Ann. of Dyslexia
DOI 10.1007/s11881-009-0032-y

Computer-assisted instruction to prevent early reading difficulties in students at risk for dyslexia: Outcomes from two instructional approaches

Joseph K. Torgesen · Richard K. Wagner · Carol A. Rashotte · Jeannine Herron · Patricia Lindamood

Received: 23 June 2009 / Accepted: 20 October 2009

Abstract The relative effectiveness of two computer-assisted instructional programs designed to provide instruction and practice in foundational reading skills was examined. First-grade students at risk for reading disabilities received approximately 80 h of small-group instruction in four 50-min sessions per week from October through May. Approximately half of the instruction was delivered by specially trained teachers to prepare students for their work on the computer, and half was delivered by the computer programs. At the end of first grade, there were no differences in student reading performance between students assigned to the different intervention conditions, but the combined-intervention students performed significantly better than control students who had been exposed to their school's normal reading program. Significant differences were obtained for phonemic awareness, phonemic decoding, reading accuracy, rapid automatic naming, and reading comprehension. A follow-up test at the end of second grade showed a similar pattern of differences, although only differences in phonemic awareness, phonemic decoding, and rapid naming remained statistically reliable.

Patricia Lindamood, deceased

J. K. Torgesen (✉) · R. K. Wagner
Florida Center for Reading Research and Department of Psychology, Florida State University, Tallahassee, FL, USA
e-mail: torgesen@fcrr.org

R. K. Wagner
e-mail: rkwagner@psy.fsu.edu

C. A. Rashotte
Department of Psychology, Florida State University, Tallahassee, FL, USA
e-mail: carol.rashotte@gmail.com

J. Herron
Talking Fingers, Inc., San Rafael, CA, USA
e-mail: herron@talkingfingers.com

P. Lindamood
Lindamood-Bell Learning Processes, San Luis Obispo, CA, USA

Published online: 06 January 2010

Keywords Computer-assisted instruction · Dyslexia · Early reading instruction · Prevention of reading disabilities

The last three decades have been a period of enormous growth in the understanding of early reading development (National Reading Panel, 2000; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Stanovich, 2000). For instance, the way that early growth in phonemic awareness and knowledge of letter–sound correspondences support growth in the ability to read text accurately is now well understood (Share & Stanovich, 1995). The connections between early growth of phonemic decoding skills and later development of reading fluency, as well as the relationships between fluency of reading text and growth of reading comprehension, are also firmly established (Ehri, 2002; Samuels & Farstrup, 2006).

Over this same period of time, new knowledge about the factors that make it difficult for many students to learn to read well in first and second grade has been generated. Although reading difficulties can arise from many sources (Morrison, Bachman, & Connor, 2005), one subgroup of poor readers, in particular, is of special interest in this study. These are students who are at risk for reading difficulties because of weaknesses in the phonological component of their natural capacity for language (Liberman, Shankweiler, & Liberman, 1989). Scientific research over the past three decades has documented that this subgroup of poor readers experiences a "bottleneck" to reading growth primarily because of early difficulties in acquiring accurate and fluent phonemic decoding skills (Perfetti, 1985; Torgesen, 1999). These difficulties, in turn, have a serious impact on the development of reading fluency and reading comprehension. Students with these types of primary reading difficulties are currently labeled dyslexic (Lyon, Shaywitz, & Shaywitz, 1993). The most widely accepted current definition of dyslexia states:

> It is characterized by difficulties with accurate and/or or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction (from the website of the International Dyslexia Association).

Fortunately, recent research has demonstrated that it is possible to prevent the emergence of early word-level reading difficulties in most students with phonologically based reading difficulties. For example, Torgesen (2004) concluded that, if effective interventions such as those reported in recent research were generally available to all students who needed them, the incidence of early reading difficulties could be reduced to between 1.6% and 6% of the total population. A more recent study that provided powerful interventions to a mixed group of students at risk for reading difficulties (Mathes, Denton, Fletcher, Anthony, Francis, & Schatschneider, 2005) reported an estimated population failure rate of less than 1% if the most effective intervention in that study was made available to any student who needed it.

A recent examination of nine studies that each provided 100 or more sessions of preventive instruction (between 25 and 173 h) at some point during kindergarten or first grade showed that a variety of different approaches could be successful in accelerating early reading development in at-risk students (Scammaca, Vaughn, Roberts, Wanzek, & Torgesen, 2007). However, all the successful interventions did have some things in common, including provision of explicit instruction in phonemic awareness and phonemic decoding, along with practice reading text and comprehension instruction. In addition, all of the studies provided instruction one on one or in small groups and involved daily or near-daily intervention sessions.

In spite of the evidence-based knowledge about reading, reading difficulties, and reading instruction that is currently available, most knowledgeable observers would agree that, in the USA, this knowledge is not being applied effectively in our schools (Pressley, 2002). The difficulties implementing effective instruction for at-risk students arise from a complex set of circumstances, with two particularly difficult challenges being lack of knowledge and skill on the part of many teachers and lack of instructional resources. Inadequately trained teachers experience difficulties providing the explicit, systematic, and motivating instruction that is needed for at-risk students (Moats, 1999). Inadequate financial and personnel resources make it difficult to provide the additional time and extra intensity of instruction necessary to help many students with reading disabilities avoid falling behind in reading development (Fielding, Kerr, & Rosier, 2007). Scammaca et al. (2007) estimated the cost of interventions in the studies they reviewed to range between \$150 and \$6,500 per student, with an average cost of \$2,400. One method to reduce the cost of early intervention noted in this review involves use of paraprofessionals to provide instruction within programs that contain explicit instructional guidance as part of their teacher manuals..

