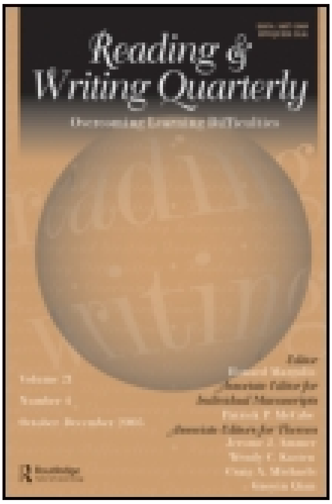


Reading & Writing Quarterly: Overcoming Learning Difficulties
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/urwl20

Long-Term Intervention Effects of Spelling Development for Children With Compromised Preliteracy Skills

Nina L. Saine [a] , Marja-Kristiina Lerkkanen [a] , Timo Ahonen [a] , Asko Tolvanen [a] & Heikki Lyytinen [a]

[a] University of Jyväskylä , Jyväskylä , Finland
Published online: 09 Jul 2013.

Reading & Writing Quarterly, 29:333–357, 2013

ISSN: 1057-3569 print/1521-0963 online
DOI: 10.1080/10573569.2013.741962

Long-Term Intervention Effects of Spelling Development for Children With Compromised Preliteracy Skills

NINA L. SAINE
MARJA-KRISTIINA LERKKANEN
TIMO AHONEN
ASKO TOLVANEN
HEIKKI LYYTINEN
University of Jyväskylä, Jyväskylä, Finland

The aim of this longitudinal study was to build a model of the predictive values (poor phonological awareness, low letter knowledge, and slow naming speed) of spelling in 3 contrasting reading groups: a regular and a computer-assisted remedial intervention and mainstream instruction. The participants were 7-year-old Finnish school beginners (N = 166). The interventions took place in 4 weekly sessions of 45 min each over a period of 28 weeks in groups of 5 during Grade 1. We compared postintervention spelling development across the groups. The children who received systematic phonics-based training via the computer-assisted intervention reached the postinstruction level of the mainstream group by Grade 3. Computer-assisted treatment produced the best results, and mainstream instruction achieved better results than the regular remedial reading intervention. Low phonological awareness seemed to play a central role in spelling development in spite of a combination of deficits.

The research reported here was supported by a grant from the Research Foundation of the Mannerheim League for Child Welfare, the Jyväskylä Longitudinal Study of Dyslexia, the Graduate School of Psychology, and the Niilo Mäki Institute. The development of the prevention game technology has been supported by Finnish Centre of Excellence Programs No. 44858 and No. 213486 (2000–2005 and 2006–present) of the Academy of Finland. We are grateful to the teachers, parents, and children at the participating schools for their unstinting support during this long-term research project.

Address correspondence to Nina L. Saine, Department of Psychology, University of Jyväskylä, P.O. Box 35, 40014 Jyväskylä, Finland. E-mail: nina@saine.fi

Spelling ability as well as reading ability can be predicted by language skills (Berninger & O'Donnell, 2004; Ehri, 1989, 1997). Both skills reflect understanding of the principles of how spoken language is represented in print and knowledge of the mappings between the orthographic and phonological representations of words (see, e.g., Ehri, 1997; Perfetti, 1997; Treiman, 2000; Treiman, Sotak, & Bowman, 2001; Ziegler & Goswami, 2005). Spelling is commonly a challenge for people with reading disabilities (e.g., Berninger, 2001; Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008b; Lyon, Shaywitz, & Shaywitz, 2003). Moreover, it has been reported in intervention studies that phonemic skills support further literacy skills of at-risk children (e.g., Hatcher, Hulme, & Ellis, 1994; Hatcher et al., 2006; Hatcher, Hulme, & Snowling, 2004; Iversen & Tunmer, 1993). Yet very little is known about what kinds of interventions produce the best results for spelling development (for an exception, see Berninger et al., 2008b). The present longitudinal study was designed to determine the long-term effects of literacy interventions (regular remedial intervention and computer-assisted remedial intervention) for children with compromised preliteracy skills in the highly regular orthography of the Finnish language.

THE LINK BETWEEN SPELLING AND READING DEVELOPMENT

Ehri (1987, 1989) reported that in principle reading and spelling develop hand in hand. Ehri's (1989) theory on learning to spell (see also Gentry, 1982) thus corresponds to her postulated reading stages (prealphabetic, partial-alphabetic, full-alphabetic, consolidated-alphabetic, and automatic stages). In the *precommunicative stage,* the child generates spellings that resemble print using randomly selected letters or numbers. In the *semiphonetic stage,* the child learns the names or sounds of letters, selects letters for words on the basis of letter names or letter sounds, and uses this knowledge in spelling. In the *phonetic stage,* the child's spelling contains letters for all of the sounds in words, and knowledge of grapheme–phoneme correspondence is demonstrated. As the child's experience of words expands, he or she reaches the *transitional stage.* At this point, the child becomes aware of the visual features of words and begins to combine understanding of how a word sounds with knowledge of how the word looks. The child's fluency in reading and spelling will thus increase.

It is evident that competent spelling requires a sufficient mastery of letter knowledge and phonological awareness (see, e.g., Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008a). Reading and spelling skills would thus seem to be based on the same preskills (i.e., letter knowledge and phonological awareness). Rapid automatic naming as a preliteracy skill has been shown to be a predictor of responding to spelling instruction (Amtmann, Abbott, & Berninger, 2008) and reading fluency (Parrila, Kirby, & McQuarrie, 2004; Wolf & Katzir-Cohen, 2001). Spelling is also affected by independent reading and exposure to text: Avid readers see more words in print and have more opportunities to learn the spellings of specific words (Spear-Swerling, 2005).

The early phases of learning to spell and read are heavily influenced by the orthography of the child's language. The present study was conducted in the highly regular orthography of the Finnish language, which has the shallowest orthography (with high symmetric consistency at the level of single graphemes and phonemes) and the simplest syllabic structure among the European languages (Seymour, Aro, & Erskine, 2003). Across languages, while those with more transparent relations between phonology and orthography seem to produce less severe difficulties with reading accuracy, spelling problems may be more marked, which suggests that the phonological and orthographic components of spelling and word reading are dissociable (Caravolas, 2005). Reading and spelling instruction in Finland, including in the classrooms of this particular study, includes learning letter names as well as listening, segmenting, and blending phonemes and syllables. After a few letters and sounds have been mastered, they are combined into CV/VC syllables and CV/VC–CV/VC words. When a Finnish-speaking child has acquired the names of the letters and a systematic knowledge of the letter-sound rules, he or she can easily read all Finnish words (e.g., Lyytinen, Leinonen, Nikula, Aro, & Leiwo, 1995). Therefore, in the context of the Finnish language one third of children can read when they enter school at the age of 7, and most of the remaining children acquire their basic word-reading skills during the first grade (Holopainen, Ahonen, & Lyytinen, 2001; Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2004; Seymour et al., 2003). In contrast, it was acknowledged by Lerkkanen et al. (2010) that spelling skills develop more slowly than accurate reading during the first 2 years of school.

THE IMPORTANCE OF EARLY PREDICTION AND INTERVENTION FOR SPELLING

Spelling and reading problems seem to be linked by deficits involving phonological processing (Berninger & O'Donnell, 2004). Recent research by Berninger et al. (2008b) indicated that spelling disability is primarily a disorder in word-level written language processing and furthermore that spelling and reading skills seem to have the same underlying deficits. In the Finnish language the most challenging problem is associated with a subword factor. This is because of complexity in the variation of phonemic duration. Finnish readers have to master the distinction between short and long phonemes, which is expressed in writing by one or a repeated letter of the phoneme in question. Spelling errors associated with this factor represent the most common challenges for poor Finnish readers (Lyytinen et al., 1995).

