hanline, 2008). However, few of the reviewed studies investigated whether these instructional approaches promoted the development of reading accuracy and comprehension skills in children with ASD. In addition, none of the reviewed studies evaluated the effects of comprehensive literacy instruction that targets all of the key reading-related abilities identified by the NRP. Given that children with ASD have been shown to benefit from some individual elements of literacy instruction, the evaluation of more comprehensive instructional approaches is of critical importance.

ABRACADABRA

ABRACADABRA (hereafter referred to as ABRA; Centre for the Study of Learning and Performance [CSLP], 2009) is a freely available literacy program designed to improve the reading and writing skills of all children, including those at risk of low literacy abilities. ABRA learning objectives are informed by the recommendations of the NRP (NICHD, 2000) and other reviews of effective reading interventions (see Abrami et al., 2010, for a description and explanation of the development of ABRA). Specifically, ABRA targets the development of foundational literacy skills including alphabetics, reading fluency, reading comprehension, and writing. Instruction targeting these skills is delivered using a combination of computer activities and noncomputerized extension tasks. According to Abrami et al. (2010), the pedagogical underpinnings of ABRA are intended to replicate those of balanced literacy programs, as described by Chall (1967) and Adams (1990). That is, ABRA learning activities emphasize a balance between children's code (i.e., phonics and word study) and meaning-based skill development (i.e., reading comprehension), and engagement with real literature.

ABRA is the focus of an ongoing research program at the CSLP at Concordia University. A recent meta-analysis identified nine randomized control trials and quasi-experimental studies that have examined the effects of ABRA on literacy outcomes as defined by the NRP (Abrami, Borohkovski, & Lysneko, 2015). These studies included Kindergarten, Grade 1, and Grade 2 children from diverse populations. There was no mention of children with disabilities. For example, research conducted by Wolgemuth et al. (2013) included indigenous Australian children, and the study conducted by Abrami et al. (2014) was undertaken in Sub-Saharan Africa. Across studies, students received between 10 to 32 hours of ABRA instruction in small groups or whole class settings for periods ranging from 8 to 16 weeks. Generally, these previous studies utilized standardized measures to assess outcomes. The results of the meta-analysis revealed that children who received ABRA instruction exhibited statistically significant gains in phonemic awareness, phonics, vocabulary, and listening comprehension compared with children in control conditions, with small effect sizes. Improvements in reading accuracy, reading comprehension, and reading fluency were evident in some previous studies; however, these gains did not always reach statistical significance. Divergent findings across some of the previous studies may be attributed to differences in the implementation of ABRA (e.g., small group vs. whole class administration of ABRA; differences in hours of instruction).

Computer-Assisted Instruction

Pedagogical approaches, such as ABRA, which utilize computer-assisted instruction (CAI) may be well suited to children with ASD (Grynszpan, Weiss, Perez-Diaz, & Gal, 2014). Unlike teacher-directed instruction, CAI is not heavily contingent upon social communicative abilities, which are a key deficit for children in this population (Williams et al., 2002). Previous research has shown that children with ASD tend to be more responsive during CAI that targets social, language, and communication development as compared with teacher directed approaches (Ploog, Scharf, Nelson, & Brooks, 2013).

A recent review evaluated the use of CAI for the teaching of reading and related skills for children with ASD (Ramdoss et al., 2011). Twelve studies were included in the review, involving a total of 94 participants. Evidence supported the use of CAI to develop skills associated with reading, including phonological awareness (e.g., Heimann, Nelson, Tjus, & Gillberg, 1995), receptive language (e.g., Whalen et al., 2010), vocabulary (e.g., Moore & Calvert, 2000), and sentence construction (e.g., Basil & Reyes, 2003), as well as component reading skills, decoding (e.g., Tjus, Heimann, & Nelson, 1998), and reading comprehension (e.g., Basil & Reyes, 2003). On average, analyses revealed large effects for these CAI programs. However, there was considerable variability across studies, with some showing CAI to be no more beneficial for children with ASD than teacher-led instruction (e.g., Travers et al., 2011).

Several issues need to be considered when evaluating the effects of CAI in children with ASD. Previous studies have often involved small samples, many comprised of less than 10 participants in total. Thus, some studies may have lacked the statistical power to draw definitive conclusions. In addition, some previous studies have utilized CAI programs that are difficult to access (e.g., Coleman-Martin et al., 2005), costly (e.g., Whalen et al., 2010), and/or are now considered outdated (e.g., Heimann et al., 1995). Thus, the real-world applicability of many of the CAI programs that have been evaluated is questionable. Finally, many previous studies have relied on nonstandardized measures of literacy to evaluate outcomes following CAI (e.g., Whitcomb, Bass, & Luiselli, 2011). The lack of standardized measures in the previous research limits the generalizability of some of these studies.

The Current Study

In the current study we sought to explore the effects of ABRA on the reading skills of a diverse group of children with ASD. Literacy instruction was delivered using ABRA's freely available web application and noncomputerized extension tasks. Unlike previous ABRA research, the current study was conducted independently of the CSLP.

The study was guided by three research questions.

1. Can ABRA instruction improve the reading skills of children with ASD when compared with a control group of children with ASD who do not receive ABRA instruction?

2. Are improvements in reading ability following ABRA instruction observed across both word and passage levels for children with ASD?

