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Efficacy of ABRACADABRA literacy instruction in a school setting for children with autism spectrum disorders

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ABSTRACT

Background: There is evidence indicating that instruction using ABRACADABRA (ABRA) – a free web application designed to promote literacy development – may benefit children with autism spectrum disorders (ASD) when administered on an individualized basis in children's homes.
Aims: Here, we investigated the efficacy of ABRA instruction administered in small groups of children with ASD within a school setting.
Methods and procedures: Children were aged 5.83–8.42 years (n = 23). Some children were assigned to an instruction group and received a minimum of 20 h of ABRA instruction over 9 weeks (n = 11). The other children comprised an age- and ability-matched control group (n = 12) and received business as usual literacy instruction. Outcome measures included word-level accuracy, passage-level accuracy, and passage-level comprehension, all assessed using standardized tests that were independent of ABRA.
Outcomes and results: ANOVAs comparing pre- versus post-instruction raw scores showed statistically significant improvements in word- and passage-level reading accuracy for the instruction group relative to the control group, with large effect sizes. Gains in reading comprehension for the instruction group were not statistically significant and, in a posthoc correlational analysis, appeared to be related to children's socialisation skills (r = .62).
Conclusions and implications: Literacy instruction using ABRA is associated with improvement in reading accuracy for children with ASD when administered in small groups within a school setting. Children with ASD may require additional supports to make gains in reading comprehension when literacy instruction using ABRA is delivered in groups.

What this paper adds

The ABRACADABRA program (ABRA) is designed to improve early literacy skills via game-based learning activities. In a previous study by Bailey, Arciuli, and Stancliffe (2017a), children with autism spectrum disorders (ASD) received ABRA instruction and participated in shared book reading on a one-to-one basis with an ABRA facilitator in their homes. Results showed significant gains in word- and passage-level reading accuracy and passage-level reading comprehension in an instruction group relative to a control group. While individualized instruction in participant's homes has many benefits, it is more economical if the literacy skills of children with ASD can be improved using group-based instruction within schools. In the current study we investigated the efficacy of ABRA instruction for children with ASD when administered by teachers to small groups within a school setting. For each ABRA session, children spent time on a personal computer as well as engaging in small group activities using a shared computer. After these computer activities, children engaged in shared book reading without a computer in small groups. Results demonstrated that ABRA

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was effective in improving reading accuracy skills in an instruction group relative to a control group. By contrast, ABRA instruction appeared to be less effective in improving reading comprehension in a school setting. This may be because of increased demands on social communication skills when ABRA is administered in groups; however, this requires further investigation.

1. Introduction

Autism spectrum disorders (ASD) are a group of early-onset neurodevelopmental disorders characterized by social communication deficits and restricted or repetitive patterns of behavior or interests (*Diagnostic and Statistical Manual of Mental Disorders* [5th ed.; *DSM-5*], American Psychiatric Association, 2013). These core characteristics can be accompanied by difficulties with oral and written language as well as broader learning impairments which adversely affect children's educational achievement (Charman et al., 2011; Happé, Booth, Charlton, & Hughes, 2006; Tager-Flusberg, Paul, & Lord, 2005; Vivanti, Barbaro, Hudry, Dissanayake, & Prior, 2013). With an estimated 1 in 132 individuals diagnosed with ASD worldwide (Baxter et al., 2015), there is a pressing need to identify effective methods for improving educational outcomes for children in this population.

Here we focussed on improving children's literacy skills using computer-assisted instruction. In the first study of its kind, we assessed the efficacy of the freely available web-based ABRACADABRA program administered to small groups of children with ASD by teachers in a school setting. Hereafter, we refer to ABRACADABRA as ABRA (developed by the Centre for the Study of Learning & Performance, 2009). Our outcomes of interest were word-level reading accuracy, passage-level reading accuracy, and passage-level reading comprehension skills in an instruction group (who undertook ABRA activities at school during some of their dedicated literacy instruction time each week over 9 weeks) versus a business as usual control group (who did not undertake any ABRA activities over the same 9-week period).

1.1. Reading and ASD

According the Simple View of Reading (Gough & Tunmer, 1986), skilled reading requires that children accurately decode text while also attending to and understanding its meaning. The development of these abilities – reading accuracy and comprehension – can be delayed or impaired for some children with ASD (Åsberg, Kopp, Berg-Kelly, & Gillberg, 2010; Brown, Oram-Cardy, & Johnson, 2013; Estes, Rivera, Bryan, Cali, & Dawson, 2011; Huemer & Mann, 2010). In a seminal study, Nation et al. (2006) profiled the reading accuracy and comprehension skills of 41 children with ASD aged 6–16 years using the Neale Analysis of Reading Ability – 2nd edition (NARA-2; Neale, 1997; Nation, Clarke, Wright, & Williams, 2006). Results showed that approximately 22% of children were completely unable to read. As a group, the remaining children achieved a mean reading accuracy score which fell within the normal range. Reading comprehension scores were significantly lower, with approximately 34% of children achieving results more than one standard deviation below their reading accuracy scores. Further analyses revealed that reading accuracy and comprehension scores shared a considerably weaker correlation than that reported in previous studies involving typically developing children (Nation & Snowling, 1997). These findings are consistent with several more recent investigations showing that children with ASD are at risk of experiencing both reading accuracy and reading comprehension difficulties, and that reading accuracy and comprehension skills may develop more autonomously for children with ASD as compared to their typically developing peers (Arciuli, Stevens, Trembath, & Simpson, 2013; Norbury & Nation, 2011).