It has been emphasized that children should be screened at the beginning of school and that those at risk can be successfully helped by early intervention (e.g., Lyytinen, Ronimus, Alanko, Poikkeus, & Taanila, 2007). It is widely documented that training in phonological skills significantly improves children's ability to read. The findings of a review by Ehri et al. (2001) revealed that this is equally true for spelling. Furthermore, phonological awareness training prior to school or during the first grade seems to have a significant effect on later spelling ability (Ball & Blachman, 1991; Byrne & Fielding-Barnsley, 1993; Castle, Riach, & Nicholson, 1994; Lundberg, Frost, & Petersen, 1988). Moreover, the results of a study undertaken by Schneider, Roth, and Ennemoser (2000) indicated that combined training in letter knowledge and phonological awareness yielded the strongest effects on spelling (as well as reading) in Grades 1 and 2. Thus, these findings confirmed the phonological linkage hypothesis of Hatcher et al. (1994): Combining phonological awareness training with instruction in letter-sound knowledge has more powerful effects on subsequent literacy achievement than phonological awareness training alone. Also, Boland (1993) found significant positive correlations between decoding and spelling proficiency in the primary grades (Boland, 1993). Similar findings have been reported by Berninger, Cartwright, Yates, Swanson, and Abbott (1994) and Zutell and Rasinski (1989) for the intermediate grades.

Berninger et al. (2008b) stated that at-risk children should continue to receive specialized intervention until all of their writing (as well as reading skills) reaches the targeted level. Although spelling problems often persist (e.g., Berninger et al., 2008b; Rose, 2009; Spear-Swerling, 2005), specialized instruction has been shown to be effective. However, these individuals may require continuing treatment (Berninger, 2006), and more specifically ongoing explicit instruction focusing on spelling, including awareness and coordination of phonological, orthographic, and morphological word forms and their parts (Berninger et al., 2008b). Moreover, children showing signs of dyslexia should not be dismissed from special education until their problems are resolved (see, e.g., Berninger et al., 2008b).

APPROACHES TO INTERVENTION: COMPUTER-ASSISTED INTERVENTION IN SPELLING DEVELOPMENT

Computer-assisted reading instruction is currently being explored as an individual-orientated, intensive, and viable method of training reading skills (McCormick, 1999; Torgesen, 2002). Much less, however, is known about its impact on spelling skills. Previous computer-assisted intervention studies have recognized that a computer-assisted reading intervention can be effective in training at-risk children (e.g., Fawcett, Nicolson, Moss, Nicolson, & Reason, 2001; Magnan & Ecalle, 2006; Nicolson, Fawcett, Moss, Nicolson, &

Reason, 1999; Nicolson, Fawcett, & Nicolson, 2000; Regtvoort & van der Leij, 2007; Torgesen, Wagner, Rashotte, Herron, & Lindamood, 2009). Similarly, computer applications have been acknowledged to be useful instruments in training the literacy skills of children with reading disabilities (e.g., Elbro, Rasmussen, & Spelling, 1996; Hurford & Sanders, 1990; Jiménez et al., 2003, 2007; Lynch, Fawcett, & Nicolson, 2000; van Daal & Reitsma, 2000; Wentink, van Bon, & Schreuder, 1997; Wise, Ring, & Olson, 1999). Meta-analyses by Soe, Koki, and Chang (2000), the National Institute of Child Health and Human Development (2000), and a review by Blok, Oostdam, Otter, and Overmaat (2002) also support these findings.

However, much less is known about the impacts of computer-based phonological skill and letter knowledge training on spelling outcomes. Usually, computer-based spelling training is based on minimizing the impact of poor spelling in a writing task by using spell checkers or text-to-speech functions (see, e.g., Rose, 2009). Computers have not been used in a training environment to promote the fluent and accurate preliteracy skills required for successful spelling, although Brooks (2007) has argued that computer approaches work best when they are precisely targeted. Furthermore, most of the studies mentioned previously did not have a control condition, nor did they contrast the development of training groups with the development of a mainstream group (for an exception, see Regtvoort & van der Leij, 2007). Moreover, follow-ups were largely absent, and effect sizes were presented in only a few studies (for exceptions, see Nicolson et al., 2000; Regtvoort & van der Leij, 2007). In the present longitudinal study, the progress of two remedial reading groups, one receiving regular remedial reading instruction and the other receiving computer-assisted remedial reading instruction, was compared with the progress of mainstreamers. The goal of the study was to shed new light on what kinds of interventions produce the best results in spelling development and furthermore to build a model of predictive value of spelling acquisition, as little has been done previously on these topics.

AIMS

The first aim of this study was to build a model of the predictive value of spelling acquisition in three contrasting groups whose literacy learning was supported differently, that is, via participation in a regular remedial reading intervention, a computer-assisted remedial reading intervention (including GraphoGame computer-assisted training), or mainstream instruction. The second aim was to test a model of predictors (i.e., phonological awareness, letter knowledge, and rapid automatized naming) of later spelling ability. The third aim was to determine the effect of various intervention approaches on the spelling outcomes of students.

Previous studies within the present research project have examined reading subskill outcomes in a regular remedial reading intervention and computer-assisted remedial reading intervention (Saine, Lerkkanen, Ahonen, Tolvanen, & Lyytinen, 2010, 2011). It was found that the long-term effects of reading accuracy and fluency improved significantly if children received computer-assisted reading intervention during Grade 1. In the present study the long-term intervention effects of spelling development for children with compromised preliteracy skills were investigated in the highly regular Finnish orthography.

METHODS

Participants and Procedure

All together 166 children aged 7 years old from two cohorts ($n = 85$ and $n = 81$; 88 girls and 78 boys) participated in the study. All children were followed from school entry until Grade 3 in four different schools in the province of western Finland. The 30% of children who achieved lowest in two screening assessments out of three were offered remedial reading instruction ($n = 50$). The family characteristics of at-risk children represent the average of the Finnish families in general. The target group participants, all nonreaders, were randomly divided (by being assigned random numbers) into two groups: regular remedial intervention (RRI; $n = 25$) and computer-assisted remedial reading intervention (CARRI; $n = 25$). There was no statistical difference in preliteracy skills between the RRI and CARRI groups (see Table 1). The mainstream group ($n = 116$) received phonics-based reading instruction in regular classroom teaching from their classroom teacher, with no special form of additional provision from the research group. Phonological awareness, letter knowledge, and rapid automatized naming were assessed at school entry and spelling development was assessed in May in Grade 1, in May in Grade 2, and at the beginning of Grade 3.

Measures

Letter knowledge and rapid automatized naming were measured at school entry, and six phonological subtests were also administered at this time. IQ was estimated from the vocabulary, similarities, digit span, and block design tests of the Wechsler Intelligence Scale for Children–Revised (III; Wechsler, 1999) in the spring term of the second grade in both cohorts.

Phonological awareness

Six phonological subtests of the nationally normed reading test battery (Lindeman, 1998) were used to measure phonological awareness. In the test

TABLE 1 Variable Means and Standard Deviations for the Three Groups ($N = 166$)

Variable	RRI ($n = 25$)			CARRI ($n = 25$)			Mainstream ($n = 116$)		
	M (*SD*)	Min	Max	*M* (*SD*)	Min	Max	*M* (*SD*)	Min	Max
Gender									
Number of boys	13			17			48		
Number of girls	12			8			68		
Age in months	87.4 (4.43)	81	101	86.20 (5.76)	77	102	88 (3.72)	80	98
Estimated IQ									
WISC–III, April, Grade 2 (IQ estimation)[a]	101.44 (11.80)	85	126	102.68 (11.45)	78	122	103.15 (12.70)	75	136
Phonological awareness[b]									
August, Grade 1 (screening test)									
Identification of rhyming words	3.24 (1.54)	1	6	2.96 (1.90)	0	8	9.34 (1.11)	2	10
Building words by syllable sounds	3.92 (1.15)	2	6	3.96 (1.72)	0	6	9.27 (1.04)	3	10
Word fragmentation	3.40 (1.08)	2	5	3.52 (1.33)	0	6	8.33 (1.39)	2	10
Deletion of the initial sound	4.20 (1.29)	2	7	5.40 (2.04)	2	8	8.69 (1.39)	2	10
Letter sound connection	4.96 (1.77)	2	7	5.04 (1.57)	2	7	8.45 (1.57)	4	10
Rapid automatized naming									
August, Grade 1 (screening test)	66.38 (7.11)	55.6	78.4	69.74 (6.80)	58.7	82.4	56.26 (5.18)	47.8	71.4
Letter knowledge[c]				20.88 (3.23)					
August, Grade 1 (screening test)	6.64 (2.41)	3	12	7.60 (2.29)	4	12	21.22 (5.46)	8	29
October, Grade 1 (Subtest I)	11.28 (3.04)	7	20	14.60 (3.56)	8	24	23.44 (4.59)	12	29
December, Grade 1 (Subtest II)	17.60 (3.18)	13	23	20.88 (3.23)	12	26	25.38 (3.51)	15	29
January, Grade 1 (Subtest III)	22.16 (3.64)	15	28	24.64 (2.86)	18	28	26.62 (2.53)	17	29
March, Grade 1 (Subtest IV)	27.24 (1.74)	22	29	28.88 (0.44)	27	29	28.64 (0.79)	25	29
Spelling[d]									
May, Grade 1 (posttest)	9.96 (5.47)	2	17	13.08 (5.05)	2	19	30.07 (7.77)	2	40
May, Grade 2 (Follow-up I)	18.12 (7.05)	7	32	28.08 (7.99)	4	40	31.93 (6.39)	16	40
August, Grade 3 (Follow-up II)	19.64 (7.63)	8	34	31.04 (8.26)	2	42	32.41 (6.78)	14	42