3. How large are the improvements in reading ability following ABRA instruction for children with ASD?

We hypothesized that participants with ASD would exhibit improved reading accuracy and comprehension abilities following 13 weeks of ABRA instruction compared with a wait-list control group of children with ASD. In addition, we hypothesized that the relative gains achieved by participants with ASD following ABRA instruction would be observed across three aspects of reading ability: word level accuracy, passage level accuracy, and passage level comprehension. However, we were unsure about the size of these gains.

Method

Design

The study followed a pretest/posttest control group design. Participants were assigned to one of two experimental conditions: the wait-list control group or the instruction group. Pairs of participants who were of similar age and had comparable oral language, reading and adaptive abilities were identified. Participants in each pairing were then randomly assigned to opposing experimental conditions (i.e., the wait-list control or instruction group). These groupings were later altered slightly to accommodate changes in participant availability as advised by parents (i.e., one participant was removed from the instruction group and two participants were added in their place).

Participants in the instruction group received home-based 1:1 ABRA instruction over a period of 13 weeks (26 sessions per participant). Participants in the wait-list control group continued their normal academic schedule during this time. Thus, ABRA was supplemental for the instruction group while the wait-list control group went about their school activities "business as usual." Information was not collected regarding participants' normal school literacy instruction. Pre- and postinstruction assessment was carried out at the University or in the participant's home within 9 days of the instruction period. All assessment and instruction sessions were conducted by the first author who is a certified practicing speech pathologist with previous experience working with children on the autism spectrum.

Participants

Research advertisements were circulated throughout speech pathology and psychology clinics across a large metropolitan area within Sydney, Australia. The research protocol was approved by the relevant University's Human Research Ethics Committee. Legal guardians provided written informed consent prior to participation.

Eligibility for the study required that participants met the following inclusion criteria: (a) 5–11 years of age; (b) previous formal clinical diagnosis of ASD using Diagnostic and Statistical Manual (DSM) criteria; (c) no hearing or vision impairments; (d) measurable language ability; and (e) able to demonstrate sustained attention to tasks for 15 min. Of an initial pool of 25 participants, two were excluded because they did not meet the inclusion criteria. A further three participants were excluded because of conflicts in scheduling. Twenty children formed the final sample, of whom 18 were male. As expected, the final sample was highly heterogeneous and comprised of children with differing levels of developmental, adaptive and academic functioning. Participants were enrolled in inclusive education (i.e., classrooms with peers who do not have disabilities), support classes (i.e., classrooms with peers who have disabilities within a school for students without disabilities), or specialist settings (i.e., schools for children with ASD). Demographic and diagnostic information by group (wait-list control vs. instruction) is shown in Table 1.

Independent samples t tests with alpha set at .05 showed no statistically significant differences between the instruction and wait-list control groups for age, $t(18) = -3.54$, $p = .73$, and across baseline measures of adaptive ability, vocabulary, phonological

Table 1
Demographic and Diagnostic Information by Group

Characteristic	Wait-list control	ABRA instruction
Age[a]	90.22 (19.72)	87.18 (18.65)
Sex (M:F)	8:1	10:1
Reported diagnosis (ASD/Asp./PDD-NOS)	5:1:3	8:1:2
Secondary diagnoses (ADHD/LD/AD)	1:7:3	2:9:8
School (Inclusive/Support/Specialist)	6:3:0	8:1:2
>1 language spoken at home (Y/N)	3:6	5:6

Note. Asp. = Asperger's syndrome; PDD-NOS = pervasive developmental disorder-not otherwise specified; ADHD = attention-deficit/hyperactivity disorder; LD = language difficulties; AD = articulation difficulties; Inclusive = inclusive class; Support = support class; Specialist = specialist class. Data in parentheses are *SD*s.
[a] Age is reported in months.

awareness, word level reading accuracy, passage level reading accuracy, and passage level reading comprehension (see Table 2 for independent samples *t* test results). The percentile rank measures shown in Table 2 were calculated using normative data derived from samples that included a majority of children without disabilities (see the Measures section for further details). Normative data based solely on the ASD population were not available for any of the measures.

As expected, scores for most participants placed them well below the age-adjusted average on the measure of adaptive ability (i.e., only six participants achieved percentile rankings above the 16th percentile). Scores varied considerably within each group, and across each of the measures, reflecting the broad inclusion criteria utilized in the current study.

Measures

The measures used in the current study were selected for two purposes. First, tests of oral language, reading and adaptive ability were used to obtain baseline measures in order to assign participants to either the wait-list control or instruction group. Second, tests of word and passage level reading accuracy and comprehension were used to evaluate outcomes following ABRA instruction. All of the standardized tests included in the protocol are widely used, valid and reliable measures. Each provides age or year-of-schooling referenced percentile ranks. With the exception of adaptive ability, all assessments were administered individually to each participant by the first author. The measure of adaptive ability was obtained individually via semistructured parent interview with the first author. Participants received a score of zero if unable to satisfy basal level performance criteria on a test.

Where known, we report the percentage of children with ASD in the normative sample associated with each assessment. Some normative samples included children with ASD but considered these children as belonging to broader disability classifications. For these samples, the percentage of children in autism-related classifications is reported. For the remaining normative samples, the percentage of children with disabilities is reported.