Computer technology may also be part of the long-term solution for dyslexic and other at-risk students because of its capacity to provide highly specialized instruction and practice for relatively low cost with relatively high and consistent fidelity. Empirical research indicates that current computer technology may be particularly well suited to providing support for instruction in the word-level reading skills that are so challenging for students with dyslexia (Torgesen & Barker, 1995). A recent topic report on beginning reading from the What Works Clearinghouse (2007) reported significant impacts on word-level reading skills in young children from five of seven software programs that had been evaluated in high-quality experimental research. In contrast to these positive findings, a recent large-scale evaluation of five computer-based reading programs used to provide first-grade instruction in reading in 42 schools with 2,619 students did not find a significant impact on reading growth from computer-based instruction (Dynarski et al., 2007). A potential problem with this latter study is that the computer software may have been used to *replace* teacher instruction rather than to *supplement* it. Observational data indicated that teachers provided less direct instruction in reading when computers were placed in the classroom than when they were not present.

Both the need for cost-effective intervention methods and current questions about the utility of computers to support effective early reading instruction suggest the need for further research on the conditions under which computers can be used effectively to help prevent reading difficulties in students at risk for reading difficulties. The present study evaluates the effectiveness of two computer programs when used in a way that may be particularly helpful for students with dyslexia or other reading disabilities. Computer-based instruction and practice were tightly coordinated to establish and extend knowledge and skills that were initially taught by teachers in supplemental intervention sessions. In both programs studied, computer activities were directly linked to instruction provided by the intervention teacher. In the case of one program, *Read*, *Write*, *and Type* (RWT; Herron, 1995), specific teacher lessons were developed to help students prepare for learning and practice on a computer program that had been previously developed. In the other case, software was developed to support the instruction provided in a program called *The Lindamood Phoneme Sequencing Program for Reading*, *Spelling*, *and Speech* (LIPS; P. Lindamood & P. Lindamood, 1998) that already had an extensive history of use as a teacher-led instructional program for students with dyslexia (Kennedy & Backman, 1993; Torgesen et al. 1999b).

Both programs provided explicit and systematic support for the development of phonemic awareness, phonemic decoding (and writing), and text reading accuracy.

Although both programs involved reading and understanding meaningful text as part of the instruction and practice, this emphasis was greater in the RWT program than the LIPS program as implemented in this study.

The programs also employed different approaches to teaching and establishing alphabetic reading skills. The RWT program is based on the premise that directly teaching students the spellings of phonemes, and using that knowledge to support spelling and writing activities may have unique advantages in helping students master the alphabetic principle (Herron, 2008). The LIPS program, in contrast, approaches the task of early reading instruction by providing powerful support for the development of oral motor awareness (awareness of the articulatory gestures associated with each phoneme) in support of early decoding (reading) and encoding (writing) activities. A significant portion of the instructional time in the LIPS program is spent establishing oral motor awareness as an aid to processing phonological information during reading and writing activities. By including two computer-based approaches that both addressed critical instructional needs for students with dyslexia but did so in slightly different ways, we hoped to determine whether the variation in emphases of the programs made a difference in their effectiveness for students who enter school delayed in the development of reading-related phonological skills.

The study was designed to answer three questions about the instructional conditions being evaluated:

1. Are there reliable differences in instructional impact between these two approaches to early intervention?
2. Do students receiving supplemental instruction using the RWT and LIPS programs show more rapid growth in early reading skills than students who do not receive the instruction?
3. What proportion of students receiving the computer-based instruction remained significantly impaired in reading skills following the intervention?

Method

Participant selection

The sample of students used in this study was built up from two cohorts of students attending first grade in three elementary schools. In each of two successive years, all first-grade students were screened at the beginning of the school year using a test of letter–sound knowledge to identify those students most at risk to develop reading problems. Children who performed in the bottom 35% of the sample on this test were then screened a second time with three other tests: phoneme elision (a measure of phonological awareness), serial naming of numbers (a measure of rapid automatic naming ability), and the vocabulary subtest of the Stanford-Binet Intelligence Test, Fourth Edition (Thorndike, Hagen, & Sattler, 1986). Scores from three of the screening measures (elision, rapid naming of numbers and letters, and letter–sound knowledge) were combined together into a score representing each student's probability of experiencing reading difficulties. This number was determined by using a logistic regression probability formula that included weighted scores from the three measures based on best prediction of reading outcome from a previous longitudinal study (Wagner, Torgesen, & Rashotte, 1999). Those students with the highest probability of reading difficulty who also had estimated verbal intelligence scores above 75 were selected to participate in this study. Over the 2 years in which these procedures were followed, they resulted in the selection of 112 first graders from a pool of 812 total first graders in these schools. Half of the students were recruited in the first year of the study and half during the second year. Because the screening measures we used are highly predictive of children's growth in reading ability during first grade (Fletcher, Lyon, Fuchs & Barnes, 2007; Wagner et al., 1999), we would contend that they represent the students at these schools most at risk for reading difficulties arising from weaknesses in processing phonological information.

In both years in which interventions were provided, children were randomly assigned within schools to one of three groups: RWT, LIPS, and a treatment-as-usual control group. Across the 2 years, 36 children received instruction in the RWT group and 36 in the LIPS group, and 40 children served in the control group. Of the 112 children who completed the instruction and received the immediate posttests, 55.6% were male, 33.1% were minority (mostly African American), and about 35% were receiving free or reduced price lunch. The elementary schools which these students attended averaged 50.5% males, 15% minority students, and 17% of students receiving free or reduced price lunch. Average age at the beginning of instruction was six and a half years. Although there was no attrition during the instructional year in first grade, at follow-up, 1 year after the end of instruction, the number of participating students was 108, with 34, 35, and 39 students participating in the RWT, LIPS, and control conditions, respectively. Of the four students who had moved away from the testing area at follow-up, two were male and two were minority.