There is evidence that established models outlining the underpinnings of reading accuracy, based on research with typically developing children, are applicable to children with ASD (Jacobs & Richdale, 2014; Nash & Arciuli, 2016; Newman et al., 2007). Research on reading comprehension has returned similar results, indicating that children with ASD and typically developing children draw on many of the same underlying abilities when attempting to derive meaning from text (Norbury & Nation, 2011). However, it has been noted that additional abilities, such as social communication and higher-order language skills, may be especially important for reading comprehension for children with ASD (McIntyre et al., 2017; Ricketts, Jones, Happé, & Charman, 2013). In summary, while children with ASD and typically developing children draw on the same underlying abilities when learning to read, it appears that additional variables may influence reading comprehension for children with ASD.

1.2. Literacy instruction for children with ASD

Research on the direct remediation of reading difficulties for children with ASD is beginning to emerge. Within this field, there is growing support for the provision of evidence-based reading instruction consistent with the recommendations of the National Reading Panel (NRP; National Institute of Child Health & Human Development, 2000) and other national reviews of effective reading instruction (e.g., Rose, 2009; Rowe, 2006). These reviews highlight that effective literacy instruction incorporates a focus on five key elements: phonemic awareness, phonics, vocabulary, reading fluency, and reading comprehension skills. Phonemic awareness and phonics instruction have been linked to improvements in reading accuracy for children with ASD (Bailey, Angell, & Stoner, 2011; Leytham, Pierce, Baker, Miller, & Tandy, 2015; Nopprapun & Holloway, 2014), while vocabulary instruction and training in comprehension strategies have shown some promise in addressing reading comprehension (Bethune & Wood, 2013; Howorth, Lopata, Thomeer, & Rodgers, 2016; Roux, Dion, & Barrette, 2015; Roux, Dion, Barrette, Dupéré, & Fuchs, 2015; Stringfield, Luscre, & Gast, 2011). There is also preliminary evidence that repeated oral reading practice may improve reading fluency for some children in this population (Barnes & Rehfeldt, 2013; Reisner, Lancaster, McMullin, & Ho, 2014). These findings suggest that *individual elements* of evidence-based literacy instruction can improve reading for children with ASD.

A small number of studies have investigated the effects of comprehensive evidence-based literacy instruction, encompassing *all* *five elements* recommended by the NRP, on reading for children with ASD (i.e., Bailey et al., 2017a; Beecher & Childre, 2012; Grindle, Hughes, Saville, Huxley, & Hastings, 2013; Whitcomb, Bass, & Luiselli, 2011; see Bailey, Arciuli, & Stancliffe, 2017b), for a study of the effects of comprehensive instruction on spelling outcomes). These studies each reported improvements in reading accuracy for children with ASD following literacy instruction. Of these studies, Bailey et al. (2017a) was the only one to examine reading comprehension as well as reading accuracy outcomes. In addition, Bailey et al. (2017a) differed from the others in using the web-based ABRA program.

The ABRA program is a free web application designed to improve early literacy skills via game-based learning activities which comply with current recommendations relating to technology-based literacy instruction for at-risk learners (Savage et al., 2010). In the study by Bailey et al. (2017a) eleven children with ASD aged 5–12 years received 26 h of ABRA instruction on a one-to-one basis with an ABRA facilitator in their homes over a period of 13 weeks as an additional literacy aid outside of school hours. Nine age- and ability-matched children with ASD comprised a control group. Results revealed statistically significant gains in word- and passage-level reading accuracy as well as passage-level reading comprehension from pre- to post-instruction in the instruction group relative to the control group, with large effect sizes. This suggests that ABRA instruction is highly effective in improving the reading abilities of children with ASD when administered on a one-to-one basis outside of school hours. While this kind of individualized instruction in participant's homes has many benefits, it is more economical if literacy skills can be improved using group-based instruction within the school setting (Vaughn, Denton, & Fletcher, 2010). School is a crucial eco-system where many children spend a great deal of their time. As such, it is important to examine the efficacy of instruction that shifts from being researcher-administered to teacher-administered. Moreover, both group-based literacy instruction within the school setting, and teacher-administered literacy instruction, are relatively under-researched with regard to children with ASD by comparison with research on typically developing children.

1.3. ABRA instruction in a school setting

Aside from the studies by Bailey et al. (2017a, 2017b), all of the previous ABRA research has been conducted with children who do not have ASD. This previous research on children without ASD has focused on ABRA delivery in schools. Abrami, Borokhovski, and Lysenko (2015) investigated ABRA instruction across nine studies that met criteria for inclusion in a meta-analysis. All studies involved participants in Kindergarten through Grade 2, and most ($n = 5$) were conducted within Canadian schools. The remaining four studies took place in schools in Australia, Kenya, and Hong Kong. Children who received 8 to 16 weeks of ABRA instruction were found to make significant gains in phonemic awareness, phonics, vocabulary, and listening comprehension skills. There were no significant gains in reading comprehension following exposure to ABRA, and reading accuracy outcomes were not considered as part of the meta-analysis. However, individual studies have reported improvements in reading accuracy (Piquette, Savage, & Abrami, 2014), and in reading comprehension following ABRA instruction that was implemented with high fidelity (Savage, Abrami, Hipps, & Deault, 2009). A recently published RCT conducted in 48 UK classrooms also found improvements in general reading ability, including reading comprehension skills, for children who received 20 weeks of ABRA instruction (McNally, Ruiz-Valenzuela, & Rolfe, 2016). Taken together, these results show that ABRA instruction can be used effectively in a school setting to improve reading skills for a diverse range of typically developing children.

