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Computer-Assisted Remedial Reading Intervention for School Beginners at Risk for Reading Disability

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The aim of the longitudinal study was to investigate whether a computer application designed for remedial reading training can enhance letter knowledge, reading accuracy, fluency, and spelling of at-risk children. The participants, 7-year-old Finnish school beginners (N = 166), were assigned to 1 of 3 groups: (a) regular remedial reading intervention (n = 25), (b) computer-assessed reading intervention (n = 25), and (c) mainstream reading instruction (n = 116). Based on the results, computer-assisted remedial reading intervention was highly beneficial, whereas regular type of intervention was less successful. The results indicated that at-risk children require computer-based letter–name and letter–sound training to acquire adequate decoding and spelling skills, and to reach the level of their non-at-risk peers.

Poor phonological awareness and letter knowledge have been acknowledged as main obstacles to successful reading acquisition (e.g., Bradley & Bryant, 1983; McCormick, 1999; Torgesen, 1998). The literature cited earlier provides the theoretical background for reading intervention programs that promote these two key factors (e.g., Hatcher, Hulme, & Snowling, 2004; Wimmer & Mayringer, 2002) and further spelling ability (cf. Hatcher et al., 2006; Share, 1995). However, although, early training in letter–sound relations has been advocated (Beech, Pedley, & Barlow, 1994), research on letter–sound interventions is scarce, as are training studies among at-risk school beginners. Consequently, in the present study reading acquisition was explored in two at-risk groups. The benefits of regular remedial reading intervention (RRI) and computer-assisted remedial reading intervention (CARRI) were scrutinized in school beginners with compromised prereading skills in orthographically regular Finnish language context.

The main focus in theoretical accounts of literacy skill development has been on word recognition because of its central role in beginning reading. Process-oriented theories share the idea of a continuum: Each stage of development builds upon earlier experiences and provides the foundation for later ones (e.g., Ehri, 1989; Ehri & McCormick, 1998; Frith, 1985). All readers will pass through the stages from prereading to skilled reading. A point of divergence, however, is in the importance attached to letter–sound knowledge when children begin to read and spell.

One of the most frequently used models of reading achievement in beginning readers is Ehri's (Ehri & McCormick, 1998) stage model, in which the acquisition of alphabetic knowledge and facility with letter–sound relations is of pivotal importance in the process of learning to read and spell. In Ehri's model, each of the five stages characterizes the learner's understanding and use of the alphabetic system in word reading. During *the prealphabetic stage*, the child acquires oral language skills and begins to identify printed signs from the environment, learning the shapes and names of letters. Transition to *the partial-alphabetic stage* is thus signaled when the child starts attending to specific letter–sound relations to aid word recognition. In *the full-alphabetic stage*, the child is able to recognize the connections fully between the letters and

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sounds they encounter in words. In *the consolidated-alphabetic stage*, child begins to operate with multi-letter units in words and store the orthography and spelling patterns in the word memory. In *the automatic stage*, words are read proficiently with increasing automaticy and speed.

Ehri's (1989) theory on learning to spell thus corresponds to her postulated reading stages. In *the precommunicative stage*, the child generates spellings that resemble print using randomly selected letters. 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 of letters, 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 upgrades, she or he 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 has been demonstrated that the most efficient reading intervention programs combine explicit training in phonological awareness with highly structured reading instruction (e.g., Hatcher, Hulme, & Ellis, 1994; Hatcher et al., 2006). Furthermore, the evidence obtained indicates that reading underachievement in children at risk for reading failure is preventable by explicit instruction in letter–sound correspondences (Foorman, Francis, Fletcher, Schatschneider, & Mehta, 1998). For example, Lovett, Barron, and Benson (2003) have emphasized the necessity of direct remediation of phonological awareness deficits, systematic and explicit instruction in letter and letter cluster-sound mappings, and reinforcement of word identification, learning through text reading practice by using a controlled decodable reading vocabulary. Despite of the existing knowledge on the basic elements of reading acquisition, the mainstream approach often fails to support at-risk children adequately in acquiring sufficient letter knowledge to develop fluent and accurate reading and spelling ability (see, e.g., Hatcher et al., 2004). It has been demonstrated that at-risk children may require a more individualized approach (Torgesen, 2005). Therefore, overcrowded early literacy settings are likely to challenge at-risk students, who acquire reading skills by degrees and require abundant repetition for decoding.