Procedure

From October through May, children in both instructional conditions were taught in groups of three by teachers that were specially recruited and trained for this study. The children received four 50-min sessions per week over the course of the school year for an average of 80.4 h for the RWT group and 84.3 h for the LIPS group. Approximately 75% of the students received their intervention instruction outside of the regularly scheduled reading block. The rest of the students were pulled from the classroom when the students broke into small groups for individualized instruction. None of the students were pulled out of the classroom when students were receiving reading instruction from their classroom teachers as a whole class. Differences in total hours of instruction across groups was not significant, and it resulted from slightly different patterns of student and teacher absence in the two instructional conditions.

Approximately half of the time in each instructional session was devoted to direct instruction in early reading skills from the teachers, and the other half was spent practicing these skills on the computer as well as engaging in text-level reading and writing experiences via the computer. Time diaries kept by the teachers indicated that the RWT teachers tended to have their students spend more time on the computers (44.6 versus 35.8 h) while children in the LIPS condition spent more time receiving small-group instruction from the teachers (54.5 versus 35.8 h). Although an attempt was made to guide the amount of time teachers spent teaching vs. the time children spent on the computer, this difference emerged because, according to teacher reports, the computer activities in the RWT program were more attractive and engaging than those that were available to support the LIPS program.

Children assigned to the control condition received no instruction by our teachers although many of these children received special support from either their classroom teachers during the small-group instructional time in the reading block or from resource personnel in their schools. Thus, the instruction provided to the students in the intervention conditions was a mix of *supplemental* and *supplanting* instruction. Some of the students in the intervention conditions would likely have received substantial individual help from their teachers if they had not been assigned to the intervention condition. However, the school was not able to provide any of the students in the control condition with the amount of small-group, individualized instruction provided to students in the intervention conditions. The classroom reading curriculum in two of the three schools was Open Court's *Collections for Young Scholars* (Open Court Reading, 1995). One school did not use a standard core reading curriculum but instead permitted teachers to employ a variety of materials for reading instruction according to their own choice.

Instructional materials for interventions The *Read Write and Type* program was developed by Dr. Jeanine Herron (1995) to help children acquire beginning alphabetic reading skills through engaging in writing and spelling activities. The software uses colorful animation, digitized speech, and an engaging story line to lead children through a set of activities that provide practice in phonetic spelling and writing. It provides explicit instruction and practice in phonological awareness, letter–sound correspondences, and phonemic decoding but does so primarily in the context of encouraging children to express themselves in written language while they learn keyboarding skills on the computer. The program encourages children to learn formal touch-typing skills so they can respond to writing and spelling prompts without looking at the computer keys. To encourage students to learn touch typing without looking at the keys, the keyboard was covered during part of the instruction for many students. This was accomplished with a small box that allowed students to type but prevented them from seeing the keyboard.

In the RWT program, children spend a significant proportion of their time processing meaningful written material, and they are encouraged to acquire "phonics" knowledge to enable written communication. The teacher lessons were designed to preteach the skills required in work on the computer. Across a series of 40 lessons (which frequently extended across multiple instructional sessions), the teacher introduced the graphemes for 40 phonemes and had the children practice "typing" words containing these phonemes on paper keyboards prior to working on the computer. Explicit instruction was provided in proper fingering techniques for typing. Phonemes were introduced by teachers in the context of rhyming stories, and children were taught to manipulate them during oral language phonemic awareness activities. Similar phonemic awareness activities were practiced on the computer, and then children practiced spelling and typing words that contained the new phonemes. The program also contained extensive provisions for systematic review of previous learning. All of the instructional groups finished all the activities on the computer before the end of the instructional year, and then they engaged in a set of structured and free writing experiences and spent part of every session reading their own and other's writing. Examples of structured writing experiences included generating and typing sentences containing specific words or completing a sentence in which a sentence stem was provided. Free writing consisted of writing brief stories to prompts. All writing was done on the computer within a simple word processing program.

The *Lindamood Phoneme Sequencing Program for Reading*, *Spelling*, *and Speech* (P. Lindamood & P. Lindamood, 1998) provided explicit instruction in phonemic awareness by leading children to discover and label the articulatory gestures associated with each phoneme. This discovery work was followed with activities to build skills in tracking the phonemes in words using mouth–form pictures, colored blocks, and letters to represent the phonemes in words. Although children in this condition spent most of their time building phonemic awareness and phonemic decoding skills, they also began reading text as soon as they showed reasonable mastery of an initial group of 10 consonants and three vowels. Part of this reading took place on the computer, through the use of a computerized version of the *Poppin Readers* (Smith, 1992) that was specially created for this study. The *Poppin Readers* are written with highly decodable text that follows the instructional sequence of the LIPS program. Children were able to read these books on the computer relatively independently because they could click on any word they had trouble with, and the computer pronounced it for them.

Both the oral awareness and phonemic decoding and encoding skills taught by the teachers in the LIPS program were reinforced and practiced using software that was specially developed to mimic the instructional activities and feedback provided by teachers. This software contained a variety of activities that used mouth–form pictures and colored blocks to help children acquire fluency and accuracy in identifying phonemes within words, and it also had spelling and phonemic decoding activities using letters.

Teachers Instruction in the two reading programs was provided by six certified teachers who had participated in a previous project with us and who had considerable experience working with children with reading problems. Three of the teachers were randomly assigned to the LIPS program and three to the RWT program. Each teacher worked approximately one half of the time and taught two groups of three children over the course of a year for a total of 12 students per teacher during the 2 years of the study. The same teachers provided instruction over the 2 years.

All teachers received 18 h of preservice training in either the LIPS or RWT method at the beginning of each year. Separate 3-hour staff meetings for the RWT and LIPS teachers were held on a biweekly basis for teachers in each instructional program to discuss instructional or behavioral issues that might arise. Approximately half of these staff meetings were attended by supervisors with special expertise in the programs being implemented by the teachers and who had viewed videotapes of the instruction during the preceding month. Approximately 10% of the instructional sessions for each teacher were videotaped for supervisory purposes to monitor fidelity of implementation. Although no formal analysis of fidelity was conducted, information from the videotapes indicated that teacher fidelity to the instructional procedures and materials of both methods was very high throughout the implementation period.