In addition to its evidence-based content, the success of ABRA may be attributed to the program's computer-assisted modality. Educational technology can be highly engaging (Cheung & Slavin, 2012; National Institute of Child Health & Human Development, 2000; Slavin, Lake, Chambers, Cheung, & Davis, 2009), and may provide users with a greater level of control over their learning relative to pen-and-paper tasks (Boekaerts & Corno, 2005; Zimmerman & Tsikalas, 2005). This is critically important in the classroom context as increased student autonomy may reduce demands on educators, allowing them to direct their instructional efforts towards those children with the greatest needs (Lynch, Fawcett, & Nicolson, 2000; Mathes, Torgesen, & Allor, 2001). These advantages mean that computer-assisted programs such as ABRA may be more effective in facilitating school-based literacy learning as compared to more traditional non-computerized learning environments.

The advantages of the computer-assisted aspects of ABRA have been discussed in previous research involving typically developing children. For example, Savage et al. (2009) suggested that ABRA's interface and instructional design meet the highest-level criteria for educational software targeting literacy set out in Bishop and Santoro (2006). Indeed, evaluation of ABRA using Bishop and Santoro's (2006) framework shows that the program's interface is aesthetically pleasing, operationally supportive, and highly interactive. In addition, literacy instruction in ABRA is appropriately systemic, supportive, and motivating. The benefits of these features are evident in the positive learning outcomes reported for typically developing children following group-based ABRA instruction (Abrami et al., 2015). Bailey et al. (2017a) suggested that ABRA's features also result in positive learning outcomes for children with ASD when administered on a one-to-one basis in children's homes. Whether children with ASD might also benefit from ABRA instruction administered in a school setting was the focus of the current study.

1.4. The current study

We investigated the efficacy of ABRA instruction for improving reading accuracy and reading comprehension in children with ASD when administered within a school setting. ABRA instruction was delivered by teachers who received training in the program. For each ABRA session, children spent time on a personal computer as well as engaging in small group activities using a shared computer. After these computer activities, children engaged in shared book reading without a computer in small groups. The study was guided by two research questions.

1 Can ABRA instruction improve the reading accuracy skills of children with ASD when administered in a school setting?
2 Can ABRA instruction improve the reading comprehension skills of children with ASD when administered in a school setting?

We hypothesized that children with ASD would exhibit significant gains in reading accuracy and reading comprehension following ABRA instruction in a school setting by comparison with a control group.

2. Method

2.1. Participants

This research was approved by the Human Research Ethics Committee at The University of Sydney and by Autism Spectrum Australia (ASPECT) – the organization that was responsible for the schooling of students involved in this project. The school principal, teachers, and parents provided written consent prior to participation.

The ASPECT literacy coordinator identified children that would meet the following inclusion criteria: (i) 5–11 years of age; (ii) previous formal clinical diagnosis of ASD using DSM criteria; (iii) no hearing or vision impairments; (iv) measurable language ability (able to complete a standardized test of receptive vocabulary, see Measures); (v) able to identify at least one letter of the alphabet; and (vi) able to demonstrate sustained attention to tasks for 15 min. The final sample consisted of 23 children (all males) from two classes that were overseen by the ASPECT organization. One class (Classroom A) was situated within an inclusive school attended by children with ASD and typically developing children while the other (Classroom B) was part of a specialist school attended only by children with ASD.

Participants were assigned to either an instruction group (ABRA sessions) or control group (individualized, small group, and whole class lessons, as deemed appropriate by teachers on any given day, which we describe as 'business as usual'). To ensure equivalence across groups, pairs of participants who achieved similar raw scores on standardized tests of oral language, reading, and adaptive abilities were identified. Participants in each pair were then randomly assigned to the instruction or control group. Due to a late enrolment, one child was added to the control group after the initial group assignments. This resulted in the control group (n = 12; 7 inclusive class students from classroom A and 5 specialist class students from classroom B) being slightly largely than the instruction group (n = 11; 5 inclusive class students from classroom A and 6 specialist class students from classroom B). Participant information by group is shown in Table 1. Participants' scores varied within each group reflecting the broad inclusion criteria utilized in the current study, although there were no statistically significant differences in this variability across groups.

Kolmogorov-Smirnov tests showed that data collected via some of the pre-instruction assessment measures were not normally distributed, meaning that the assumption for parametric analyses was not always met. However, some parametric analyses, such as t tests, are still thought to be robust when the assumption of normality is violated. As such, we tested pre-instruction differences between the two groups using independent samples t tests and then cross-checked these results using equivalent non-parametric analyses as recommended by Rasch and Guiard (2004).

As shown in Table 1, independent samples t tests showed no statistically significant differences across groups in terms of adaptive ability, vocabulary, phonological awareness, word-level reading accuracy, passage-level reading accuracy, or passage-level reading comprehension. The groups were also matched for age (mean age instruction group = 88.18 months, range = 70–97 months; mean age control group = 88.75 months, range = 73–101 months; $t(21) = .158$, $p = .876$). Non-parametric Mann Whitney tests returned the same findings (no statistically significant group differences with regard to age or any pre-instruction assessment measures).

2.2. Measures

A series of widely utilised, valid, and reliable standardized assessments were used to obtain baseline measures in order to assign participants to age- and ability-matched groups (instruction versus control). With the exception of adaptive ability, all assessments

Table 1
Raw scores for each pre-instruction baseline measure by group.