Adaptive ability. Each parent participated in a semistructured interview using the Survey Interview Form from the Vineland Adaptive Behavior Scales–2nd Edition (VABS-2; Sparrow, Cicchetti, & Balla, 2005). The test evaluated the domains of communication (receptive, expressive, written), daily living skills (personal, domestic, community), and socialization (interpersonal relationships, play and leisure time, coping skills). Additional items measuring fine and gross motor skills were administered to parents of participants aged six years and younger ($n = 10$). Children with health impairments, traumatic brain injury, multiple impairments, and/or autism comprised 1.7% of the VABS-2 normative sample. Thus, most of the children included in the normative sample did not have disabilities. For the current sample, the VABS-2 was found to have a high level of internal consistency for children aged seven years and older (Cronbach's alpha = .97), and children aged six years and younger (Cronbach's alpha = .99).

Vocabulary. The Peabody Picture Vocabulary Test–4th edition (PPVT-4; Dunn & Dunn, 2007) is a test of receptive vocabulary. Using Form A, participants were instructed to select one of four images best illustrating a target word verbally presented by the researcher. The PPVT-4 includes many simple items to improve measurement of lower functioning and younger children. Children with ASD constituted 0.2% of the PPVT-4 normative sample. The vast majority of the remaining children did not have disabilities. For the current sample, the PPVT-4 was found to have a high level of internal consistency (Cronbach's alpha = .98).

Phonological awareness. The Phonological Awareness Composite Score (PACS) from the Comprehensive Test of Phonological Processing – 2nd Edition (CTOPP – 2; Wagner, Torgesen, Rashotte, & Pearson, 2013) was used to assess phonological awareness. The PACS is comprised of three related subtests: (a) Elision, which is a sound deletion task that measures ability to segment and manipulate sounds within words; (b) Blending Words, where participants listened to a series of audio-recorded sounds and were then required to blend these sounds together to form a whole word; and (c) Sound Matching (for participants aged five to six years only), in which participants identified one picture from a choice of three that began with the same sound as a word read by the researcher. Participants aged 7 to 11 years ($n = 10$) completed a Phoneme Isolation task, where they were instructed to identify the phoneme occupying a specified position in a target word. Children with learning or health impairments constituted approximately 5% of the CTOPP-2 normative sample—the remainder of the sample did not have disabilities. For the current sample, the CTOPP-2 was shown to have a high level of internal

Table 2
Mean Age-Based Percentile Rank for Each Preinstruction Measure by Group

Measure	Wait-list control ($n = 9$)			ABRA instruction ($n = 11$)					
	M	*SD*	Range	*M*	*SD*	Range	$t(18)$	*p*	Cohen's *d*
Adaptive ability	17.56	25.74	1–84	18.36	19.93	2–63	.08	.94	.04
Vocabulary	29.14	30.83	.3–79	26.00	19.45	1–53	.29	.78	.12
Phonological awareness	16.11	17.93	0–39	15.09	20.04	0–63	.12	.91	.05
Word level reading accuracy	38.89	35.44	2–87	43.27	31.61	2–98	.29	.77	.13
Passage level reading accuracy[a]	19.89	25.90	0–65	25.45	26.77	0–81	.47	.64	.21
Reading comprehension[a]	16.67	26.98	0–68	15.55	17.28	0–53	.11	.91	.05

Note. Adaptive ability: Vineland Adaptive Behavior Scales (VABS-2), Adaptive Behavior Composite; Vocabulary: Peabody Picture Vocabulary Test (PPVT-4); Phonological awareness: Comprehensive Test of Phonological Processing (CTOPP-2), Phonological Awareness Composite Score; Word level reading accuracy: Wide Range Achievement Test (WRAT-4), Word Identification subtest; Passage level reading accuracy and reading comprehension: Neale Analysis of Reading Ability (NARA-3).
[a] Data for passage level reading accuracy and reading comprehension are year-of-schooling based percentile ranks.

consistency for children aged six years and younger (Cronbach's alpha = .97), and children aged seven years and older (Cronbach's alpha = .98).

Word level reading accuracy. The Word Reading subtest of the Wide Range Achievement Test–4th Edition (WRAT-4; Wilkinson & Robertson, 2006) was used to measure participants' ability to accurately decode letters and words. Participants were directed to read aloud a list of individual letters followed by a list of real words. Word reading targets were arranged in order of least (e.g., "cat") to most difficult (e.g., "usurp"). Children with disabilities constituted approximately 5% of the WRAT-4 normative sample. The remaining children in the normative sample did not have disabilities. For the current sample, the WRAT-4 was found to have a high level of internal consistency (Cronbach's alpha = .95).

Passage level reading accuracy. The Reading Accuracy Composite Score from the Neale Analysis of Reading Ability–3rd edition (NARA-3; Neale, 1999) was used to assess participants' ability to accurately decode passage level text. This assessment required participants to read aloud a series of passages of increasing length and complexity. The NARA-3 manual does not report the number of children with ASD, or other disabilities, in its normative sample. For the current sample, the reading accuracy composite was found to have high internal consistency (Cronbach's alpha = .82).

Passage level reading comprehension. The Reading Comprehension Composite Score from the NARA-3 (Neale, 1999) was used to assess participants' ability to derive meaning from written text at the passage level. This involved participants reading a series of passages aloud before being asked a number of prescribed questions related to the text. For the current sample, the reading comprehension composite was shown to have high internal consistency (Cronbach's alpha = .95).