Test materials All instructed students were assessed immediately prior to reading instruction (pre), at the end of the instructional year (post), and 1 year following instruction (post2). Students in the control condition received only three of the pretests that were included in the initial screening; however, they received all of the tests that were given at posttest (post) and follow-up (post2). Although it would have been desirable to administer the full range of pretests to students assigned to the control group, this was precluded by both study resources and by agreement with the participating schools. However, equivalence of the experimental and control groups was assured through the random assignment process and verified by the equivalence of their performance on the screening measures.

Tests included measures that assessed phonological processing abilities (phonological awareness and rapid automatic naming), word-level reading measures (word accuracy, word efficiency), phonemic decoding accuracy and fluency (nonword reading and nonword efficiency), text reading measures (accuracy, fluency, comprehension), spelling, and verbal ability. Unless otherwise indicated, these tests were administered at each test time.

Three phonological awareness measures that were part of the prenorm version of the *Comprehensive Test of Phonological Processing* (CTOPP; Torgesen, Wagner, & Rashotte, 1999a) were given. They are as follows:

1. *Elision*. This is a 25-item test on which the student is asked to say a word then say what is left after omitting designated sounds.
2. *Blending words*. This 29-item test requires the student to listen to a series of sounds and then put the separate sounds together to make a whole word.
3. *Segmenting words*. On this 26-item test, the student is asked to repeat a word then say it one sound at a time.

Two naming measures that were prenorm versions from the CTOPP (Wagner et al., 1999) were also given. These included:

1. *Rapid digit naming.* On this test, the student is required to name as quickly as possible 36 single-digit numbers that are arrayed in four lines of nine numbers each on an 8 × 11-in. card. Time to read the 36 numbers is recorded. The student repeats the task with a second card that has the numbers ordered differently. Times for each card are averaged.
2. *Rapid letter naming*. This test is the same as rapid digit naming except the items to be named are lower-case letters.

Two measures of word reading accuracy/fluency were administered. These were:

1. *Word identification.* The word identification subtest of the Woodcock Reading Mastery Test-Revised (WRMT; Woodcock, 1987) requires students to read individually presented words.
2. *Word efficiency.* This subtest was a prenorm version of the Test of Word Reading Efficiency (TOWRE; Torgesen et al., 1999a) and required students to read as many printed real words as they could within 45 s.

We also administered two measures of phonemic decoding skills. These were:

1. *Word analysis.* The word attack subtest of the WRMT (Woodcock, 1987) requires students to read individually presented nonwords.
2. *Phonemic decoding efficiency.* This subtest was a prenorm version of the TOWRE (Torgesen et al., 1999a) and required students to read as many pronounceable printed nonwords as they could decode within 45 s.
3. Measures of text reading accuracy and text reading fluency were obtained from the Gray Oral Reading Test (GORT-3; Wiederholt & Bryant, 1992) at follow-up testing only. Students were required to read a series of short paragraphs that gradually increased in difficulty level. The number of word errors that occurred at each level determined their word accuracy score. Amount of time taken to read each paragraph provided a rate measure.

Reading comprehension was assessed using two measures. These were:

1. The *passage comprehension* subtest of the WRMT (Woodcock, 1987) asked students to read silently a series of paragraphs and supply the key missing word in the paragraph. This test was given only at post and post2.
2. The *reading comprehension* score from the GORT-3 (Wiederholt & Bryant, 1992) was calculated from the number of questions students were able to answer correctly from passages of increasing difficulty. This test required students to answer five multiple-

choice comprehension questions after reading each paragraph. The questions and four alternative answers were read to the student by the examiner. This task was given only at the post2 to provide a more complete assessment of reading comprehension at this point.

Spelling was assessed using two measures. A developmental spelling analysis (Tangel & Blachman, 1992) that measured accuracy of phonemic representations in spelling was given at post only and the spelling subtest from the Wide-Range Achievement Test-Revised (Jastak & Jastak, 1978) was given only at post2 because the developmental spelling analysis was not available at this level.

Children's broad verbal ability was estimated from the vocabulary subtest of the *Stanford-Binet Intelligence Scale*, *4th ed*. (Thorndike et al., 1986). This test was given only at pretest and required children to define a series of increasingly difficult and less frequent words.

The probability of reading difficulty score was described earlier. Higher scores indicate greater probability of reading problems.

Results

We were interested in answering three questions from the outcomes of this study. These questions were: (1) were there reliable differences in reading outcomes between the two instructional methods either at immediate posttest or 1 year later; (2) did the intervention groups show stronger reading outcomes than were obtained for children in the treatment-as-usual group; and (3) what percentage of the children remained significantly impaired in reading skills following the intervention? There were no statistically significant differences among groups on the pretest variables, and we used multivariate analyses of variance (MANOVA) with two planned contrasts to answer the first two questions at the end of the intervention period (post) and at the 1-year follow-up (post2). The unit of analysis was individual students rather than instructional groups (of three students each) since students were the unit of random assignment and approximately half of the intervention was provided in a completely individualized way by computers. Further, an analysis of the variance in outcome measures related to individual instructional group membership produced intraclass correlations ranging from 0 to 0.29, with an average of 0.06, which suggests that the risk of type I error inflation is minimal.

Differences between intervention groups

Table 1 presents pre, post, and post2 scores for the students in the treatment and control groups who were assessed at both post and post2. For variables that allowed calculation of norm referenced standard scores, those values are reported in this table to illustrate the performance of the students compared to national norms. However, raw scores were used in all statistical analyses.