	Control (n = 12)			ABRA instruction (n = 11)					
Measure	*M*	*SD*	Range	*M*	*SD*	Range	$t(21)$	p	Cohen's d
Adaptive ability	249.82	38.42	190-308	262.82	54.26	188-396	0.65[a]	.52	.28
Vocabulary	82.17	27.71	43-130	86.45	24.88	49-133	0.39	.70	.16
Phonological awareness	10.75	8.94	3-34	14.18	7.47	3-25	0.99	.33	.42
Word-level reading accuracy	19.58	9.01	1-37	22.09	6.52	15-34	0.76	.46	.32
Passage-level reading accuracy	8.50	11.98	0-36	10.91	12.21	0-37	0.48	.64	.20
Reading comprehension	1.75	4.14	0-14	1.82	2.14	0-6	0.05	.96	.02

Note. Adaptive ability: Vineland Adaptive Behavior Scale (VABS-2), Adaptive Behavior Composite comprised of Communication, Daily Living Skills, Socialisation, and Motor Skills Domains; 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 Reading subtest; Passage-level reading accuracy and reading comprehension: Neale Analysis of Reading Ability (NARA-3).

[a] Data from one child in the control group missing as parent was unavailable for interview (df = 20).

were administered individually to child participants. Children's adaptive ability was assessed via semi-structured parent interview.

2.2.1. Adaptive ability

The Survey Interview Form from the Vineland Adaptive Behavior Scales was used to assess adaptive ability: socialization, communication, and daily living skills (VABS-2; Sparrow, Cicchetti, & Balla, 2005). Additional items measuring fine and gross motor skills were administered to parents of participants aged 6 years and younger. For our sample, the VABS-2 had high internal consistency for children aged seven years or older (Cronbach's α = .98), and 6 years or younger (Cronbach's α = .99).[1]

2.2.2. Vocabulary

The Peabody Picture Vocabulary Test is a test of receptive vocabulary (PPVT-4; Dunn & Dunn, 2007). Participants select one of four images best illustrating a target word verbally presented by the researcher. For our sample, the PPVT-4 had high internal consistency (Cronbach's α = .98).

2.2.3. Phonological awareness

We used the Phonological Awareness Composite Score from the Comprehensive Test of Phonological Processing (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013). This score was derived using the Elision, Blending Words, and Sound Matching subtests. Children aged 7 years and older completed the Phoneme Isolation subtest in place of the Sound Matching subtest. For our sample, the CTOPP-2 had high internal consistency for children aged 6 years or younger (Cronbach's α = .95), and those aged 7 years or older (Cronbach's α = .98).

2.2.4. Word-level reading accuracy

The Word Reading subtest of the Wide Range Achievement Test measures the ability to name letters and decode real words (WRAT-4; Wilkinson & Robertson, 2006). For children in our sample, the WRAT-4 had high internal consistency (Cronbach's α = .94).

2.2.5. Passage-level reading accuracy

The Reading Accuracy Composite score from the Neale Analysis of Reading Ability assesses passage-level reading accuracy (NARA-3; Neale, 1999). Participants are assessed on their ability to accurately read a series of passages of increasing length and complexity. The Reading Accuracy Composite had adequate internal consistency for our sample (Cronbach's α = .72).

2.2.6. Passage-level reading comprehension

We used the Reading Comprehension Composite score from the NARA-3 (Neale, 1999). This test requires participants to read passages aloud before being asked a number of comprehension questions related to the text. For the current sample, the Reading Comprehension Composite had adequate internal consistency (Cronbach's α = .72).

2.3. Procedure

The study followed a pre-test/post-test control group design. Pre- and post-instruction assessments were conducted by a single experimenter in a quiet room at the school. Instruction sessions took place in the school library as this was the only room in the school where a number of computers were available for use by children. The library was closed for use by other students and staff and only accessible to participants in the ABRA instruction group during the scheduled ABRA sessions. All sessions occurred within school hours.

2.3.1. Pre-instruction assessment

Participants completed a battery of adaptive ability, oral language, and reading tests during a single assessment session (see Measures). Assessment sessions ranged from 50 to 80 minutes duration depending on the individual child's abilities and behaviors.

2.3.2. Post-instruction assessment

The post-instruction assessment followed the same procedures as the pre-instruction assessment and included three outcome measures: (i) word-level accuracy; (ii) passage-level accuracy; and (iii) passage-level comprehension.

2.3.3. ABRA instruction

Children in the instruction group were divided into 2 subgroups (n = 5–6) prior to engaging with ABRA. These subgroups were matched on the basis of age and pre-instruction assessment measures. Each subgroup comprised a mix of children from the specialist class and the inclusive class. ABRA instruction was administered over a 9-week period[2] with the two subgroups, each completing one 75-minute and one 90-minute instruction session per week independent of one another. For the remainder of the week they received

[1] Cronbach α values for all of our measures refer to reliability for children in this study.

[2] In Australia the school term is 10 weeks in duration. We conducted this project in the final term of the school year which meant that the ABRA instruction had to be completed within 9 weeks, with subsequent post-instruction assessments in the final week of term.