Note. RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention; WISC–III = Wechsler Intelligence Scale for Children–Revised (III).
[a]IQ was estimated from the vocabulary, similarities, digit span, and block design tests of the WISC–III. [b]Maximum score = 10. [c]Maximum score = 29. [d]Maximum score = 40.

book the Kuder-Richardson coefficient for the test is given as 0.75–0.87, and reliability using Spearman-Brown is 0.93–0.94 at school entry.

Rapid automatized naming test (Ahonen, Tuovinen, & Leppäsaari, 1999)

Colors were used to measure automatized naming. The reliability coefficients were not given, but the mean in the test book was 54.7 s ($SD = 13.0$, range = 38–108 s) for Grade 1.

Letter knowledge

Progress in letter knowledge was assessed five times during the 10-month period of first grade. Each time the 29 letters of the Finnish alphabet were presented to the participants in mixed order. Each correctly named letter scored 1 point, and thus the maximum score was 29. This test was created for this particular study, and therefore reliability coefficients are not available.

Lukilasse normative word spelling test (Häyrinen, Serenius-Sirve, & Korkman, 1999)

The Lukilasse Normative Word Spelling Test was used to measure spelling ability. For Grades 1 and 2, the test consisted of 20 dictated Finnish words ranging from CVV to multisyllabic word forms. The score (maximum = 40 points) was based upon the relevant age norms and the number of words written correctly. The Grade 3 spelling test consisted of words and sentences, including punctuation and capital letters at the beginning of the sentences. The spelling test was carried out at the end of the experiment (May, Grade 1, posttest) and in both follow-ups. Cronbach's alpha reliability coefficient in the manual is .98 for Grade 1, .97 for Grade 2, and .97 for Grade 3.

Intervention

The training regimes in the first grade consisted of four weekly sessions of 45 min each held over a period of 28 weeks. These sessions were designed for children working in groups of five in a resource room setup and were incorporated into the first-grade literacy curriculum. After 6 weeks of formal schooling the interventions began in October of Grade 1. The average period of time the children spent in the resource room was 66 hr. Both experimental groups (RRI and CARRI) were trained by the same remedial reading specialist to eliminate trainer effects.

RRI

The regular phonics-based remedial reading instruction package in the RRI group was administrated by using regular remedial procedures for first graders in groups of five. Each 45-min remedial intervention period was divided into four segments: (a) prereading activities that linked reading, spelling, and phonology (lasting 15 min), such as games of letter-sound associations and sound synthesis into syllables and words, and fluency using flashcards; (b) activities of word segmentation (lasting 10 min), for example identifying and manipulating syllables and sounds within words, rhyming words, omitting sounds from words, making sound substitutions within words, and identifying words as units within sentences; (c) activities of decoding and spelling (lasting 10 min), such as writing words or pseudo-words while paying attention to letter-sound relationships, recoding, decoding, fluency, reading, and writing in context; and (d) vocabulary training (lasting 10 min) by using improvisation cards, mimicry, pantomime, acting, and illustrating charades on a blackboard or telling stories. The intervention package progressed from easier to more challenging activities. (See the description of the interventions for the two intervention groups in Appendix A.)

CARRI

The CARRI group used the same phonics-based remedial reading package as the RRI group with the difference that the GraphoGame application was used during the first segment instead of the prereading activities described in the previous section. Thus, the students had 10–15 min individual time with GraphoGame at the beginning of each session. Mean time-on-task was 4 hr 53 min. The computer-assisted training and regular remedial reading training overlapped in the first segment. Two to three participants at a time practiced for 10–15 min with the computer application (on three PC computers with Windows XP and an Internet connection) while the others completed the regular remedial reading tasks scheduled for the second segment. As soon as the students in the first group finished the participants switched tasks.

The GraphoGame computer-assisted intervention was specially developed for children with learning disabilities and at risk for dyslexia. The software was developed within the context of the Jyväskylä Longitudinal Study of Dyslexia (see, e.g., Lyytinen et al., 2004) with the overall aim of preventing developmental reading disabilities among children at risk for reading failure (for further details, see Lyytinen, Erskine, Kujala, Ojanen, & Richardson, 2009; Lyytinen et al., 2007). The GraphoGame application provides productive drill and practice in preliteracy and literacy skills, such as the integration of letter-sound relations and phonemic awareness, decoding skills, and further practice in accuracy and fluency. In spelling training a child hears a word via headphones and is asked to spell the word by replacing boxes containing single letters or syllables in the right order. When the child clicks the target letter or syllable the program produces the sound of the letter or syllable to help the child build the word correctly.

The application delivers context-free practice on specific syllable and word identification skills. The graphics used in GraphoGame include falling balls that contain an orthographic stimulus. Simultaneously with the falling balls an auditory stimulus is given via headphones. The ball, which matches the auditory stimulus, is selected from among two to nine falling balls on the orthographic target. From two to nine orthographic items fall as balls on the screen. GraphoGame begins with exercises in letter-sound correspondence. The training in phonemic awareness is implemented by immediate exposure to letters and sound relations. After of the student has acquired the target letter-sound correspondence, GraphoGame progresses gradually in stages to sound synthesis in syllables, words, and pseudo-words, aiming for acquisition of the alphabetic principles of the Finnish language.

GraphoGame is programmed to support the individual rate of acquisition by adapting the task difficulty to the level of personal achievement. The ultimate aim is an automatic connection between the auditory and orthographic stimulus. Participants who make progress are assigned new, more complicated tasks. Intervention data and logs are recorded on the server at the University of Jyväskylä, Finland. Online recordings enable researchers to monitor the responses of each individual while the application makes automatic adjustments to meet the special needs of each individual. At the time of the experiment the GraphoGame application was only used for research purposes. Nowadays, GraphoGame is available free to all Finnish- and Swedish-speaking children via support from the Finnish Ministry of Education.

The children were also taught in their own classrooms by their regular primary school teacher during the intervention period (7 months). During the present interventions, the 166 participating children did not receive any other interventions. Later on, in Grade 2, the 22 lowest achieving children in the RRI ($n = 20$) and CARRI ($n = 2$) groups received remedial reading training based on reading accuracy and further reading fluency that was not enriched with any computer-assisted intervention applications. The remaining children were placed in mainstream reading groups in their home classes and did not receive any intervention after Grade 1.

STATISTICAL ANALYSIS

First, in the nonlinear latent growth curve model letter knowledge was used to build a comprehensive model. Instead of the initial level and slope the final level and slope were used to estimate the developmental features of letter knowledge. This was done for the following reasons: (a) to determine the effect of the intervention on the level of letter knowledge achieved and (b) to control for achieved letter knowledge as a predictor of later spelling.