MANOVAS contrasting the two treatment groups were conducted for the outcomes grouped under the headings *word accuracy/fluency*, *phonemic decoding accuracy/fluency*, *phonological awareness*, and *rapid naming*. Since only one measure was available for reading comprehension and spelling at the immediate posttest, those contrasts were performed using analysis of variance. None of the contrasts between the two treatment groups was statistically significant at the immediate posttest.

Table 1 Pretest, immediate posttest (post), and 1-year follow-up (post2) scores for students in the intervention and control groups

Measure	LIPS (*N*=35)			RWT (*N*=34)			Control (*N*=39)		
	Pre	Post	Post2	Pre	Post	Post2	Pre	Post	Post2
Word accuracy/fluency									
Word identification[a]	87.2	110.6	106.8	85.6	107.0	103.8		100.6	99.8
SD	9.3	12.2	12.8	9.6	12.4	11.0		15.6	14.8
Word efficiency	2.9	26.9	44.3	2.7	23.5	42.7		21.0	38.6
SD	2.5	11.1	12.0	2.5	9.3	10.9		11.4	14.4
Phonemic decoding accuracy/fluency									
Word attack[a]	73.6	113.7	112.5	76.4	108.3	104.4		99.5	99.6
SD	7.2	12.1	15.7	10.2	12.2	11.9		15.0	20.4
Nonword efficiency	0.6	16.8	26.1	0.6	12.6	22.6		10.6	20.2
SD	0.6	7.6	9.0	0.7	7.0	8.4		7.7	12.8
Text reading accuracy/fluency									
Gray accuracy[a]			97.4			96.8			92.4
SD			12.8			11.3			14.2
Gray rate[a]			97.2			94.7			92.2
SD			10.7			9.5			14.7
Reading Comprehension									
Pass. comprehension[a]		102.2	98.9		100.2	96.7		95.4	93.7
SD		10.0	8.5		9.6	7.6		14.4	12.6
Gray comprehension[a]			99.2			96.4			95.6
SD			14.5			11.8			13.8
Phonological awareness									
Blending words	8.6	20.6	22.7	8.4	22.0	22.0		18.2	21.6
SD	4.2	4.5	4.2	4.6	4.0	4.0		5.4	5.4
Elision	4.6	15.3	17.4	5.1	13.8	16.5	4.8	12.5	15.7
SD	2.1	4.2	4.8	2.3	4.2	4.4	2.1	4.6	4.4
Segmenting words	2.8	15.6	16.1	3.4	14.6	14.6		11.7	14.2
SD	3.7	3.7	3.9	4.1	4.6	4.6		4.5	3.5
Rapid naming									
Naming digits	0.9	01.3	1.7	0.9	1.4	01.7	0.8	1.2	1.6
SD	0.3	0.3	0.4	0.2	0.3	0.3	0.2	0.3	0.4
Naming letters		01.2	01.7		01.3	01.7		01.2	01.5
SD		0.3	0.3		0.3	0.3		0.3	0.3
Spelling									
Developmental		25.1			25.0			23.4	
SD		2.7			2.6			3.2	
WRAT spelling			37.6			36.2			34.9
SD			4.4			3.2			4.6
Est. verbal ability									
Vocabulary[a]	96.1			96.0			95.9		
SD	12.5			11.2			11.4		

Table 1 (continued)

	LIPS (N=35)			RWT (N=34)			Control (N=39)		
Measure	Pre	Post	Post2	Pre	Post	Post2	Pre	Post	Post2
Probability of reading problems									
Letter sound knowledge	10.9			9.5			10.2		
SD	5.6			5.9			5.0		
Probability score[b]	0.70			0.70			0.71		
SD	0.22			0.22			0.18		

[a] Standard scores based on a mean of 100 and SD of 15

[b] Higher scores indicate greater probability of reading problems

Similar MANOVAS were conducted for the follow-up data, including a MANOVA for reading comprehension, because two measures of this construct were available. As with the immediate posttest, none of the differences between treatment groups was statistically significant at the 1-year follow-up.

Table 1 shows that both instructional conditions in this study (classroom plus intervention instruction) powerfully accelerated growth of word-level reading skills during first grade. Across the two interventions, students began first grade with standard scores for word identification and word attack of 86.4 and 75.0, respectively. Corresponding standard scores at the end of first grade were 108.8 and 111.0. This represents an improvement from approximately the 16th to the 73rd percentile for word reading accuracy and from the fifth to the 77th percentile for phonemic decoding skill.

At the same time, it should be noted that the instruction provided to the students in the control group also accelerated their reading development. Given the similar pretest scores of students in the control group to those in the intervention group on phonemic awareness, rapid naming, and letter knowledge, it is reasonable to assume that their pretest scores for phonemic decoding and word reading accuracy would have also been very similar. If this was in fact true, then the combination of whole class and differentiated instruction provided to students in the control group was sufficient to increase their percentile rank in phonemic decoding from the fifth percentile at the beginning of first grade to the 50th percentile at the end of first grade. During the same period of time, these students improved from the 16th to the 50th percentile in word reading accuracy.

Comparison of reading growth between students in the intervention conditions verses those in the control group

The groupings of outcome variables and analytic procedures for the second contrast (between the combined treatment groups and the control group) were the same as those used in the contrast between treatment groups. In these analyses, however, there were statistically significant differences at the immediate posttest in outcomes for word accuracy/fluency, $F(2, 105)=9.5$, $p<0.001$, phonemic decoding accuracy/fluency $F(2, 105)=11.3$, $p<0.001$, phonological awareness $F(3, 105)=6.8$, $p<0.001$, rapid naming $F(2, 105)=5.0$, $p<0.01$, reading comprehension $F(1, 106)=6.7$, $p<0.05$, and spelling $F(1, 106)=8.7$, $p<0.01$.