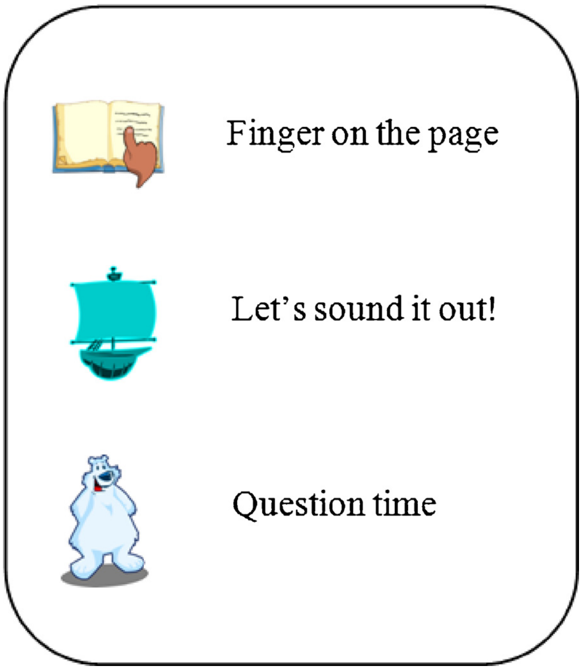

Fig. 1. Visual scaffold used to prompt tracking, decoding, and question answering. Icons are drawn from ABRA computer activities targeting these abilities.

their business as usual literacy instruction. Each child in the instruction group engaged with ABRA for a minimum of 20 h during the instruction period (M = 23.27, SD = 1.18, range = 20–24.5).

ABRA sessions comprised: (i) 20–25 mins of word-level activities targeting alphabetics, high-frequency word identification, or word spelling skills; (ii) 25–35 mins of passage-level computer activities targeting reading fluency or comprehension skills; (iii) 20 mins of non-computerized shared book reading which aimed to revisit skills targeted during the preceding computer activities; and (iv) 10 mins of free play. Word-level activities were conducted with each participant working independently at their own computer equipped with headphones. Passage-level computer activities involved groups of 2–4 participants working collaboratively on a single shared computer. Participants remained in these groups as they transitioned onto the non-computerized shared book reading activities which were conducted using a popular Australian series: the graded Fitzroy Readers (Berryman & O'Carroll, 2012; for more information see www.fitzprog.com.au/for-schools/english/readers.html). Simple visual scaffolds were used to promote participants' implementation of reading skills during these shared reading activities (see example in Fig. 1).

The pre-instruction assessment data provided information on each child's literacy abilities and were used to identify learning objectives, tasks, and task difficulty settings appropriate for instruction (see Abrami, White, & Wade, 2010, for details regarding ABRA goal setting and learning activities). These were reviewed following each instruction session. A performance criterion of 65–85% accuracy was employed to identify word-level activities of appropriate content and difficulty for instruction. Skill mastery was set at 85% accuracy for each word-level activity, maintained over three consecutive sessions. These same criteria were used during the passage-level activities that were undertaken in small groups although the average across the group was considered (i.e., 65–85% accuracy for appropriate difficulty and 85% accuracy for mastery).

2.4. Implementation fidelity

We considered context, compliance, and competence fidelity (O'Hare & Doell, 2015). Context fidelity requires that the precursors necessary for effective instruction are in place before implementing a program. In the current study, ABRA instruction was implemented by four of the participants' regular classroom teachers (hereafter ABRA instructors). Each ABRA instructor completed two 90-minute interactive training sessions which were conducted by a single experimenter with previous experience using ABRA (hereafter ABRA facilitator) before they began administering the program. These sessions included information on the theoretical underpinnings of ABRA and program and session structure, as well as guidelines on navigating the ABRA interface and data recording. Written information was provided to instructors to read between training sessions. ABRA instructors gained hands on experience using ABRA during each training session and were required to demonstrate proficient use of the software before they began administering the program.

Compliance fidelity refers to the utilization of core elements of a program during implementation. In line with recommendations, instruction sessions included a combination of word- and passage-level computer activities as well as non-computerized activities. Each participant's progression was documented to ensure appropriate learning objectives (e.g., a performance criterion of 85%

accuracy was used to identify skill mastery), and all children completed a minimum of 20 h of instruction. In these ways, session plans and notes taken during each session show that the core elements of ABRA instruction, including instructional content and duration, were implemented.

Competence fidelity is the level of skill with which a program is administered. This was guaranteed to some extent in the current study due to the standardized nature of the ABRA activities. For example, the same video introduction was provided to all child participants in the instruction group prior to commencing computer activities. The ABRA facilitator attended each instruction session in order to observe instructors' use of the program, and to provide technical and pedagogical support. These steps were taken to ensure that ABRA was conducted in line with the recommendations of the CSLP; however, it should be noted that competence fidelity was not independently verified.

2.5. Data analysis

A series of 2 × 2 ANOVAs (Time x Group) with $\alpha = .05$ were conducted to evaluate the effects of ABRA instruction on participants' reading abilities. Time was a within participants factor and group was a between participants factor. Dependent variables were word-level reading accuracy, passage-level reading accuracy, and passage-level reading comprehension (raw scores comprised each dependent variable). Interpretation of effect sizes: we interpreted η_p^2 of .01 as a small effect size, .06 as a medium effect size, and .14 as a large effect size (Richardson, 2011). ANCOVAs using age in months as a covariate were also conducted. As the assumption of normality was not met for some variables, we cross-checked results from the ANOVAs by comparing pre-post difference scores for reading accuracy and comprehension for the instruction group versus the control group using non-parametric Mann Whitney tests.

3. Results

Pre/post assessment raw scores for each of the outcome measures are provided by group in Table 2. Generally, children in the instruction group showed improvements in their reading abilities after ABRA instruction by comparison with the control group.