Computer-assisted reading instruction has currently been explored as an individual-orientated, intensive and viable method of training reading skills (Torgesen, 2002). Previous studies have recognized that computer-assisted reading intervention can be effective in training at-risk children (e.g., Magnan & Ecalle, 2006; Nicolson, Fawcett, & Nicolson, 2000; Regtvoort & van der Leij, 2007). In a similar vein, 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; Jiménez et al., 2007; van Daal & Reitsma, 2000; Wise, Ring, & Olson, 1999). The meta-analyses by Soe, Koki, and Chang (2000), the National Reading Panel (2000), and the review by Blok, Oostdam, Otter, and Overmaat (2002) also support these findings. However, most of the studies reviewed did not have a control condition, nor did they contrast the development of training groups with the development of the mainstream group (for an exception, see Regtvoort & van der Leij, 2007). Follow-ups were largely absent and effect sizes were presented in only a few of studies. In the present longitudinal study, the progress of the two remedial reading groups, RRI and CARRI, was contrasted to the progress of mainstreamers. Several assessments along with two follow-ups were included to determine changes in reading and spelling abilities. In addition, effect sizes were calculated to assess the effectiveness of the programs.

The aim of the present study was to investigate whether the computer-assisted remedial reading application can enhance letter knowledge, reading accuracy, fluency, and spelling in children with low prereading skills and risk for reading disabilities. Based on the research literature presented in the area of computer-assisted interventions (e.g., Elbro et al., 1996; Jiménez et al., 2007; van Daal & Reitsma, 2000; Wentink, van Bon, & Schreuder, 1997; Wise et al., 1999), it was hypothesized in the present study that the computer-assisted intervention would be a more powerful instrument in training the literacy skills of children at risk for reading disabilities than RRI, due to the intensive individual-orientated learning environment with individualized repetition that it enables. The two intervention conditions were: a RRI, and the same intervention approach complemented CARRI using the GraphoGame computer program (Lyytinen, Ronimus, Alanko, Poikkeus, & Taanila, 2007). The mainstream condition was applied along with the two remedial interventions to assess the progress in the acquisition of letter knowledge, reading accuracy, fluency, and spelling in three contrastive reading groups. Equally of interest were achievement levels: Can children at risk for reading disabilities attain the level of mainstreamers?

The experimental conditions were designed for beginning readers of Finnish, which has an orthography that is highly consistent in terms of the relation between sound and letter. Almost without exception, each phoneme corresponds to one grapheme and vice versa (Aro & Wimmer, 2003). Thus, the relation between grapheme and phoneme is consistent in both directions. Every word can be read and spelled in accordance with this highly bidirectionally consistent phonological strategy. This makes the acquisition of basic reading accuracy and spelling a fast and easy process for the majority of beginning readers (e.g., Holopainen, Ahonen, & Lyytinen, 2001; Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2004; Lyytinen et al., 2006).

The GraphoGame program (Lyytinen et al., 2007) was used to enrich the regular type of remedial reading intervention by providing an intensive adaptive learning environment with individualized repetition. The GraphoGame trains the three stages of the Ehri model (Ehri & McCormick, 1998) of reading achievement: the partial-alphabetic stage, the full-alphabetic stage, and the consolidated-alphabetic stage, and it applies two key alphabetic principles: phoneme awareness and letter knowledge. GraphoGame was developed to harness the cognitive operations that constitute reading a word. These include the visual operations of putting individual letters into an orthographic unit (visual word form) and their transformation into an internal sound (input phonology) and its articulation (output phonology). Earlier studies (e.g., Poshner & Rothbart, 2007; Seidenberg & McClelland, 1989) have also based their theories of decoding on cognitive operations. Further, a computer-assisted reading environment can be described as attention catching, while play-like features with immediate rewards and individualized instruction in a fun format make decoding practices less formidable and motivate the child to complete tasks.