The analysis of outcomes at the 1-year follow-up showed a similar, though less robust, pattern of differences. The students who received the interventions continued to do better than those in the control group on all the variables, but the differences were statistically reliable only for *phonemic decoding accuracy/fluency* $F(2, 105)=3.5$, $p<0.05$, rapid naming $F(2, 105)=4.5$, $p<0.05$, and spelling $F(1, 106)=6.0$, $p<0.05$. Effect sizes for all the variables in the treatment vs. control group contrasts are provided in Table 2. Effect size was calculated as the difference between the combined treatment group mean and the control group mean divided by the control group standard deviation.

Percentage of students remaining significantly impaired in reading at the conclusion of the intervention and follow-up

In addition to determining the overall effectiveness of the two programs, it is useful to know the proportion of children who remained significantly impaired in reading at the end of the intervention. To be consistent with the criteria adopted in earlier papers on "treatment resisters" (Torgesen, 2000, 2004), significant impairment was defined as performance below the 30th percentile on the standardized measures used in this study. This same criterion for identifying students still struggling in reading following early intervention was used in an important recent study by Mathes et al. (2005) cited in the introduction.

Table 3 provides a comparison of the percentage of children in the combined treatment groups versus those in the control group who remained below the 30th percentile on the key reading measures at the end of first grade and 1 year later. The percentages show that the control group had more children at the end of first grade who performed below the 30th percentile on important reading measures than children who received the interventions. It is also apparent from the percentages at the end of second grade (post2) that this discrepancy between instructional and control groups continued even after instruction had been terminated for a year.

Table 2 Effect sizes for the contrast between intervention groups and the control group

Outcome variable	Effect size	
	Immediate posttest	1-year follow-up
Word identification	0.53[a]	0.37
Word efficiency	0.37[a]	0.34
Word attack	0.77[a]	0.43[a]
Nonword efficiency	0.53[a]	0.32[a]
Text reading accuracy		0.33
Text reading rate		0.26
Passage comprehension (WRMT-R)	0.40	0.33
Passage comprehension (gray)		0.16
Blending words	0.57[a]	0.14
Elision	0.45[a]	0.28
Segmenting words	0.76[a]	0.33
Rapid naming digits	0.50[a]	0.04
Rapid naming letters	0.17	0.66[a]
Developmental spelling	0.51	
WRAT spelling		0.43

[a] These comparisons were statistically significant in post hoc univariate analyses following significant MANOVAS

Table 3 Percent of children in the intervention and control groups who fell below the 30th percentile in reading skill at the end of first grade (post) and at the end of second grade (post2)

Measures	Post		Post2	
	Intervention	Control	Intervention	Control
Word identification	5.7	25.2	12.9	32.5
Word attack	8.6	35.7	11.4	30.8
Pass. comprehension	17.1	40.1	17.1	45.6
Est. verbal IQ	40.1	32.5		

The percentages in Table 3 can be used to estimate the percentage of students in the full population from which these students were selected who would have remained significantly impaired in reading if the interventions and classroom instruction in this study were available to all students who needed them (Torgesen, 2000). This rough estimate can be obtained by multiplying the percentages in Table 3 by 0.138 if we assume that the sample used in this study were the 13.8% of students most at risk for reading difficulties in their schools. From these calculations, it is apparent that the introduction of intensive computer-assisted interventions like those studied here, in the context of what was actually quite effective overall classroom instruction, would reduce the number of children with poor reading skills at the end of first grade from 3.5% ($0.138\times0.25=0.0345$) to less than 1% ($0.138\times0.057=0.0079$) for word reading accuracy, from 4.8% to 1.2% for phonetic decoding accuracy, and from 5.5% to 2.0% for reading comprehension.

Discussion

Answers to the questions in this study are straightforward. Although reading outcomes for students who received the LIPS intervention were slightly stronger than for students receiving the RWT intervention, none of these differences was statistically reliable. Thus, neither the relatively greater emphasis on reading-connected text and writing activities in the RWT program nor the explicit oral motor awareness training included in the LIPS program differentially effected the reading growth of the at-risk students in this study. Of course, this study is not a definitive test of the value of any of the particular aspects of either program because these aspects were not uniquely manipulated in the comparison between the two programs.

In contrast to the lack of significant differences in outcome for students in the two intervention conditions, students who received the interventions in this study showed reliably stronger outcomes in phonological awareness, rapid naming, phonemic decoding, word reading accuracy/fluency, spelling, and reading comprehension at the end of first grade. One year following the conclusion of the intervention, at the end of second grade, the groups who received the interventions continued to perform better than the control group in all areas, but the differences were statistically significant only for phonemic decoding, rapid naming, and spelling. At the end of first grade, the effect sizes (comparing the treatment groups vs. the control group) for phonemic decoding, word reading accuracy, and passage comprehension as measured by the Woodcock Reading Mastery Test were 0.77, 0.53, and 0.40, respectively. At the end of second grade, effect sizes for these same three measures were 0.43, 0.37, and 0.33, respectively.

These results must be qualified by the fact that the computer-based instruction in this study was offered as a supplement, rather than as a replacement for teacher-led instruction. In the absence of a treatment control condition that provided additional instruction but did not involve computer-based support, it is not possible to say whether the effects arose from the specific nature of the interventions themselves or simply from the fact that students in the intervention conditions received more instruction in reading than students in the control condition. The results do indicate, however, that the computer-supported intervention model used in this study is one way to provide effective supplemental reading instruction for young students. Based on the strong reading growth of students in the control group, we would also add that a significant part of the acceleration in growth of the students receiving the interventions was likely due to reading instruction they received in their regular classrooms.

We were not surprised that effects were stronger immediately following the intervention than 1 year afterward. This pattern is typical of intervention research in which powerful interventions are followed by a period of time in which the intervention is no longer available (Scammaca et al., 2007; Shanahan & Barr, 1995). Not only do students who receive the intervention tend to develop more slowly once the intervention is withdrawn (hence the slight reduction in standard scores; Olson, Wise, Ring, & Johnson, 1997), but also interventions in second grade are more likely to be provided to the lower-performing students in the control group than to students who received the interventions in first grade. It remains a matter for future research to determine how long intervention supports need to be in place for individual children in order to prevent a relative decline in reading skill once the intervention is withdrawn. In the case of students with developmental dyslexia, this intervention period may need to extend at least until word-level reading skills (including the more complex decoding skills acquired in second and third grade) are firmly established.