3.1. Word-level reading accuracy

Mean raw scores showed improvement for children in the instruction group from pre- to post-assessment with little change observed in the mean scores achieved by participants in the control group. In terms of word-level reading accuracy raw scores, we observed a statistically significant main effect of Time, $F\,(1, 21) = 19.41$, $p < .001$, $\eta_p^2 = .48$, showing gains in accuracy from pre- to post-assessment. There was no significant main effect of Group, $F\,(1, 21) = 1.30$, $p = .27$, $\eta_p^2 = .06$. The Time x Group interaction was statistically significant, $F\,(1, 21) = 9.04$, $p = .007$, with a large effect size, $\eta_p^2 = .30$, 90% CI (.06, .50). Similarly, ANCOVA results with age in months as a covariate showed a statistically significant interaction, Time x Group: $F\,(1, 20) = 8.66$, $p = .008$, with a large effect size, $\eta_p^2 = .30$, 90% CI (.05, .50). Median pre-post difference scores for the word-level reading accuracy measure were 3 for the instruction group and 1 for the control group. Non-parametric analysis showed that improvement in word reading accuracy was significantly larger for the instruction group relative to the control group, $U = 26.00$, $z = -2.50$, $p = .01$.

The median age-based percentile rank for word-level reading accuracy increased by 24 from pre- to post-assessment in the instruction group (from 10 to 34). For the control group the median age-based percentile rank decreased by 1 from pre- to post-assessment (from 13 to 12).

3.2. Passage-level reading accuracy

In terms of mean raw scores, there was considerable improvement in passage-level reading accuracy in the instruction group with only a relatively small change in the control group. Analysis of the passage-level reading accuracy raw scores revealed a statistically significant main effect of Time, $F\,(1, 21) = 22.10$, $p < .001$, $\eta_p^2 = .51$, and no significant main effect of Group, $F\,(1, 21) = 0.57$, $p =$

Table 2
Mean pre- and post-instruction raw scores for each outcome measure by group.

	Control (n = 12)			ABRA instruction (n = 11)		
Measure	*M*	*SD*	Range	*M*	*SD*	Range
Pre-instruction						
Word-level reading accuracy	19.58	9.01	1-37	22.09	6.52	15-34
Passage-level reading accuracy	8.50	11.98	0-36	10.91	12.21	0-37
Passage-level reading comprehension	1.75	4.14	0-14	1.82	2.14	0-6
Post-instruction						
Word-level reading accuracy	20.17	8.64	2-36	25.18	7.20	16-38
Passage-level reading accuracy	10.42	12.70	0-39	16.00	14.44	0-43
Passage-level reading comprehension	2.33	4.44	0 -15	3.64	4.48	0-12

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

.46, η_p^2 = .03. The Time x Group interaction was statistically significant, F (1, 21) = 4.53, p = .045, with a large effect size, η_p^2 = .18, 90% CI (.00, .39). Similarly, ANCOVA results with age in months as a covariate showed a statistically significant interaction (Time x Group: F [1, 20] = 4.46, p = .047, with a large effect size, η_p^2 = .18, 90% CI [.00, .40]). The median difference scores for passage-level reading accuracy were 6 for the instruction group and 1 for the control group. This group difference was not statistically significant, U = 36.00, z = -1.88, p = .06.

The median age-based percentile rank for passage-level reading accuracy increased by 16 from pre- to post-assessment in the instruction group (from 7 to 23). For the control group, the median age-based percentile rank increased by 5 from pre- to post-assessment (from 5 to 10).

3.3. Passage-level reading comprehension

Reading comprehension raw scores were generally low at pre-instruction assessment and improved for both groups at post-instruction assessment. There was a statistically significant main effect of Time for passage-level reading comprehension, F (1, 21) = 7.05, p = .02, η_p^2 = .25. Neither the main effect of Group, F (1, 21) = 0.19, p = .67, η_p^2 = .01, nor the Time x Group interaction, F (1, 21) = 1.87, p = .19, η_p^2 = .08, 90% CI (.00, .29), were statistically significant. ANCOVA results with age in months as a covariate were similar showing no statistically significant interaction (Time x Group: F [1, 20] = 1.75, p = .20, η_p^2 = .08, 90% CI [.00, .29]). Median difference scores were 1 for the instruction group and 0 for the control group. With alpha set at .05, non-parametric analyses showed that this group difference was not statistically significant, U = 48.50, z = -1.17, p = .24.

The median age-based percentile rank for passage-level reading accuracy increased by 8 from pre- to post-assessment in the instruction group (from 2 to 10). For the control group there was no increase in the median age-based percentile rank from pre- to post-assessment (remaining at $<$ 1).

3.4. Posthoc analysis of links with socialisation skills

Given some previous research has suggested that social communication skills might be related to reading ability in children with ASD, we conducted a series of posthoc correlational analyses looking at relations between children's scores on the Socialisation Domain of the VABS-2 (Sparrow et al., 2005) and pre-post difference scores using parametric analyses (Pearson's r). Non-parametric (Spearman's r) analyses were used for the Control group as socialisation scores were not normally distributed for this group. Results revealed a statistically significant relationship between socialisation skills and pre-post reading comprehension difference scores for children in the instruction group (r = .62, p = .04).[3] Children with higher socialisation adaptive abilities tended to achieve greater gains in reading comprehension during group-based ABRA instruction. Reading comprehension difference scores were not significantly related to socialisation skills for children in the control group (r_s = .23, p = .50). There were no significant correlations between socialisation scores and the pre-post difference scores for word-level reading accuracy (r = .15, p = .65) or passage-level accuracy (r = .42, p = .20) in the instruction group or the control group (r_s = .30, p = .37 and r_s = .06, p = .87, respectively). As noted, if α is corrected in view of multiple tests, the one statistically significant correlation is no longer significant; however, that particular r value is the largest and indicates a large effect size.