Second, spelling was predicted from the growth factors of letter knowledge, phonological awareness, and rapid automatized naming, and the final model goodness of fit was evaluated using the chi-square test, in which a nonsignificant *p* value indicates a good fit. Other fit indexes used were the root mean square error of approximation (with a value of 0.06 or less indicating a good fit) and the comparative fit index and Tucker–Lewis index (with values of 0.95 or greater indicating a good fit; B. O. Muthén, 1998–2004).

The analyses were performed using the Mplus 5.1 program (L. K. Muthén & Muthén, 1998–2007). The method of estimation was full information maximum likelihood with robust standard errors and the adjusted chi-square test (Monotone Likelihood Ratio), both of which correct bias due to skewed distributions. We used the group of 116 mainstream students as the normative group when building the spelling model by means of the structural equation modeling technique. The intervention groups were dummy coded, forming two new variables RRI ($n = 25$) and CARRI ($n = 25$). The observed variables as well as the latent growth factors were regressed on the dummy variables based on the large modification index. These effects were the main effects of the RRI and CARRI groups, explaining the differences in mean values between groups. To be able to test the paths between the intervention groups and the normative mainstream group, we formed the interaction variables and tested them the same way as was done for the main effects. If statistical tests showed no differences in path coefficients, they were fixed equally between groups. The equality of main or interaction effects between groups was tested using the Satorra-Bentler scaled difference chi-square test (Satorra & Bentler, 2001).

In addition, analysis of variance (ANOVA) overall test was used to examine whether each of the intervention groups differed from one another in spelling in Grade 1, Grade 2, and Grade 3; if the overall test was significant, the analyses were continued doing a pairwise comparison across groups using Bonferroni corrected *p* values. The appropriateness of structural equation modeling and ANOVA for the data analysis was ensured by checking intraclass correlations due to differences between intervention groups of five members.

RESULTS

The results revealed that the intraclass correlations were very small and statistically nonsignificant, except for the last measurement of letter knowledge in January of Grade 1 (see Table 2). These results revealed that the methods were appropriate and that nonnested data could be used.

Moreover, the first stage of building a model of the development of spelling was to estimate nonlinear growth model for letter knowledge, where the factor loadings for nonlinear growth component were fixed to zero in the last measurements, producing the level factor that captured the variation in the final level of letter knowledge.

To build a model of the development of spelling, we used the growth components of letter knowledge, preintervention risk factors in phonological awareness, and rapid automatized naming as predictors in all three groups. Differences in this development and in the predictions between the two experimental intervention groups and the mainstream group were taken into account using the modification index. First, in the analysis the paths from the dummy-coded variables were added to the observed and latent variables in the model if needed. This procedure yielded a prediction related directly to the effects of the interventions explaining the differences in mean values between groups. Second, the regression paths between the dependent and interaction variables were added to the model if needed. These paths explained statistically significant differences in the regression coefficients between groups. The final model fit the data well: $\chi^2(69, N = 166) = 82.23$, $p = .13$, Tucker–Lewis index = 0.99, comparative fit index = 0.99, root mean square error of approximation = .034, standardized root-mean-square residual = .03. Next the results of the model are explained.

Nonlinear Growth Model for Letter Knowledge

The first aim of this study is described in Figure 1. With the nonlinear growth model, the explained variance in letter knowledge across measurements was 93% to 99%. The factor loadings differed mostly between the second and third measurements; this means that the CARRI group had the fastest growth in letter knowledge of all three groups compared in this study. In the first measurement, the model consisted of intercept corrections for the RRI group and especially for the CARRI group, explaining the faster growth in letter knowledge between the first and second measurements in the RRI and CARRI groups compared to the mainstream group. This model was part of the model predicting spelling development.

Predictors of Spelling Development

Based on second aim spelling in the first grade was predicted by phonological awareness in all three contrasting research groups, as a higher level of phonological awareness at school entry predicted better spelling outcomes in May of Grade 1 (the regression coefficients were .93 for both the RRI and mainstream groups and .71 for the CARRI group).

Spelling outcomes in the second grade were predicted by spelling in the first grade (regression coefficient = .56 for all three research groups), revealing moderate stability. A slower rate in the development of letter knowledge from school entry (August, Grade 1) to the midpoint of Grade 1 (January, Grade 1) predicted better spelling (regression coefficient = –.87) in Grade 2 in all three research groups. In addition, slow naming speed predicted slightly better spelling in Grade 2 via the slope of letter knowledge. Better phonological

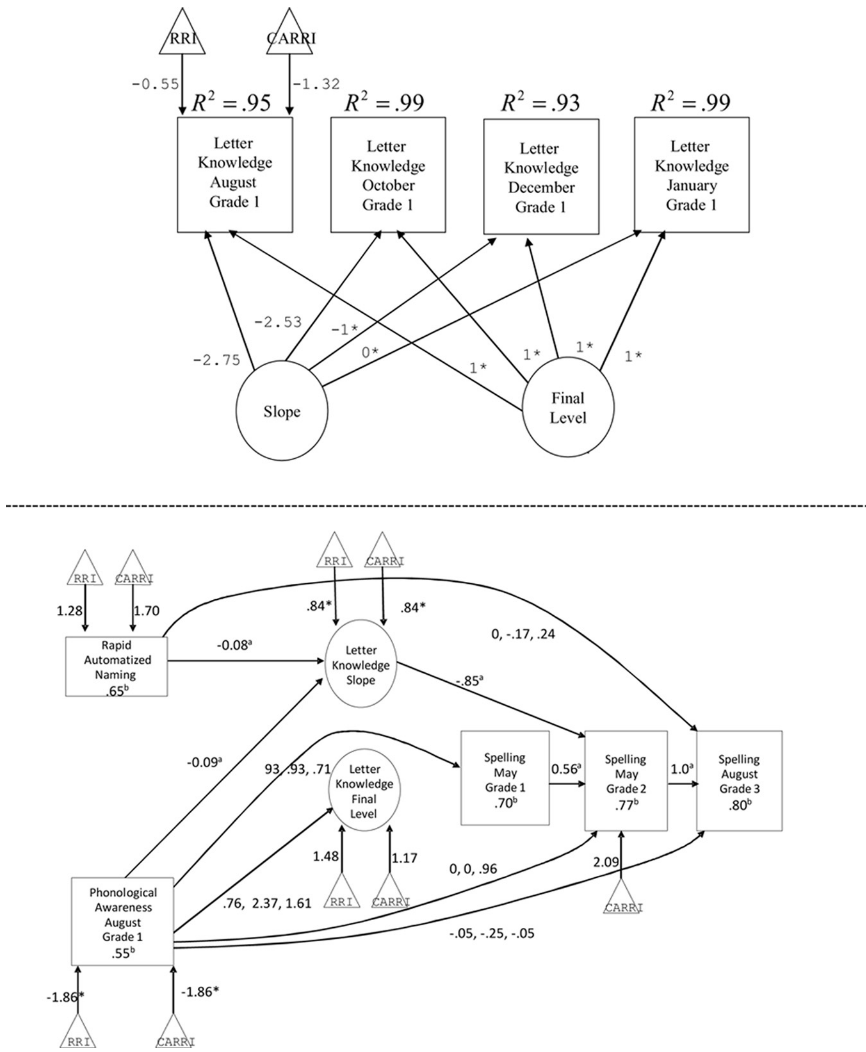


FIGURE 1 The predictors of spelling. The path coefficients of the triangles are intercepts, and the path coefficients between variables are regression coefficients (the first coefficient is for the mainstream group, the second coefficient is for the RRI group, and the third coefficient is for the CARRI group). *Intercepts were fixed equally between the RRI and CARRI groups. [a]Regression coefficients were equal for all groups. [b]Standard deviation of the mainstream group. RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention.

awareness in school entry (August, Grade 1) also predicted slightly better spelling in Grade 2 via the slope of letter knowledge. A higher value for phonological awareness in the screening test (August, Grade 1) predicted better spelling outcomes in Grade 2 (regression coefficient = .97) in the CARRI group. In addition, the intervention effect in the CARRI group was 2.11 regression coefficients.