The most surprising outcome from this study may be the significant impact of the interventions on rapid naming of digits and letters. Only one of the methods (RWT) contained practice that emphasized fluency of responding. Although there was some instability to this effect (it was significant only for rapid naming of digits at the end of first grade and significant only for rapid naming of letters at the end of second grade), it is one of the few combined measures for which there was a significant treatment effect extending into second grade. Only one other intervention study that we are aware of included measures of rapid automatic naming at pretest and posttest and that study (Torgesen et al., 1999b) examined the effects of very intensive instruction on students with dyslexia in grades 3 and 5. Although the study did not have a traditional control group, standard scores on measures of both rapid naming of digits and rapid naming of letters improved significantly (by three to five points from pretest to posttest), showing that the interventions had accelerated development on these measures. There remain substantial ambiguities about the linguistic/cognitive abilities assessed by rapid naming tasks (Torgesen, Wagner, Rashotte, Burgess & Hecht, 1997) but at least some of what these tasks assess appears to be responsive to intensive reading instruction and practice.

Although we did not formally assess the typing skills of students in the RWT condition, observations indicated that all but three of the 34 students in this condition became accurate touch typists during the year. That is, they could type any letter of the alphabet accurately without being able to look at their fingers. These students could type with reasonable accuracy while a box was placed above their hands to cover the keyboard and prevent them from seeing their fingers. The box was used during training in order to encourage students to rely on kinesthetic rather than visual feedback as they learned to type each letter. These boxes had to be removed for the three students who did not learn touch typing because they created too much frustration that interfered with their learning the reading and writing skills taught by the program.

Because all students in the intervention condition received both teacher-led instruction and computer-based instruction and practice, it is not possible to determine whether both components of the intervention were necessary for success. Although the initial teacher-led instruction appeared to facilitate the student's use of the computer to engage in meaningful practice, we cannot say that use of the computer programs alone would not have produced a significant impact on reading growth. By the same token, the teachers in the study provided explicit instruction in basic reading skills for 20–25 min a day, and in other research (Scammaca et al., 2007), this amount of instruction has been sufficient to accelerate reading development in at-risk students. Thus, we cannot state unequivocally that the computer-based follow-up practice contributed substantially to the instructional effects that were observed.

We would assert, however, that the instructional model used in this research has some important theoretical advantages over other ways that computers are sometimes used to support reading growth for at-risk students. The most common problem with such uses is that the computer-based instruction and practice are not tightly integrated with classroom instruction or other intervention instruction the students might be receiving (Dynarski et al., 2007). In this study, the instruction provided by the teachers was integrated very closely with their experiences on the computer. In fact, the teacher-led instruction was designed to teach concepts and skills that directly prepared the students to profit from practice and further instruction on the computer. As a matter of instructional efficiency, it seems important in future research to determine whether the teacher time used to prepare students for their computer-based learning experiences provided a significant advantage in growth over what could be obtained if students were exposed to the computer exercises alone, with no preparatory instruction. If the advantage of the extra teacher time is small, then it might make sense to either lengthen the time on the computer alone or to reduce the teacher time to a bare minimum in order to save instructional costs. If reduction in teacher support time were possible without seriously compromising instructional effectiveness, it would help to realize some of the potential cost savings of computer-assisted interventions alluded to in the introduction section of this paper. In fact, if teacher support requirements were less than those provided in this study, it might be possible for regular classroom teachers to include it as part of their small-group instruction, thus avoiding extra costs for intervention teachers altogether.

One last comment about the results of this study is warranted. Although students were identified for the study because of their poor performance on tests that are typically used to diagnose dyslexia in young students (Fletcher, Lyon, Fuchs, & Barnes, 2007), it is very likely that not all students in the current sample had neurobiologically based dyslexia. In practice, it is impossible to differentiate students whose poor performance on phonologically based reading and prereading skills is based on inherent neurobiological weaknesses from those whose home backgrounds and preschool experiences have not provided adequate preparation for learning to read (Fletcher et al., 2007; Torgesen, Foorman, & Wagner, 2008). We allowed student performance on a measure of general verbal ability to vary across a broad range both because phonological difficulties can occur in students with all levels of general verbal ability (Fletcher et al., 2007) and because preexisting phonological abilities are the most important early predictor of response to the type of instruction in basic word reading skills that was provided in this study (Torgesen et al., 1999b). Thus, the use of the term "dyslexia" in the title of this study needs to be qualified by the fact that we used only language and cognitive measures to identify the study participants, and we allowed general verbal ability to vary across a relatively wide range.

Acknowledgements We wish to thank teachers and students in the Leon County School District, Tallahassee, FL, USA, for their participation in this study. The research for and preparation of this article was supported by grants HD30988 and P50 HD052120 from the National Institute of Child Health and Human Development.

References

Dynarski, M., Agodini, R., Heaviside, S., Novak, T., Carey, N., Campuzano, L., et al. (2007). *Effectiveness of reading and mathematics software products: Findings from the first student cohort*. Washington, DC: US Department of Education, Institute of Education Sciences.

Ehri, L. C. (2002). Phases of acquisition in learning to read words and implications for teaching. In R. Stainthorp & P. Tomlinson (Eds.), *Learning and teaching reading*. London: British Journal of Educational Psychology Monograph Series II.

Fielding, L., Kerr, N., & Rosier, P. (2007). *Annual growth for all students, catch-up growth for those who are behind*. Kennewick: The New Foundation Press.

Fletcher, J. M., Lyon, G. R., Fuchs, L. S., & Barnes, M. A. (2007). *Learning disabilities: From identification to intervention*. New York: Guilford.