4. Discussion

This study investigated the efficacy of ABRA instruction delivered in a school setting for children with ASD. Our first hypothesis was that children with ASD would show improvements in reading accuracy following ABRA instruction as compared to a control group of children with ASD who received business as usual literacy instruction. Our second hypothesis was that children with ASD would show improvements in reading comprehension following ABRA instruction by comparison with a control group.

4.1. Reading accuracy outcomes

Consistent with our first hypothesis, children with ASD who received ABRA instruction achieved statistically significant gains in word-level reading accuracy relative to children with ASD who received business as usual literacy instruction. Effect size estimates showed that these gains were large in magnitude (η_p^2 = .30, 90% CI [.06, .50]) and similar to those reported by Bailey et al. (2017a; η_p^2 = .41, 90% CI [.11, .59]). Moreover, the results of our parametric and non-parametric analyses in the current study were similar in terms of improvements in word-level reading accuracy. Taken together, these results suggest that ABRA instruction is effective in improving word-level reading accuracy skills for children with ASD regardless of whether the program is administered in small groups within a school setting or on a one-to-one basis in children's homes.

Parametric analysis in the current study showed statistically significant gains in passage-level reading accuracy from pre- to post-instruction for children in the instruction group relative to the control group. These gains were associated with a large effect size (η_p^2 = .18, 90% CI [.00, .39]). This statistically significant effect is consistent with the results of Bailey et al. (2017a) although we note the different effect size and associated confidence intervals obtained in the earlier study (η_p^2 = .41, 90% CI [.11, .59]). Non-parametric analysis of data collected in the current study showed that children in the instruction group tended to achieve larger gains

[3] Correction for multiple tests would affect statistical significance.

in passage-level reading accuracy as compared to the control group; however, this was not statistically significant ($p = .06$).

4.2. Reading comprehension outcomes

Contrary to our second hypothesis, there were no statistically significant improvements in reading comprehension for children with ASD who received 9 weeks of ABRA instruction as compared to the control group in either parametric or non-parametric analyses. This stands in contrast to the statistically significant and large gains in reading comprehension achieved by children in the study reported by Bailey et al. (2017a) who received 13 weeks of ABRA instruction. This may suggest that ABRA is only effective in improving reading comprehension for children with ASD when administered on a one-to-one basis in children's homes as compared to when it is administered in small groups in a school setting. Another possibility is that reading comprehension skills did not show improvement in the current study on account of the ABRA instruction period being 4 weeks shorter than in the previous study. This possibility is discussed further in the following sections.

4.3. Home-based versus school-based ABRA instruction

Comparison of the current results and those reported in the previous study by Bailey et al. (2017a) may provide insights into some of the variables associated with effective literacy instruction for children with ASD. In particular, it is worth considering the extent to which instruction was tailored to individual participants and the social demands associated with ABRA across the two studies.

4.3.1. Instruction specificity

In the current study, word-level learning objectives were identified for each participant using their pre-instruction assessment data. For example, early alphabetic skills were targeted as a priority for children who achieved low scores on the letter reading component of the WRAT-4, whereas word decoding abilities were targeted for children with adequate letter reading skills. Word-level learning objectives were also assessed for suitability in this study using a performance criterion of 65–85% accuracy. A criterion of 85% accuracy achieved over three consecutive sessions was used to identify skill mastery. These steps ensured that word-level ABRA activities were tailored to match the specific needs and abilities of individual participants. This procedure followed that of Bailey et al. (2017a).

Passage-level activities in the current study were not tailored to individual participants in the same way as word-level activities due to the group-based instruction format. In the current study, group-based activities accommodated a range of abilities in terms of both reading accuracy and comprehension. A performance criterion of 65–85% accuracy was used as a guide for identifying passage-level activities of suitable content and difficulty. However, some children performed either above or below this criterion, meaning that activities were not at an optimal level for all participants all of the time. This is in contrast to Bailey et al. (2017a) where passage-level activities were determined based on the 65–85% performance criterion for each child. Therefore, reduced instruction specificity may have impacted the development of passage-level reading skills in the current study.

4.3.2. Social demands

One of the characteristics common to all children on the autism spectrum is difficulties with social communication as it is a diagnostic criterion (American Psychiatric Association, 2013). It is useful to consider how learning environments may place different demands on children's social communication skills. Children with ASD have been found to have difficulties coordinating their attention between social partners and objects (Mundy & Burnette, 2005), such as books and computers, which could impact their literacy development during group-based instruction. Difficulties understanding and initiating communication could also limit children's ability to engage in reciprocal interaction which may impede successful participation in group-based discussion (Dawson et al., 2004; Mundy & Burnette, 2005; Rotheram-Fuller, Kasari, Chamberlain, & Locke, 2010). It follows that the group-based learning activities in the current study, which focussed on reading comprehension, may have been more taxing on children's social communication skills as compared to the wholly individualized instruction provided in Bailey et al. (2017a). Indeed, correlational analyses showed a relationship between socialisation scores and improvements in reading comprehension in the instruction group, but not the control group, in the current study. This is in line with previous studies that have found a link between social communication skills and reading ability (Ricketts et al., 2013). If our instruction group had included children with higher socialisation abilities these skills may have been beneficial during group-based activities and we may have seen statistically significant effects of ABRA on reading comprehension. In addition, if our group-based activities focusing on reading comprehension had been designed with social communication limitations in mind, we may have seen significant effects of ABRA on reading comprehension. These possibilities are speculative and should be investigated in future studies.