Procedure

Preinstruction assessment. Participants completed a standardized assessment battery of reading, oral language and adaptive abilities (see Measures section for a description of these assessments). The battery was necessary because we wanted to make sure that the groups were equivalent prior to one group receiving instruction. Assessment tasks were administered in the order in which they appear in the preceding section. Assessment sessions ranged from 60- to 90-min duration, depending on the abilities and behaviors of individual participants.

ABRACADABRA instruction. ABRA was implemented as per the standard recommended protocol with the exception of two purposeful adaptations, which were discussed with and approved by the CSLP. First, as a consequence of the 1:1 setting used in the current study, ABRA instruction sessions did not include collaborative work with child peers. Instead, additional time was assigned to the computer activities and a reward task at the end of the session, and participants worked collaboratively with the first author during the ABRA extension tasks (e.g., taking turns reading pages of a story). Second, in anticipation that some children with ASD would perform less consistently than children without disabilities, the criterion used to identify skill mastery was lowered slightly from 90% to 85% accuracy (further details regarding skill mastery are provided below).

ABRA activities targeted four key literacy abilities: (a) alphabetics, (b) reading fluency, (c) reading comprehension, and (d) writing (Table 3). Word level activities used to promote alphabetics (i.e., the ability to associate sounds with letters and use these sounds to create words) were presented in a hierarchical sequence. The sequence began with early developing skills (e.g., sound matching) and ended with more complex tasks (e.g., word segmentation and blending). Word attack skills targeted during the word level computer tasks were incorporated into passage level reading fluency and comprehension tasks. For example, participants could click on unfamiliar words in the passage level prediction task and observe them being decoded. Writing tasks required participants to type word and passage level targets on a computer to dictation. Within most activities, skill development and task autonomy were targeted using a system of least (e.g., encouraging independent decoding) to most (e.g., demonstrated decoding) prompts. Reward contingencies (e.g., shots in a hockey-themed comprehension game) were used to encourage ongoing participant motivation and engagement.

ABRA's balanced curriculum and graded learning tasks permitted highly individualized literacy instruction. The preinstruction assessment data was used to inform the researchers of each participant's profile of literacy abilities (i.e., relative strengths and weaknesses). These profiles were used in conjunction with the ABRA manual to identify learning objectives, tasks, and task difficulty settings appropriate for instruction. Learning objectives, tasks, and associated task difficulty settings were reviewed following each instruction session using ongoing measures of participant performance. A performance criterion of 65%–85% accuracy was employed to identify tasks of appropriate content and difficulty for instruction. Skill mastery was set at 85% accuracy for each independent task, maintained over three consecutive sessions.

Instruction consisted of two 60-min training sessions delivered weekly over a 13-week period working 1:1 with participants. Instruction sessions were conducted outside of school hours, and therefore necessarily in participants' homes, to minimize disruption to school activities. Computer activities were presented on a 15.6" laptop with participants seated one meter from the screen at eye level. These activities were designed to encourage independent participation (e.g., animated videos demonstrating task completion appeared prior to each activity). However, the experimenter was present for the duration of each session and assisted participants in transitioning between tasks. All participants had at least some ability to independently operate a standard computer mouse prior to commencing ABRA instruction. Some participants received additional support, in the form of hand-over-hand assistance, to operate the hardware during tasks which required rapid responses. Breaks were provided to participants as required throughout the instruction sessions.

Each 60-min ABRA session followed a routine structure. First, participants completed a 15-min computer task targeting word level abilities (i.e., alphabetics, high-frequency word identification, or word spelling). Next, participants completed a 20-min computer task targeting passage level abilities (i.e., reading fluency, reading comprehension, or sentence spelling). Skills targeted during the computer activities were then revisited during a 15-min, noncomputerized extension task which involved interaction between the experimenter and participant (e.g., shared reading or spelling games). Consistent with previous ABRA research, these extension tasks were guided by the

Table 3
ABRACADABRA Activities

Literacy domain	Task level	Task name	Task description
Alphabetics	All alphabetics tasks were word level	Matching sounds	Identify matching sounds
		Alphabet song	Sing along to the alphabet song
		Word counting	Count words in an audio-recording
		Syllable counting	Count syllables in an audio-recording
		Same word	Identify same vs. different words
		Same phoneme	Identify same vs. different phonemes
		Word matching	Identify words with same vs. different initial or final phoneme
		Animated alphabet	Watch animations featuring letter sounds, a letter-writing cue and an alliterative phrase for each letter of the alphabet
		Letter sound search	Identify letters corresponding to audio-recorded phonemes
		Letter identification bingo	Identify letters by name
		Rhyme matching	Identify pairs of rhyming words
		Word families	Substitute initial letter(s) to form a new word (e.g., map → mat → bat)
		Auditory blending	Match phonemically segmented word to image
		Auditory segmenting	Match audio-recording of full word to segmented version of target word
		Blending train	Identify target word following phonemically segmented audio-recording
		Basic decoding	Decode written word and match to corresponding image
		Word changing	Substitute letters to form a new word (e.g., rat → mat → map)
Reading fluency	Word level	High frequency words	Identify a list of high frequency words
	Passage level	Tracking	Scan passage level text from left to right
	Passage level	Expression	Identify audio-recording as being read with good vs. bad expression then read the same passage aloud with appropriate expression
	Passage level	Accuracy	Read passage of text without error
	Passage level	Speed	Read passage of text at appropriate pace
Reading comprehension	All reading comprehension tasks were passage level	Prediction	Predict future events during passage level narrative
		Comprehension monitoring	Identify words incorrectly substituted in the text
		Sequencing	Place story images in linear order following reading
		Summarizing	Respond to questions during passage level reading task (questions designed to highlight important plot elements)
		Vocabulary	Select sentences containing correct use of a target word
		Vocabulary (ESL)	Match audio-recorded words to corresponding images. Participants then included target words in a cloze passage.
		Story response	Respond verbally to questions following reading
		Story elements	Respond to multiple choice questions following reading
Writing	Word level	Spelling words	Words typed to dictation
	Passage level	Spelling sentences	Sentences typed to dictation

recommendations of the ABRA manual. At the end of each session, participants were rewarded with a 10-min free choice activity (e.g., Legos).