Herron, J. (1995). *Read, write, & type*. San Rafael: Talking Fingers.

Herron, J. (2008). Why phonics teaching must change. *Educational Leadership, 25*, 77–81.

Jastak, J. F., & Jastak, S. (1978). The wide range achievement test- revised. Wilmington, Del.: Jastak Associates.

Kennedy, K. & Backman, J. (1993). Effectiveness of the Lindamood Auditory Discrimination In Depth Program with students with learning disabilities. *Learning Disabilities Research and Practice, 8*(4), 253–259.

Liberman, I. Y., Shankweiler, D., & Liberman, A. M. (1989). The alphabetic principle and learning to read. In D. Shankweiler & I. Y. Liberman (Eds.), *Phonology and reading disability: Solving the reading puzzle* (pp. 1–33). Ann Arbor: U. of Michigan Press.

Lindamood, P. & Lindamood, P. (1998). *The Lindamood phoneme sequencing program for reading, spelling, and speech*. Austin: PRO-ED.

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53*, 1–14.

Mathes, P. G., Denton, C. A., Fletcher, J. M., Anthony, J. L., Francis, D. J., & Schatschneider, C. (2005). The effects of theoretically different instruction and student characteristics on the skills of struggling readers. *Reading Research Quarterly, 40*, 148–182.

Moats, L. C. (1999). *Teaching reading is rocket science*. Washington, DC: American Federation of Teachers.

Morrison, F. J., Bachman, H., & Connor, C. M. (2005). *Improving literacy in America: Guidelines from research*. New Haven: Yale University Press.

National Reading Panel. (2000). *A report of the national reading panel: Teaching children to read*. Washington, DC: National Institute of Child Health and Human Development.

Olson, R. K., Wise, B. W., Ring, J., & Johnson, M. (1997). Computer-based remedial training in phoneme awareness and phonological decoding: Effects on the post-training development on word recognition. *Scientific Studies of Reading, 1*, 235–253.

Open Court Reading. (1995). *Collections for young scholars*. New York: McGraw-Hill.

Perfetti, C. A. (1985). *Reading ability*. New York: Oxford University Press.

Pressley, M. (2002). *Reading instruction that works: The case for balanced teaching* (2nd ed.). New York: Guilford.

Rayner, K., Foorman, B. R., Perfetti, C. A., Pesetsky, D., & Seidenberg, M. S. (2001). How psychological science informs the teaching of reading. *Psychological Science in the Public Interest, 2*, 31–73.

Samuels, S. J. & Farstrup, A. (2006). *Reading fluency: The forgotten dimension of reading success*. Newark: International Reading Association.

Scammaca, N., Vaughn, S., Roberts, G., Wanzek, J., & Torgesen, J. K. (2007). *Extensive reading interventions in grades k–3: From research to practice*. Portsmouth: RMC Research Corporation, Center on Instruction.

Shanahan, T. & Barr, R. (1995). Reading recovery: An independent evaluation of the effects of an early instructional intervention for at-risk learners. *Reading Research Quarterly, 30*, 958–996.

Share, D. L. & Stanovich, K. E. (1995). Cognitive processes in early reading development: Accommodating individual differences into a model of acquisition. *Issues in Education: Contributions from Educational Psychology, 1*, 1–57.

Smith, L. (1992). *Auditory discrimination reading series-sequence B*. Independence: Poppin Creations.

Stanovich, K. E. (2000). *Progress in understanding reading: Scientific foundations and new frontiers*. New York: Guildford.

Tangel, D. M., & Blachman, B. A. (l992). Effect of phoneme awareness instruction on kindergarten children's invented spelling. *Journal of Reading Behavior, 24*, 233–261.

Thorndike, R. L., Hagen, E. P., & Sattler, J. M. (1986). *Stanford-Binet intelligence scale* (4th ed.). Chicago: Riverside.

Torgesen, J. K. (1999). Phonologically based reading disabilities: Toward a coherent theory of one kind of learning disability. In R. J. Sternberg & L. Spear-Swerling (Eds.), *Perspectives on learning disabilities* (pp. 231–262). New Haven: Westview.

Torgesen, J. K. (2000). Individual differences in response to early interventions in reading: The lingering problem of treatment resisters. *Learning Disabilities Research and Practice, 15*, 55–64.

Torgesen, J. K. (2004). Lessons learned from the last 20 years of research on interventions for students who experience difficulty learning to read. In P. McCardle & V. Chhabra (Eds.), *The voice of evidence in reading research*. Baltimore: Brookes.

Torgesen, J. K. & Barker, T. (1995). Computers as aids in the prevention and remediation of reading disabilities. *Learning Disabilities Quarterly, 18*, 76–88.

Torgesen, J. K., Foorman, B. R., & Wagner, R. K. (2008). *Dyslexia: A brief for educators, parents, and legislators in Florida. FCRR technical report #8*. Tallahassee: FCRR.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1999a). *Test of word reading efficiency*. Austin: PRO-ED.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S. R., & Hecht, S. A. (1997). The contributions of phonological awareness and rapid automatic naming ability to the growth of word reading skills in second to fifth grade children. *Scientific Studies of Reading, 1*, 161–185.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Rose, E., Lindamood, P., Conway, T., et al. (1999b). Preventing reading failure in young children with phonological processing disabilities: Group and individual responses to instruction. *Journal of Educational Psychology, 91*, 579–593.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). *Comprehensive test of phonological processing*. Austin: PRO-ED.

What Works Clearinghouse. (2007). *Beginning reading*. Washington, DC: Institute for Education Sciences.

Wiederholt, J. L. & Bryant, B. R. (1992). *Gray oral reading test – 3*. Austin: PRO-ED.

Woodcock, R. W. (1987). *Woodcock reading mastery tests-revised*. Circle Pines: American Guidance Service.