Spelling outcomes in Grade 3 were predicted by spelling in the second grade (regression coefficient = 1.0 for all three research groups), revealing high stability. A lower value for phonological awareness in the screening test (August, Grade 1) predicted a better spelling outcome in Grade 3 (regression coefficients = –.05 for the CARRI and mainstream groups and –.25 for the RRI group) in all three research groups. In addition, faster naming speed as measured at school entry predicted better spelling in Grade 3 in the RRI group (regression coefficient = –.17), whereas slow naming speed predicted better spelling in Grade 3 in the CARRI group (regression coefficient = .24).

Using the standardized predicted mean values, which were calculated by using equation Index A (see Appendix B) and standardized using the predicted mean and standard deviation of the mainstream group, the results showed that spelling in Grades 1, 2, and 3 developed more slowly in the RRI and CARRI groups than in the mainstream group (see Figure 1). The model predicted that the mean values for spelling in Grade 1 were 2.53 and 1.94 *SD* higher for the RRI and CARRI groups, respectively, than the mean value of the mainstream group. The standardized predicted mean values in spelling were 2.12 and 1.38 *SD* higher in Grade 2 for the RRI and CARRI groups, respectively, than the mean value of the mainstream group. Standardized predicted values in spelling were 1.90 and 0.87 *SD* higher in Grade 3 for the RRI and CARRI groups, respectively, than the mean value of the mainstream group.

Differences in Mean Values in Spelling Among Groups in Grade 1, Grade 2, and Grade 3

The third aim of this study was to examine whether the average spelling skills differed among the three groups. ANOVA was used to analyze the results separately for Grade 1, Grade 2, and Grade 3 (see Table 2).

TABLE 2 Intraclass Correlation Coefficients and Statistical Significance

Measure	Intraclass correlation coefficient	*p*
Letter knowledge		
Letter knowledge 1 (school entry screening)	.003	.989
Letter knowledge 2 (October, Grade 1)	.002	.991
Letter knowledge 3 (December, Grade 1)	.095	.456
Letter knowledge 4 (January, Grade 1)	.199	.029
School entry screening		
Phonological awareness	.014	.877
Rapid automatized naming	.028	.797
Spelling		
Spelling 1 (May, Grade 1)	.000	1.0
Spelling 2 (May, Grade 2)	.020	.739
Spelling 3 (August, Grade 3)	.012	.858

The mean values in spelling of the groups differed in May of Grade 1, $F(2, 163) = 119.78$, $p \leq .001$. The mainstream group had a higher mean and differed significantly from both experimental groups ($p < .001$) at that time. The Bonferroni pairwise test indicated that the CARRI group did not differ statistically from the RRI group. The results 12 months later (May, Grade 2) revealed that the groups differed significantly from one another, $F(2, 163) = 43.55$, $p \leq .001$. The RRI group had a lower mean value than either the CARRI or mainstream groups (Bonferroni pairwise test $p < .001$ for both), whereas the CARRI group had a lower mean value than the mainstream group ($p < .05$). Eighteen months later (August, Grade 3) the groups differed significantly from one another, $F(2, 163) = 33.05$, $p < .001$. The RRI group had a lower mean value than either the CARRI or mainstream groups (Bonferroni pairwise test $p < .001$ for both), but there was no longer a statistical difference between the CARRI and mainstream groups.

Effect Sizes for the Three Intervention Groups

Progress from posttest to Follow-Up 1 was faster in the CARRI than the RRI group, $F(1, 48) = 10.15$, $p \leq .003$. The improvement in the CARRI and RRI groups was greater than that in the mainstream group: CARRI, $F(1, 139) = 68.27$, $p < .001$; RRI, $F(1, 139) = 14.23$, $p < .001$. As shown in Table 3, the improvement in effect size in the CARRI group was 0.90 greater than in the RRI group (and 1.70 greater than in the mainstream group).

At Follow-Up 2, the RRI group differed significantly from the CARRI and mainstream groups: CARRI, $t(48) = 5.07$, $p < .001$; mainstream, $t(139) = –8.36$, $p < .001$. However, no statistically significant difference emerged between the CARRI and mainstream groups. As shown in Table 3, the achievement level in effect size in the CARRI group was 1.68 higher (–.20 lower) than in the RRI group (mainstream group).

TABLE 3 Effect Sizes for Measures of Spelling Attainment in the Three Groups ($N = 166$)

Measure	CARRI versus RRI	RRI versus mainstream	CARRI versus mainstream
Letter knowledge			
Subtest I – screening	0.32[a]	0.57b	0.89[c]
Subtest II – Subtest I	0.13	0.58b	0.71[b]
Subtest III – Subtest II	–0.05	0.58b	0.53[b]
Subtest IV – Subtest III	–0.24	0.59b	0.35[a]
Subtest IV	2.08[c]	–1.77	0.30[a]
Spelling			
Follow-up I – posttest	0.90[c]	–0.80	1.70[c]
Follow-up II	1.68[c]	–1.88	–0.20

Note. RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention.
[a]Cohen's $d = 0.1–0.4$, small effect. [b]Cohen's $d = 0.5–0.7$, medium effect. [c]Cohen's $d = \geq 0.8$, large effect.

DISCUSSION

In the present study, independent of the risk factors, it seemed possible to help at-risk children with multiple risks with the computer-assisted phonics-based GraphoGame remedial reading intervention. The results revealed that computer-assisted treatment was effective in supporting the spelling development of at-risk children in the highly regular Finnish orthography. The regular remedial intervention failed to raise the level of spelling skill of the at-risk children to that of the mainstream children. Low phonological awareness seemed to play a central role in spelling development in spite of a combination of deficits. The remedial reading intervention enriched with GraphoGame seemed to be effective in raising the level of spelling of at-risk children to that of mainstream children.

The results reveal that to reach the average level of mainstreamers, children at risk for reading disability require intensive training and enough time to rehabilitate their skills. This is in line with the findings of Lerkkanen et al. (2010) that accurate spelling developed more slowly than accurate reading during the first 2 years of school. Based on the present study, the spelling skills of at-risk children seem to be remediable by a computer-assisted reading intervention program if the training regime is carefully planned and administered regularly as part of remedial reading training in the daily schedule. These findings are in accord with those of Berninger et al. (2006), Berninger et al. (2008b), and Lyon et al. (2003), who stated that spelling is commonly a challenge for people with reading disabilities. In the present study combinations of deficits with low phonological awareness seemed to be the biggest challenge for spelling remediation.

Spelling was clearly a challenge for those children who had compromised prereading skills at the beginning of Grade 1. However, these early features of reading disabilities seemed to be remediable by continuing training in phonological skills and letter-sound connections via the GraphoGame computer application. This finding is in line with earlier studies that have also focused on long-term training in spelling skills (see, e.g., Ball & Blachman, 1991; Byrne & Fielding-Barnsley, 1993; Castle et al., 1994; Lundberg et al., 1988). The present study reveals that early intervention can help to overcome spelling problems resulting from a number of risk factors, as also shown by Berninger et al. (2006, 2008a).

Berninger and O'Donnell (2004) stated that spelling and word-reading problems seem to be linked by deficits involving phonological processing. Furthermore, the level of phonological awareness at the beginning of school has been shown to affect spelling development during the first years of school (Bradley & Bryant, 1983; Schneider & Näslund, 1993; Wimmer, Landerl, Linortner, & Hummer, 1991). Correspondingly, in the present study phonological awareness played a pivotal role in predicting spelling outcomes. Presumably, children with phonological insensitivity do not receive sufficient amounts of repetition and drill and practice via the regular (i.e., RRI) type of intervention (see also Bentum & Aaron, 2003). Remedial reading intervention enriched with such computer applications as GraphoGame may be a more viable method.

In the present study, at-risk children with compromised phonological skills needed intensive letter-sound training to help them to spell skillfully in a language with highly regular orthography (i.e., Finnish). It can be assumed that the children in the computer-assisted remedial reading group (CARRI) received more consistent stimulation with long-term effect, which therefore resulted in greater spelling achievement. The computer-assisted remedial reading intervention may engage basic decoding skills required in a transparent language such as Finnish for adequate spelling performance. It is important to note that the children in the CARRI group, who received the systematic computer-assisted remedial intervention, reached the level of spelling of the mainstream group by the beginning of Grade 3. This means that at-risk children require more intensive training than regular remedial reading intervention is able to provide. Unfortunately, this confirms the findings of Bentum and Aaron (2003) that regular remedial programs are not effective enough and require active improvement. This disquieting finding requires further investigation; it should also be brought into the debate on remedial reading instruction.