In this study, a randomized controlled trial was used, as this design seems to provide the best evidence for the effectiveness of an intervention. Randomized controlled trials are particularly suitable in areas where well-developed theoretical and empirical support exists for a particular intervention (Harrington, Cartwright-Hatton, & Stein, 2002). The studies of phonological awareness and reading disorders (RDs) presented earlier clearly meet the essential theoretical and empirical criteria. The present study was then an attempt to introduce the idea of the randomized controlled trial to the field of remedial reading intervention. Torgerson and Torgerson (2001) reported on the need for randomized controlled trials in educational research. Since then the results of several randomized controlled trials (e.g., Borman et al., 2007; Vadasay, Sanders, & Peyton, 2006) have been published.

Method

Participants

Seven-year-old native Finnish-speaking children were selected for participation in the study by means of a screening process. Two cohorts (n = 88 and n = 83) of school beginners were screened in the province of Western Finland. The participating schools were from the same school district. The district is in a middle-class suburban area with consistent socioeconomic status and population density. Five children were excluded due to failure to obtain parental consent to participate (2 children) or change of schools (3 children). Thus, 166 children from the two cohorts (n = 85 and n = 81; 88 girls and 78 boys) finally participated in the study.

Procedure

All the children were followed from school entry to the beginning of the third grade. The prereading skills of all the 7-year-old school beginners participating in the study (N = 166) were tested during first 2 weeks of the first grade. The screening included (a) letter knowledge, (b) six phonological subtests of the nationally normed reading test battery (ALLU; Lindeman, 1998), and (c) the Rapid Automatized Naming Test (RAN; Ahonen, Tuovinen, & Leppäsaari, 1999). In the letter knowledge examination, the 29 letters of the Finnish alphabet were presented in mixed order individually to each child. The examiner pointed to the letter and the child was asked to name it. Responses were accepted as correct if the child produced the appropriate name or phonetic sound of the letter. The six phonological subtests (ALLU; Lindeman, 1998) measuring the children's phonological abilities, such as identification of rhyming words, building words by syllable sounds, word fragmentation, deletion of initial sounds, letter–sound relations, and deletion of final sounds, were administered in groups. The RAN was used to assess automatized naming speed. IQ was estimated by the vocabulary, similarities, digit span, and block design tests of the WISC–III (Wechsler, 1999) in the spring term of the second grade in both cohorts.

The lowest achieving 30% of these children, in two screening assessments out of three, were offered remedial reading intervention. This cut-point was based on statistics compiled by the Finnish Central Statistical Office (2009), according to which 26%–30% of Finnish children receive remedial reading training in Grades 1 and 2. After that, the target group participants were randomly divided, by being assigned random numbers, into two groups. Thus, each participant had a 50% chance of ending up in either of the two equivalent intervention conditions. Consent for the remedial reading intervention and research protocols was obtained at the time of the parental interview. After these procedures, the 50 (30 boys, 20 girls) lowest achieving children with possible risk for RD were randomly divided into two experimental groups of 25, whereas the remaining 116 children (48 boys, 68 girls) formed the mainstream reading group.

A questionnaire was administered to parents ($N = 50$) on the children's family background, including parents' level of education, parental marital status, size of family, child's birth order, and information about family risk for RDs. The representativeness of the children's family background with respect to the general Finnish population was good. Among the children's mothers, 16% (RRI) and 24% (CARRI) had a master's degree or higher, 72% (RRI) and 60% (CARRI) had a BA or vocational school degree, and 12% (RRI) and 16% (CARRI) had no education beyond comprehensive school. Among the children's fathers, 20% in both intervention groups had a master's degree or higher, 56% (RRI) and 64% (CARRI) had a BA or vocational school degree, and 24% (RRI) and 16% (CARRI) had no education beyond comprehensive. This educational distribution indicated that most of the children came from middle-class families with average socioeconomic status.