Postinstruction assessment. The postinstruction assessment included three outcome measures: (a) word level reading accuracy, (b) passage level reading accuracy, and (c) passage level reading comprehension.

Implementation Fidelity

Implementation fidelity was addressed across three levels: context, compliance, and competence fidelity (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). Context fidelity requires that the precursors necessary for effective instruction are in place prior to a program's implementation. In the current study, the first author ensured high context fidelity prior to beginning instruction by gaining access to the ABRA learning materials and the ABRA Learning Tool Kit Teacher Guide (hereafter referred to as the ABRA manual; Abrami, White, & Wade, 2010), and by completing ABRA administration training. ABRA administration training comprised two sessions conducted by a representative from the CSLP. During these training sessions, the first author and CSLP representative discussed the theoretical, developmental and pedagogical underpinnings of ABRA. The CSLP rep-

Table 4
Mean Raw Scores Pre- and Postinstruction for Each Outcome Measure by Group

	Wait-list control (n = 9)			ABRA instruction (n = 11)		
Measure	*M*	*SD*	Range	*M*	*SD*	Range
Preinstruction						
Word level reading accuracy	25.33	12.29	8–45	25.82	10.80	8–43
Passage level reading accuracy	20.11	23.60	0–64	20.09	18.64	0–45
Passage level reading comprehension	5.67	8.50	0–22	5.00	5.33	0–15
Postinstruction						
Word level reading accuracy	24.89	12.24	7–47	28.64	10.21	13–43
Passage level reading accuracy	19.44	22.75	0–65	25.82	21.29	1–58
Passage level reading comprehension	5.89	8.94	0–25	8.64	7.89	1–25

Note. Word level reading accuracy: Wide Range Achievement Test (WRAT-4), Word Identification subtest; Passage level reading accuracy and reading comprehension: Neale Analysis of Reading Ability (NARA-3).

resentative also presented information relevant to the administration of ABRA in the current study (e.g., the modifications necessary to accommodate 1:1 instruction) and demonstrated the use of the program. Before and between the training sessions, the first author was required to complete readings, including previous ABRA research, ABRA manual (Abrami, White, & Wade, 2010) and the teacher's zone on the CSLP website, and become proficient in the use of the ABRA software.

Compliance fidelity refers to the degree to which the core elements of a program are utilized during its implementation. Consistent with the recommendations of the CSLP (as per the ABRA manual and ABRA administration training), instruction sessions were individually planned to include computer and noncomputerized learning tasks targeting a balance of code and meaning-based learning objectives. Each participant's progression through these learning objectives was documented to ensure that all children completed the prescribed 26 hr of instruction and that learning objectives complied with the recommendations of the CSLP (e.g., performance criterion of 85% accuracy was used to identify skill mastery). In these ways, written documents composed during the instruction period (i.e., session plans and session notes) show that the core elements of ABRA instruction, including instructional content and duration, were implemented in the current study.

Competence fidelity is the level of skill with which the core elements of a program are delivered during its implementation. The standardized nature of the ABRA computer activities goes some way toward ensuring competence fidelity in the current study. For example, preprogrammed video models that are embedded within the ABRA computer program itself ensured that participants received an appropriate introduction to each computerized ABRA activity. However, external measures relating to the first author's implementation of ABRA were not collected. As such, competence fidelity cannot be independently verified in the current study.

Results

Raw scores for each of the outcome measures are provided in Table 4. As can be seen, children in the wait-list control group maintained or showed slight decreases in their raw scores over time. By contrast, children in the instruction group showed increases in their raw scores.

As the children within each group were of different ages and grades we converted raw scores to percentile ranks. The effects of ABRA instruction on participants' reading performance were evaluated using a series of 2 × 2 analyses of variance (ANOVAs; Time × Group) with $\alpha = .05$. The dependent variable used in these analyses was either age-based percentile rank (for the measure of word level reading accuracy percentile rank is calculated based on age in months) or year-of-schooling referenced percentile rank (for the measures of passage level reading accuracy and comprehension percentile ranks are calculated based on grade). ANOVAs conducted using participants' raw scores are also reported.

Word Level Reading Accuracy

A statistically significant interaction effect was observed for Time × Group on the word level reading accuracy measure, $F(1, 18) = 5.73$, $p < .05$, with a large effect size, $\eta_p^2 = .24$.[1] As shown in Figure 1, scores for participants in the instruction group increased from pre- to postinstruction assessment, suggesting improved word level reading ability. By contrast, scores for the wait-list control group decreased between these two time points.[2] Analysis of raw scores revealed a similar result, Time × Group interaction: $F(1, 18) = 12.50$, $p < .01$, $\eta_p^2 = .41$.