Limitations

A number of limitations need be taken into consideration in any attempt to generalize these results. First, our subjects were middle-class children presenting at school entry some decoding problems. Many interventions are designed for children from less advantaged backgrounds, and our findings cannot be directly applied to these children. Second, our sample size was quite small, and further replication is warranted before the program can be adopted in practice. Third, although Finnish children begin formal schooling in the year of their seventh birthday, with adequate teaching the transparency of the Finnish orthography enables a child to spell (and read) accurately very rapidly (within a year) compared to children who speak languages with more opaque orthographies. Therefore, if they are to be applied more widely, CARRI interventions need to be tested among children learning to spell and read in less regular orthographies. Finally, both the RRI and CARRI groups were taught by the same remedial reading specialist. This was done to avoid possible trainer effects. However, the at-risk children along with the 116 mainstreamers were taught by the same class teachers during lessons other than spelling and reading. This might have had an effect on the reading acquisition of the at-risk children. The class teachers knew which children were being taught in the remedial reading groups. Consequently, they may have devoted extra attention to these children during other classroom activities. However, four to five children in each home classroom were in a remedial reading group. Therefore, individual attention from individual class teachers could hardly have been a priority. Also, teachers were blind to the research group setting and other research practices.

In conclusion, children at risk for reading disabilities can be identified at the time of school entry. Moreover, spelling abilities can be predicted by preliteracy skills as measured at school entry (see also Berninger & O'Donnell, 2004). The present results suggest that compromised development of spelling skills can be avoided by an early intensive intervention (see also Berninger et al., 2006, 2008b). Moreover, school beginners who are at risk for reading and spelling disabilities could possibly benefit if they participate in a remedial reading and spelling intervention that is enriched by computer-assisted reading training such as GraphoGame. A computer-assisted remedial reading regime in a group of four to five students may have a preventive role and moreover a permanent impact on spelling skills. If the fundamental levels of reading and spelling skills such as letter-sound connection, phonology, and accurate decoding are engaged by a systematic early intervention that includes computerized training, at-risk children may attain an adequate level of spelling.

In sum, the main finding of the present study for the arena of remedial reading and spelling intervention is that computer-assisted training may enrich regular remedial reading intervention and help at-risk children to gain reading and spelling skills required for future academic performance. A game-like computer-assisted literacy environment may be more motivating for at-risk children and might help the remedial specialist reduce risks for reading and spelling failure. In a computer-assisted environment, the child may have a chance to learn to read and spell in a way that is presumably more fun, which may enhance his or her willingness to practice literacy skills more than regular methods. In contrast, children who receive fewer stimuli in their regular remedial reading instruction tend to find literacy skill training laborious and thus are likely to dislike literacy training (see, e.g., Morgan, Fuchs, Compton, Cordray, & Fuchs, 2008). To avoid frustration, a wide range of intervention equipment may enrich resource room education; computer applications may be new viable methods. However, computer programs are not yet developed enough to be depended on as the major source of an intervention, despite these rather promising results. It is not suggested that computer-assisted remedial training alone will work as the major source of an intervention for struggling children. A well-structured, research-based remedial intervention that includes regular monitoring of reading and spelling subskills is required to realize the achievements reported in the present article.

REFERENCES

Ahonen, T., Tuovinen, S., & Leppäsaari, T. (1999). *Nopean sarjallisen nimeämisen testi* [The automatized serial naming test]. Lievestuore, Finland: Haukkaranta school and Niilo Mäki Institut.

Amtmann, D., Abbott, R., & Berninger, V. (2008). Identifying and predicting classes of response to explicit, phonological spelling instruction during independent composing. *Journal of Learning Disabilities*, *41*, 218–234. doi:10.1177/0022219408315639

Ball, E., & Blachman, B. (1991). Does phoneme awareness training in kindergarten make a difference in early word recognition and developmental spelling? *Reading Research Quarterly*, *26*, 49–66. doi:10.1598/RRQ.26.1.3

Bentum, K. E., & Aaron, P. G. (2003). Does reading instruction in learning disability resource rooms really work? A longitudinal study. *Reading Psychology*, *24*, 361–382. doi:10.1080/02702710390227387

Berninger, V. (2001). Understanding the lexia in dyslexia. *Annals of Dyslexia*, *51*, 23–48.

Berninger, V. (2006). A developmental approach to learning disabilities. In I. Siegel & A. Renninger (Eds.), *Handbook of child psychology: Vol. 4. Child psychology and practice* (pp. 420–452). New York, NY: Wiley.

Berninger, V., Abbot, R., Thompson, J., Wagner, R., Swanson, H. L., Wijsman E. J., & Raskind., W. (2006). Modeling developmental phonological core deficits within a working-memory architecture in children and adults with developmental dyslexia. *Scientific Studies of Reading*, *10*, 165–198.

Berninger, V., Cartwright, A., Yates, C., Swanson, H. L., & Abbott, R. (1994). Developmental skills related to writing and reading acquisition in the intermediate grades: Shared and unique variance. *Reading and Writing*, *6*, 161–196. doi:10.1007/BF01026911

Berninger, V., Nielsen, K., Abbott, R., Wijsman, E., & Raskind, W. (2008a). Gender differences in severity of writing and reading disabilities. *Journal of School Psychology*, *46*, 151–172. doi:10.1016/j.jsp.2007.02.007

Berninger, V., Nielsen, K., Abbott, R., Wijsman, E., & Raskind, W. (2008b). Writing problems in developmental dyslexia: Under-recognized and under-treated. *Journal of School Psychology*, *46*, 1–21. doi:10.1016/j.jsp.2006.11.008

Berninger, V., & O'Donnell, L. (2004). Research-supported differential diagnosis of specific learning disabilities. In A. Prifitera, D. Saklofske, L. Weiss, & E. Rolfhus (Eds.), *WISC-IV Clinical use and interpretation* (pp. 189–233). San Diego, CA: Academic Press.

Blok, H., Oostdam, R., Otter, M. E., & Overmaat, M. (2002). Computer-assisted instruction in support of beginning reading instruction: A review. *Review of Educational Research*, *72*, 101–130. doi:10.3102/00346543072001101

Boland, T. (1993). The importance of beginning literature: Reading development in primary school and its consequences for the school career in secondary education. *European Journal of Psychology and Education*, *8*, 289–305. doi:10.1007/BF03174083

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read. A casual connection. *Nature*, *301*, 419–421.

Brooks, G. (2007). *What works for pupils with literacy difficulties?* London, UK: Department for Children, Schools and Families.

Byrne, B., & Fielding-Barnsley, R. (1993). Evaluation of a program to teach phonemic awareness to young children: A one year follow up. *Journal of Educational Psychology*, *85*, 104–111. doi:10.1037/0022-0663.85.1.104

Caravolas, M. (2005). The nature and causes of dyslexia in different languages. In *The science of reading: A handbook* (pp. 336–356). Oxford, UK: Blackwell.

Castle, J. M., Riach, J., & Nicholson, T. (1994). Getting off to a better start in reading and spelling: The effects of phonemic awareness instruction within a whole language program. *Journal of Educational Psychology*, *86*, 350–359. doi:10.1037/0022-0663.86.3.350

Ehri, L. C. (*1987*). Learning to read and spell words. *Journal of Reading Behavior*, *19*, 5–31. doi:10.1080/10862968709547585

Ehri, L. C. (1989). The development of spelling knowledge and its role in reading acquisition and reading disability. *Journal of Learning Disabilities*, *22*, 356–365.

Ehri, L. C. (1997). Learning to read and learning to spell are one and the same, almost. In C. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell* (pp. 271–295). London, UK: Erlbaum.