4.4. Limitations

While the results are encouraging, the current study has several limitations. First, pre-and post-instruction assessments were administered by the ABRA facilitator. As such, it is possible that performance on the post-instruction assessments may have been enhanced for children in the instruction group due to increased rapport and the fact that the ABRA facilitator was not blind to group membership. Arguing against this possibility, we emphasise that outcome measures were standardized assessments with limited potential for these effects. Second, competence fidelity was not independently verified. Although we can demonstrate evidence of context and compliance fidelity, future studies should look to address this limitation by seeking independent fidelity ratings. Third, aside from classroom observations undertaken prior to beginning ABRA instruction and discussions with the teachers, extensive data was not collected on children's business as usual literacy instruction so we cannot comment on whether the kinds of activities contained in ABRA were similar or different to what children were already being exposed to in their regular literacy lessons. However, we can say that all children in our study were subject to the same methods of literacy instruction. Thus, business as usual literacy instruction could not have impacted our results in a systematic way that affected the instruction group differently from the control group. Fourth, matching was group-wise rather than pair-wise, with our ABRA instruction group obtaining slightly higher mean scores on all measures at pre-instruction assessment. We acknowledge this but reiterate that there were no statistically significant group differences prior to ABRA instruction. As with all studies of this nature, it is possible that our groups differed significantly on some other measure that we did not use in our assessment battery. Related to this last point, we acknowledge ongoing debate about strengths and weaknesses of particular standardized tests of reading ability. We chose our measures so that they would be comparable with previous studies of literacy ability in children with ASD (especially the ABRA study by Bailey et al., 2017a). However, we note discussion around the use of the NARA, in particular, in assessment of reading comprehension and refer readers to the literature for more information (e.g., Cain & Oakhill, 2006; Spooner, Baddeley, & Gathercole, 2004). Finally, we acknowledge the modest sample size and lack of females in our instruction and control groups. Note that our sample size compares favourably with previous intervention studies of comprehensive literacy instruction for children with ASD (e.g., 1 child with ASD among 3 children with developmental disabilities in the study by Beecher & Childre, 2012; 4 children in the study by Grindle et al., 2013; 1 child in the study by Whitcomb et al., 2011).

4.5. Directions for future research

This study presents a number of potential avenues for future research which relate to ABRA and computer-assisted instruction more generally. A key consideration when comparing the current results with those of Bailey et al. (2017a) is the difference in instruction duration. It is possible that the instruction period in the current study (9 weeks), which was shorter relative to the instruction period in Bailey et al. (2017a; 13 weeks), may not have been adequate for improvements in reading comprehension, even though it was adequate for improvements in reading accuracy. In addition to the possibility of dose-related effects, it may be that improvements in reading comprehension take longer to 'show up' on independent standardized assessments (e.g., after 13 weeks rather than 9 weeks). Another difference between these two studies of ABRA and children with ASD is the shift from researcher-administered ABRA to teacher-administered ABRA. It seems that teacher administration of ABRA was effective in the current study in terms of children achieving gains in reading accuracy; however, teachers were more heavily involved in administering reading comprehension activities by comparison with reading accuracy activities and it may be that teachers require extended training in these aspects of ABRA instruction.

Yet another interesting avenue to pursue concerns the amount of individual needs 'tailoring' that is possible when children undertake ABRA reading comprehension activities using a shared computer. One of the strengths of ABRA is in allowing literacy instruction to be tailored to individuals based on specific criteria for skill mastery; however, ABRA instruction using a shared computer limits the ability to accommodate each child's specific needs. Related to this point, it is possible that social communication skills in children with ASD may be taxed when undertaking ABRA reading comprehension activities using a shared computer. Our correlational analyses revealed that children with lower socialisation skills made smaller gains in reading comprehension, and unlike many of the ABRA reading accuracy activities, ABRA reading comprehension activities were undertaken exclusively in small groups using a shared computer. This possibility should be explored in a larger study that systematically examines the effect of socialisation skills on individual computer use versus shared computer use during ABRA instruction. Such a study could also explore the quality of children's social interactions and the potential for children with ASD to work collaboratively during the ABRA sessions.

Also worthy of consideration is the fact that there are many elements to the ABRA sessions reported here, including some activities that utilise a computer and some that do not. It would be interesting to investigate whether it is the computerised or non-computerised parts of the ABRA sessions that are associated with change or whether the combination is important.

4.6. Conclusion

This study is the first to investigate ABRA instruction for children with ASD in a school setting. Our results demonstrate that ABRA is effective in improving children's reading accuracy skills. We found that ABRA instruction was less effective in improving reading comprehension. This may be (at least partly) because social communication skills are especially important when ABRA reading comprehension activities are undertaken in small groups in a school setting. Children with ASD who have lower socialisation skills may find such activities more taxing than individual activities undertaken with a personal computer although future research is needed to explore this possibility. Our study has implications for literacy practice within the classroom. We recommend that educators consider using the free ABRA web application to support literacy development for children with ASD. As in previous research that has demonstrated the efficacy of ABRA instruction within a school setting for the general population, ABRA appears to be a suitable program for use in the school setting for children with ASD.

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