Passage Level Reading Accuracy

Analysis of the passage level reading accuracy data revealed a statistically significant Time × Group interaction, $F(1, 18) = 10.50$, $p < .01$, with a large effect size, $\eta_p^2 = .37$. Figure 2 shows an increase in mean percentile rank for the instruction group, suggesting an improvement in passage level reading accuracy, while there was relatively little change in the reading scores of the wait-list control group. Analysis of raw scores showed a

[1] η_p^2 of .01 is considered to be a small effect size, .06 a medium effect size, and .14 a large effect size (Richardson, 2011).

[2] Note that the wait-list control group achieved very similar raw scores on the WRAT-4 at pre- and postinstruction assessment (25.33 vs. 24.89). The slight decrease in percentile rank (shown in Figure 1) is likely because of the particular norming method used in the WRAT-4 (i.e., norms are based on age in months). That is, for the wait-list control group, participants' raw scores at postinstruction assessment corresponded to slightly lower percentile rankings because these participants were not making the kind of progress that would be expected with increasing age as was seen in the normative sample (largely comprised of individuals without disabilities).

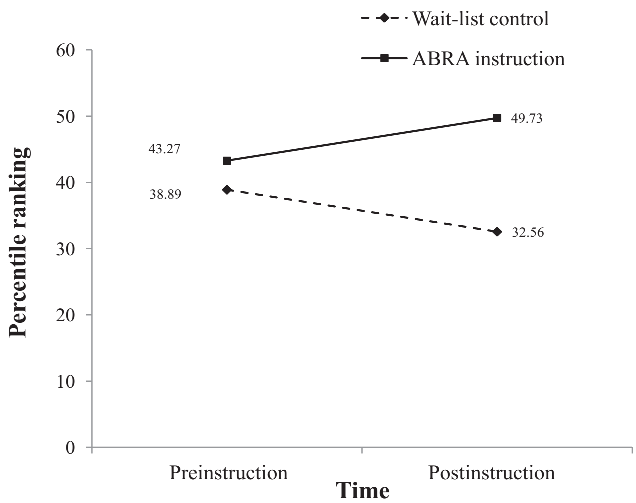

Figure 1. Mean percentile rankings for word level reading accuracy (Wide Range Achievement Test–4th Edition [WRAT-4]) by group.

similar result, Time × Group interaction: $F(1, 18) = 12.38$, $p < .01$, $\eta_p^2 = .41$.

Passage Level Reading Comprehension

A statistically significant Time × Group interaction was found for the measure of passage level reading comprehension, $F(1, 18) = 10.59$, $p < .01$, with a large effect size, $\eta_p^2 = .37$. As shown in Figure 3, percentile rank scores for the instruction group increased from pre- to postinstruction assessment, suggesting an improvement in passage level reading comprehension. Scores for the wait-list control group were relatively consistent across the two time points, indicating little change in reading comprehension skills. Analysis of participants' raw scores again revealed a similar result, Time × Group interaction: $F(1, 18) = 8.51$, $p < .01$, $\eta_p^2 = .32$.

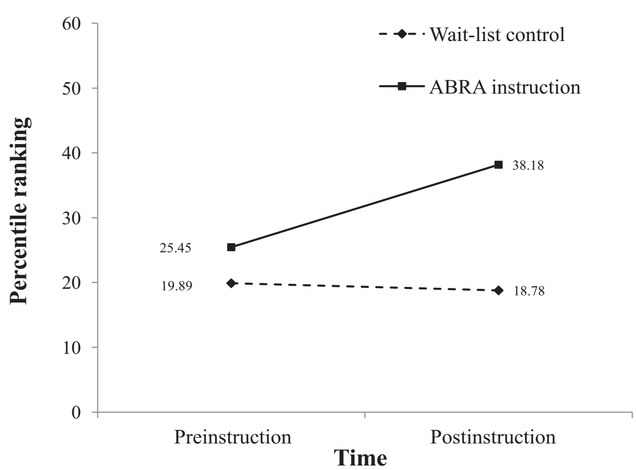

Figure 2. Mean percentile rankings for passage level reading accuracy (Neale Analysis of Reading Ability–3rd edition [NARA-3]) by group.

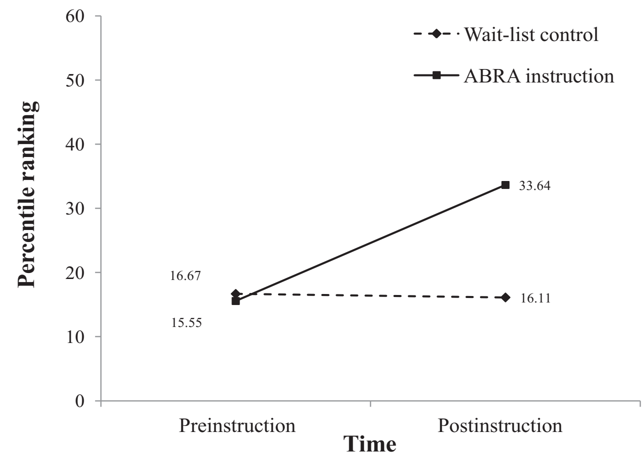

Figure 3. Mean percentile rankings for reading comprehension (Neale Analysis of Reading Ability–3rd edition [NARA-3]) by group.