Ehri, L. C., Nunes, S. R., Willows, D. M., Schuster, B. V., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly*, *36*, 250–287. doi:10.1598/RRQ.36.3.2

Elbro, C., Rasmussen, I., & Spelling, B. (1996). Teaching reading to disabled readers with language disorders: A controlled evaluation of synthetic speech feedback. *Scandinavian Journal of Psychology*, *37*, 140–155. doi:10.1111/j.1467-9450.1996.tb00647.x

Fawcett, A. J., Nicolson, R. I., Moss, H., Nicolson, M. K., & Reason, R. (2001). Effectiveness of reading intervention in junior school. *Educational Psychology*, *21*, 299–312. doi:10.1080/01443410124914

Gentry, J. R. (1982). An analysis of developmental spelling in GNYS AT WRK. *The Reading Teacher*, *36*, 192–200.

Hatcher, P. J., Hulme, C., & Ellis, A. W. (1994). Ameliorating early reading failure by integrating the teaching of reading and phonological skills: The phonological linkage hypothesis. *Child Development*, *65*, 41–57. doi:10.2307/1131364

Hatcher, P. J., Hulme, C., Miles, J. N. V., Carroll, J. M., Hatcher, J., Gibbs, S., … Snowling, M. J. (2006). Efficacy of small group reading intervention for beginning readers with reading-delay: A randomised controlled trial. *Journal of Child Psychology and Psychiatry*, *47*, 820–827. doi:10.1111/j.1469-7610.2005.01559.x

Hatcher, J. P., Hulme, C., & Snowling, M. J. (2004). Explicit phoneme training combined with phonic reading instruction helps young children at-risk of reading failure. *Journal of Child Psychology and Psychiatry*, *45*, 338–358. doi:10.1111/j.1469-7610.2004.00225.x

Häyrinen, T., Serenius-Sirve, S., & Korkman, M. (1999). *Lukilasse* [The Lukilasse Graded Achievement Package for Comprehensive School Age Children]. Helsinki, Finland: Psykologien kustannus.

Holopainen, L., Ahonen, T., & Lyytinen, H. (2001). Predicting delay in reading achievement in a highly transparent language. *Journal of Learning Disabilities*, *5*, 401–413. doi:10.1177/002221940103400502

Hurford, D. P., & Sanders, R. E. (1990). Assessment and remediation of a phonemic discrimination deficit in reading disabled second and fourth graders. *Journal of Experimental Child Psychology*, *50*, 396–415. doi:10.1016/0022-0965(90)90077-L

Iversen, S., & Tunmer, W. E. (1993). Phonological processing skills and the reading recovery programme. *Journal of Educational Psychology*, *85*, 112–126. doi: 10.1037/0022-0663.85.1.112

Jiménez, J. E., del Rossario Ortiz, M., Rodrigo, M., Hernández-Valle, M., Ramírez, G., Estévez, A., … de la Luz Trabaue, M. (2003). Do the effects of computer-assisted practice differ for children with reading disabilities with and without IQ-achievement discrepancy? *Journal of Reading Disabilities*, *36*, 34–47. doi:10 .1177/00222194030360010501

Jiménez, J. E., Hernández-Valle, M., Ramírez, G., del Rossario Ortiz, M., Rodrigo, M., Estévez, A., … de la Luz Trabaue, M. (2007). Computer speech-based remediation for reading disabilities: The size of spelling-to-sound unit in a transparent orthography. *Spanish Journal of Psychology*, *10*, 52–67.

Lerkkanen, M.-K., Poikkeus, A.-M., Ahonen, T., Siekkinen, M., Niemi, P., & Nurmi, J.-E. (2010). Luku- ja kirjoitustaidon sekä motivaation kehitys esi- ja alkuopetusvuosina [*The development of reading and spelling skills and motivation during the preschool and early primary grades*]. *Kasvatus*, *41*, 116–128.

Lerkkanen, M.-K., Rasku-Puttonen, H., Aunola, K., & Nurmi, J.-E. (2004). Predicting reading performance during the first and the second year of primary school. *British Educational Research Journal*, *30*, 67–92. doi:10.1080/01411920310001629974

Lindeman, J. (1998). *ALLU—Ala-asteen Lukutesti* [ALLU—Graded Comprehensive School Reading Test]. Turku, Finland: Oppimistutkimuksen keskus.

Lundberg, I., Frost, J., & Petersen, O.-P. (1988). Effects of an extensive program for stimulating phonological awareness in preschool children. *Reading Research Quarterly*, *23*, 264–284.

Lynch, L., Fawcett, A. J., & Nicolson, R. I. (2000). Computer-assisted reading intervention in a secondary school: An evaluation study. *British Educational Communications and Technology Agency*, *31*, 333–348. doi:10.1111/1467-8535.00166

Lyon, G. R., Shaywitz, S., & Shaywitz, B. (2003). A definition of dyslexia. *Annals of Dyslexia*, *53*, 1–14. doi:10.1007/s11881-003-0001-9

Lyytinen, H., Aro, M., Eklund, K., Erskine, J., Guttorm, T., Laakso, M.-L., … Torppa, M. (2004). The development of children at familial risk for dyslexia: Birth to early school age. *Annals of Dyslexia*, *54*, 184–220. doi:10.1007/s11881-004-0010-3

Lyytinen, H., Erskine*, J., Kujala, J., Ojanen, E., & Richardson, U. (2009). In search of a science-based application: A learning tool for reading acquisition. Scandinavian Journal of Psychology, 50*, 668–675. doi:10.1111/j.1467-9450.2009.00791.x

Lyytinen, H., Leinonen, S., Nikula, M., Aro, M., & Leiwo, M. (1995). In search of the core features of dyslexia: Observations concerning dyslexia in the highly orthographically regular Finnish language. In V. Berninger (Ed.), *The varieties of orthographic knowledge II: Relationships to phonology, reading, and writing* (pp. 177–204). Dordrecht, The Netherlands: Kluwer.

Lyytinen, H., Ronimus, M., Alanko, A., Poikkeus, A.-M., & Taanila, M. (2007). Early identification of dyslexia and the usage of computer game-based practice to support reading acquisition. *Nordic Psychology*, *59*, 109–126. doi:10.1027/1901-2276.59.2.109

Magnan, A., & Ecalle, J. (2006). Audiovisual training in children with reading disabilities. *Computers & Education*, *46*, 407–425. doi:10.1016/j.compedu.2004.08.008

McCormick, S. (1999). *Instructing children who have literacy problems* (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Morgan, P., Fuchs, D., Compton, D., Cordray, D., & Fuchs, L. (2008). Does early reading failure decrease children's reading motivation? *Journal of Learning Disabilities*, *41*, 387–404. doi:10.1177/0022219408321112

Muthén, B. O. (1998–2004). *Mplus technical appendices*. Los Angeles, CA: Muthén & Muthén.

Muthén, L. K., & Muthén, B. O. (1998–2007). *Mplus user's guide* (5th ed.). Los Angeles, CA: Authors.

National Institute of Child Health and Human Development. (2000). *Report of the National Reading Panel. Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction* (NIH Publication No. 00-4769). Washington, DC: U.S. Government Printing Office.

Nicolson, R. I., Fawcett, A. J., Moss, H., Nicolson, M. K., & Reason, R. (1999). Early reading intervention can be effective and cost-effective. *British Journal of Educational Psychology*, *69*, 47–62.

Nicolson, R. I., Fawcett, A. J., & Nicolson, M. K. (2000). Evaluation of a computer-based reading intervention in infant and junior schools. *Journal of Research in Reading*, *23*, 194–209. doi:10.1111/1467-9817.00114

Parrila, R. K., Kirby, J. R., & McQuarrie, L. (2004). Articulation rate, naming speed, verbal short term memory, and phonological awareness: Longitudinal predictors of early reading development. *Scientific Studies of Reading*, *8*, 3–26.

Perfetti, C. A. (1997). The psycholinguistics of spelling and reading. In C. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell* (pp. 21–39). London, UK: Erlbaum.

Regtvoort, A. G. F. M., & van der Leij, A. (2007). Early intervention with children of dyslexic parents: Effects of computer-based reading instruction at home on literacy acquisition. *Learning and Individual Differences*, *17*, 35–53. doi:10.1016/j.lindif.2007.01.005

Rose, J. (2009). *Identifying and teaching children and young people with dyslexia and literacy difficulties*. London, UK: Department for Children, Schools and Families.

Saine, N. L., Lerkkanen, M.-K., Ahonen, T., Tolvanen, A., & Lyytinen, H. (2010). Predicting word-level reading fluency outcomes in three contrastive groups: Remedial and computer-assisted remedial reading intervention, and mainstream instruction. *Learning and Individual Differences*, *20*, 402–414.

Saine, N. L., Lerkkanen, M.-K., Ahonen, T., Tolvanen, A., & Lyytinen, H. (2011). Computer-assisted remedial reading intervention for school beginners at-risk for reading disability. *Child Development*, *82*, 3, 1013–1028.

Satorra, A., & Bentler, P. (2001). A scaled difference chi-square test statistic for moment structure analysis. *Psychometrika*, *66*, 507–514.

Schneider, W., & Näslund, J. C. (1993). The impact of early metalinguistic competencies and memory capacities on reading and spelling in elementary school: Results of the Munich Longitudinal Study on the Genesis of individual competencies (LOGIC). *European Journal of Psychology of Education*, *8*, 273–288.

Schneider, W., Roth, E., & Ennemoser, M. (2000). Training phonological skills and letter knowledge in children at risk for dyslexia: A comparison of three kindergarten intervention programs. *Journal of Educational Psychology*, *92*, 284–295. doi:10.1037/0022-0663.92.2.284

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, *94*, 143–174. doi:0.1348/000712603321661859

Soe, K., Koki, S., & Chang, J. M. (2000). *Effect of computer-assisted instruction (CAI) on reading achievement: A meta-analysis*. Honolulu, HI: Pacific Resources for Education and Learning. Retrieved from http://eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/16/4e/22.pdf

Spear-Swerling, L. (2005). *Spelling and students with learning disabilities*. Retrieved from http://www.ldonline.org/article/5587

Torgesen, J. K. (2002). The prevention of reading difficulties. *Journal of School Psychology*, *40*, 7–26.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Herron, J., & Lindamood, P. (2009). Computer-assisted instruction to prevent early reading difficulties in students at risk for dyslexia: Outcomes from two instructional approaches. *Annals of Dyslexia*, *60*, 40–56. doi:10.1007/s11881-009-0032-y

Treiman, R. (2000). The foundations of literacy. *Current Directions in Psychological Science*, *9*, 89–92.

Treiman, R., Sotak, L., & Bowman, M. (2001). The roles of letter names and letter sounds in connecting print and speech. *Memory & Cognition*, *29*, 860–873.

van Daal, V., & Reitsma, P. (2000). Computer-assisted learning to read and spell: Results from two pilot studies. *Journal of Research in Reading*, *23*, 181–193. doi:10.1111/1467-9817.00113

Wechsler, D. (1999). *Wechsler Intelligence Scale for Children–Revised (III)*. New York, NY: Psychological Corporation.

Wentink, H. W. M. J., van Bon, W. H. T., & Schreuder, R. (1997). Training poor reader's phonological decoding skills: Evidence for syllable-bound processing. *Reading and Writing*, *9*, 163–192. doi:10.1023/A:1007921805360

Wise, B. W., Ring, J., & Olson, R. K. (1999). Training phonological awareness with and without explicit attention to articulation. *Journal of Experimental Child Psychology*, *72*, 271–304. doi:10.1006/jecp.1999.2490

Wolf, M., & Katzir-Cohen, T. (2001). Reading fluency and its intervention. *Scientific Studies of Reading*, *5*, 211–239. doi:10.1207/S1532799XSSR0503_2

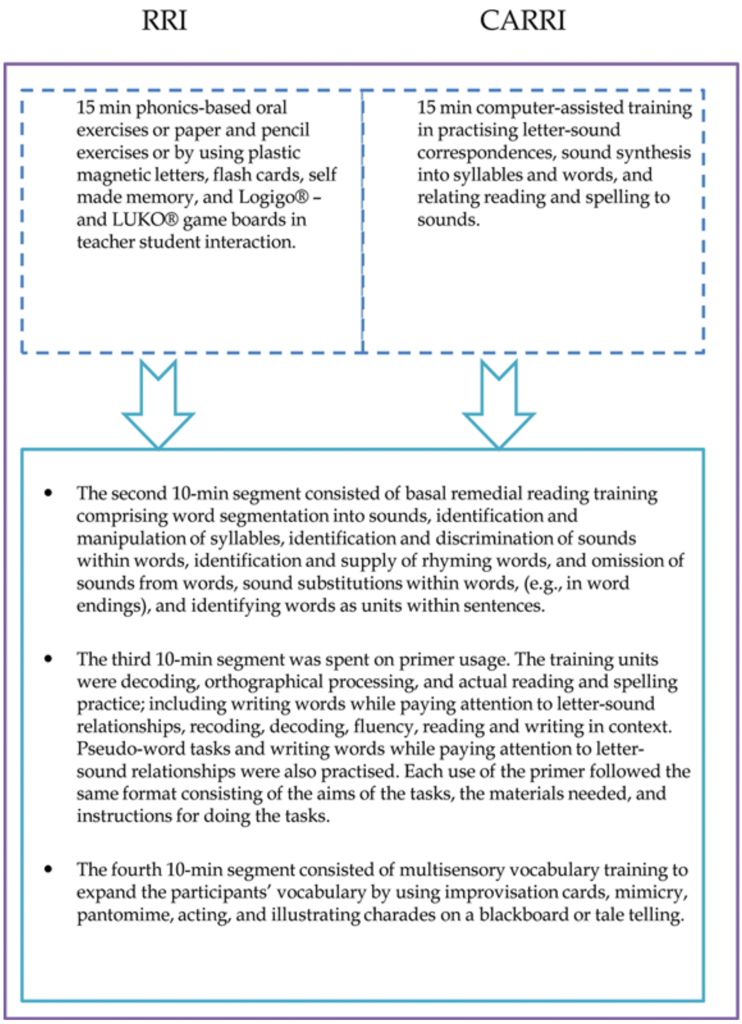
Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, *131*, 3–29. doi:10.1037/0033-2909.131.1.3

Zutell, J., & Rasinski, T. (1989). Reading and spelling connections in third and fifth grade students. *Reading Psychology*, *10*, 137–155. doi:10.1080/0270271890100203

APPENDIX A

SPELLING INDEXES IN GRADE 1, GRADE 2, AND GRADE 3

Description of Interventions



Note. RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention. (Color figure available online.)

APPENDIX B

Index A

Spelling

$$MayGrade1 = \begin{cases} 0.93 \times PA \ \ for\ the\ Mainstream\ Group \\ 0.93 \times PA \ \ for\ theRRI\ Group \\ 0.71 \times PA\ for\ the\ CARRI\ Group \end{cases}$$

Index B

Spelling

$$MayGrade2 = \begin{cases} 0.56 \times Spelling\,(Grade1) - 0.85 \times LKSlope \\ \qquad for\ the\ Mainstream\ Group \\ 0.56 \times Spelling\,(Grade1) - 0.85 \times LKSlope \quad for\ the\ RRI\ Group \\ 2.09 + 0.56 \times Spelling\,(Grade1) - 0.85 \times LKSlope + 0.96 \times PA \\ \qquad \qquad for\ the\ CARRI\ Group \end{cases}$$

Index C

Spelling

$$August\ Grade3 = \begin{cases} 1.0 \times \mathrm{Spelling(MayGrade1)} - 0.05 \times \mathrm{PA} \\ \qquad for\ the\ Mainstream\ Group \\ 1.0 \times \mathrm{Spelling(MayGrade1)} - 0.17 \times \mathrm{RAN} - 0.25 \times \mathrm{PA} \\ \qquad for\ the\ RRI\ Group \\ 1.0 \times \mathrm{Spelling(MayGrade1)} + 0.24 \times \mathrm{RAN} - 0.05 \times \mathrm{PA} \\ \qquad for\ the\ CARRI\ Group \end{cases}$$

Note. PA = phonological awareness; RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention; LKSlope = slope of letter knowledge; RAN = rapid automatized naming.