Nonparametric Analyses

In view of the modest sample size, the effects of ABRA instruction were also evaluated using nonparametric Mann–Whitney tests conducted on pre-/postinstruction percentile rank difference scores for each of the outcome measures. The median difference score for the word level reading accuracy measure was 3 for the instruction group and −1 for the wait-list control group. For the passage level reading accuracy measure, the median difference score was 13 for the instruction group and 0 for the wait-list control group. For the passage level reading comprehension measure, the median difference score was 14 for the instruction group and 0 for the wait-list control group. With alpha set at .05, analyses showed statistically significant gains for the instruction group relative to the wait-list control group across all three reading measures: word level reading accuracy ($U = 21.00$, $z = -2.17$, $p = <.05$), passage level reading accuracy ($U = 10.50$, $z = -2.99$, $p = <.01$), and passage level reading comprehension ($U = 9.50$, $z = -3.07$, $p = <.01$).

Discussion

In the current study we examined the effects of ABRACADABRA literacy instruction on the reading abilities of a diverse group of children with ASD. Our research was guided by three questions intended to ascertain (a) whether ABRA instruction could be used to facilitate reading development in children with ASD; (b) whether the gains achieved using ABRA would be observed across both word and passage level reading abilities; and (c) the size of these gains.

We hypothesized that participants in the ABRA instruction group would exhibit improved reading abilities compared with a wait-list control group. Consistent with this hypothesis, participants in the instruction group, relative to the wait-list control group, achieved statistically significant gains in reading accuracy and comprehension following 26 sessions of ABRA instruction administered over a 13-week period. Our second hypothesis was that the relative gains achieved by participants in the instruction group would be observed across both word and passage level reading abilities. The data revealed statistically significant gains for the instruction group, compared with the wait-list control group, across all three aspects of reading ability that were assessed (i.e., word level reading accuracy, passage level reading accuracy, and passage level reading comprehension), thus confirming our hypothesis.

With regard to our third hypothesis, effect size calculations showed considerable gains for the instruction group relative to the wait-list control group across each of the evaluated aspects of reading.[1] Gains achieved in the word level reading accuracy skills of the instruction group compared to the wait-list control group were large ($\eta_p^2 = .24$), suggesting that ABRA instruction was effective in facilitating substantial improvements in the word level reading abilities of children with ASD. By comparison with the wait-list control group, the instruction group also achieved large gains in their passage level reading accuracy ($\eta_p^2 = .37$) and passage level reading comprehension ($\eta_p^2 = .37$). It is interesting that gains in the instruction group were more pronounced with regard to participants' passage level reading skills as compared with their word level reading skills (as revealed by the ANOVAs that were conducted on percentile ranks—gains were equivalent in the ANOVAs that were conducted on raw scores). This uneven pattern of improvement may be further evidence that subcomponent reading skills can develop more autonomously in children with ASD as compared with children without disabilities (Arciuli et al., 2013; Nation et al., 2006).

Previous ABRA Research

The results presented here are in line with several studies showing that ABRA can have positive effects on children's reading abilities. Indeed, the effect sizes reported in the current study compare favorably with the previous ABRA research. For example, in contrast to the large effects reported in the current study, Wolgemuth et al. (2013) found ABRA instruction to have a statistically significant, medium-sized effect ($d = .36$) on the combined word reading accuracy and phonological awareness skills of children without disabilities. Other previous research has identified a modest average effect size ($g+ = 0.065$) for ABRA on the reading comprehension skills of children without disabilities (Abrami et al., 2015). Such comparisons suggest that children with ASD may be more receptive to ABRA instruction relative to children without disabilities. However, there are important differences in the way the ABRA literacy instruction was delivered in the current study versus previous studies. For instance, the current study evaluated the effects of ABRA instruction administered on a 1:1 basis whereas previous research has focused exclusively on the effects of ABRA instruction in small groups or whole class settings. Thus, comparison of effect sizes obtained from the current study and previous research should be carefully considered.

Numerous features within the ABRA program could potentially benefit children with ASD. Broadly speaking, it is posited that these features could contribute to the effectiveness of ABRA via children's improved engagement with instructional content, increased access to learning opportunities, and enhanced generalization of learned skills across instructional contexts.

Engagement. ABRA may serve to enhance the willingness and ability of children with ASD to engage with instructional content. ABRA sessions follow a set structure, which would appear well-suited to the needs of children with ASD in that they are commonly found to show a preference for repetition and predictability (Richler, Huerta, Bishop, & Lord, 2010). The interactive interface of ABRA's computer tasks is considered beneficial in that it requires children to actively engage with and respond to instruction. Active cognitive processing, such as that facilitated by ABRA, is critical to learning (Wouters, Paas, & van Merriënboer, 2008). ABRA activities also occur within the context of an overarching storyline. Embedding learning activities within a broader narrative in this way may enhance intrinsic motivation for learning (Baranowski, Buday, Thompson, & Baranowksi, 2008), and assist in the creation of an immersive learning environment (Dickey, 2006). Therefore the features of ABRA may help to reduce the difficulties some children with ASD have in engaging with instructional content.

Accessibility. ABRA instruction may promote the ability of children with ASD to access valuable literacy learning opportunities in several ways. First, learning objectives and task difficulty settings are tailored to ensure that each individual child commences instruction at an appropriate level and experiences the high rates of accurate responding necessary for efficient learning (Lamella & Tincani, 2012). Second, key reading skills and their associated learning tasks are introduced via animated video. This permits the use of visually cued instructions, the likes of which have been shown to benefit children with ASD (Quill, 1997). Third, many ABRA activities provide structured feedback using a system of least-to-most prompts. This form of feedback appears well-suited to children with ASD, many of whom prefer routine and may be averse to unpredictable feedback (Hume, Plavnick, & Odom, 2012). Considered collectively, these features are proposed to function in such a way as to assist children with ASD to access ABRA's instructional content despite their often considerable social-communicative, cognitive and behavioral difficulties.

Generalization. Our pre and post instruction testing utilized standardized assessments that were created independently of ABRA. Results revealed improvements for the instruction group relative to the wait-list control group. Thus, ABRA instruction appeared to generalize to a broader set of reading materials. ABRA's multimodal instructional approach may encourage the generalization of learnt reading skills for children with ASD in two ways. First, discrete reading skills, which are initially taught in isolation, are explicitly integrated into passage level reading tasks involving both decoding and reading comprehension. This form of embedded instruction may serve to enhance both the development of discrete skills and the abilities of children with ASD to independently apply these skills during novel tasks (Smith, Spooner, & Wood, 2013). Second, ABRA sessions are structured in such a way as to ensure that reading skills are targeted using both computer and noncomputerized learning tasks. The use of multiple mediums is proposed to aid in the development of generalized reading skills in children with ASD, many of whom are shown to have difficulty generalizing learned skills across instructional contexts (Hume, Loftin, & Lantz, 2009).

Previous CAI Research

The current study addressed some of the limitations in the previous research on CAI and ASD. These limitations include the use of small samples typically comprised of higher functioning children, reliance on nonstandardized outcome measures, and use of CAI programs that are inaccessible, expensive, or outdated. We addressed these limitations by evaluating the effects of a freely accessible, computer-assisted program on the reading skills of a relatively large, diverse sample of children with ASD using standardized outcome measures. The inclusion of standardized outcome measures in the current study permitted us to directly compare participants of different ages and to quantify changes in reading ability for each participant with ASD from pre- to postinstruction with reference to a normative sample.

Previous research has returned mixed results regarding the effects of CAI on the reading skills of children with ASD. For example, Williams et al. (2002) found nonsignificant gains in word reading accuracy for children with ASD who received instruction using an experimental computer-based literacy program. By contrast, Tjus et al. (1998) reported significant improvements in the word and sentence reading accuracy skills of children with ASD following instruction using the Delta Messages program, with large effects ($\delta_{rm} = 1.031$). Basil and Reyes (2003) also identified improvements in reading comprehension for a child with ASD following instruction using the Delta Messages program but did not report effect sizes.

It is important to note that the types of CAI investigated in previous research have differed widely in both instructional focus and mode of delivery. For example, where the current study utilized a balanced reading program (i.e., targeting both code and meaning based abilities) delivered using a web application and noncomputerized extension tasks, Tjus et al. (1998) administered a purely computerized intervention targeting only sentence construction skills. The instruction protocols employed across these studies have also differed in intensity and duration, ranging from a few days (e.g., Moore & Calvert, 2000) to several months (e.g., Bosseler & Massaro, 2003), and have involved divergent samples of children with ASD, differing widely in both age and level of functioning. Given these inconsistencies, it is difficult to directly compare the learning outcomes of children with ASD following exposure to the various CAI programs. However, the large effects reported in the current study suggest that ABRA may be among the more effective CAI programs for teaching reading skills to children with ASD.

Limitations and Future Research

While the findings reported in the current study are encouraging, several limitations warrant consideration. First, we did not collect information regarding the regular classroom literacy instruction that participants received during the instruction period. As a consequence, it is not possible to determine whether differences in classroom literacy instruction may have contributed to our results. However, given that participants in each group came from a number of different districts, we think it unlikely that classroom instruction could have had a systematic effect on the results. Second, assessment and instruction sessions were conducted by the first author. As such, it is possible that increased rapport may have affected the performance of participants in the instruction group at postinstruction assessment. However, we emphasize that pre and post instruction assessment utilized standardized measures with strict administration procedures, thereby limiting the effect of rapport. Third, external measures of competence fidelity were not collected. It is therefore unclear whether the first author implemented ABRA with a high degree of skill. However, there was strong evidence of context and compliance fidelity.

An evaluation of ABRA that addresses the above limitations with a larger sample of children with ASD is encouraged. A larger study would benefit from incorporating additional outcome measures (e.g., those relating to nonword decoding skills) and could explore the effects of ABRA on different subgroups within the ASD population, such as children with and without comorbid language difficulties. Future studies of children with ASD could also evaluate classroom-based or parent-directed administration of ABRA as well as the use of ABRA as a core, as opposed to supplemental, literacy program.

Conclusion

The current study is the first to evaluate the effects of ABRA instruction on children with ASD and, as far as we are aware, is the first investigation of ABRA to be conducted independently of the CSLP. Our findings demonstrate that children with ASD, like children without disabilities, can benefit from balanced literacy instruction that targets alphabetics, reading fluency, reading comprehension, and writing contained within the ABRA instruction program. The benefit we report here was observed across three aspects of reading ability: word level accuracy, passage level accuracy, and passage level reading comprehension. In short, the freely available, computer-assisted ABRA program shows great promise in improving reading outcomes for children with ASD.

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