In RRI 60% of children and in CARRI 56% of children came from nuclear families, 24% (RRI) and 20% (CARRI) were from single-parent families, 8% (RRI) and 8% (CARRI) were from blended families, and 8% (RRI) and 16% (CARRI) were from families where the parents were divorced and the child has two homes. Four percent of the children in both intervention groups came from families with two members and 20% of the children in both intervention groups were from families with three members. Moreover, 32% (RRI) and 24% (CARRI) of children came from families with four members, 36% (RRI) and 40% (CARRI) were from families with five members, and 8% (RRI) and 12% (CARRI) were from families with six members. Among the mothers 40% (RRI) and 49% (CARRI), among the fathers 32.3% (RRI) and 57.7% (CARRI), and among the siblings 28% (RRI) and 62% (CARRI) reported having had problems in reading and/or writing. However, no reading disability diagnoses were available.

Nine classrooms in four elementary schools participated in the study. Both treatment conditions RRI and CARRI were administered in each school. There was no statistical difference in prereading skills between the RRI and CARRI groups. The remedial training was spread over a 28-week period between October and April in the first grade. The only difference between the two conditions was the type of remedial reading intervention given during the first 15 min of the remedial reading class. The mainstream group received phonics-based reading instruction in regular classroom teaching with no special form of additional provision from the research group. The participants were taught by nine class teachers altogether. Each teacher taught their class for 2 years. All the teachers (8 female, 1 male) had a master's degree in education and were qualified primary school class teachers with at least 5 years of experience in teaching reading to school beginners. The class teachers performed the all basic teaching activities in their classes.

Measures

Letter knowledge. Progress in letter knowledge was assessed five times during the 10-month period in the 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, the maximal score being 29.

Reading accuracy. The two subtests of the nationally normed reading test battery (ALLU; Lindeman, 1998) were used to assess progress in reading. These two subtests were used as a measure of word-level reading accuracy in context. The first-grade subtest was completed in January. The test was based upon the total number of words read and connected correctly to the right object. The subtest for the third graders was administered in August (Follow-up 2). The test was based upon the total number of sentences read and connected correctly to the right object within the space of 2 min. The Kuder–Richardson reliability coefficient in the first grade was .97 and in the second grade was .82 (Lindeman, 1998).

Fluency. A time-limited fluency test (Lukilasse Graded Fluency Test; Häyrinen, Serenius-Sirve, & Korkman, 1999) was constructed to assess reading fluency and accurate decoding. The fluency test consists of 90 Finnish words ranging from VCV to multisyllabic word forms. Scoring was based upon the relevant age norms and the total number of words read aloud correctly within the space of 2 min. The fluency test was carried out twice: at the end of the experiment (posttest) and 12 months later (Follow-up 1). The reliability of the test in the first-grade test was .979 and in the second grade was .968 (Häyrinen et al., 1999).

Spelling. The Lukilasse Graded Word Spelling Test (Häyrinen et al., 1999) was used to measure spelling ability. In the first and second grades, the test consists of 20 dictated Finnish words ranging from CVV to multisyllabic word forms. The scoring, maximum 40 points, was based upon the relevant age norms and the number of words written correctly. The third-grade 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. In the first grade, the reliability of the test reported was .979, in the second grade was .968, and in the third grade was .972 (Häyrinen et al., 1999).

Interventions

The study was designed to assess the effectiveness of an intervention that would be viable in a resource room setup. Consequently, the training regimes, consisting of four weekly sessions of 45 min, held over a period of 28 weeks were designed for children working in groups of 5 and were incorporated into the first-grade literacy curriculum. After 6 weeks of formal schooling, the interventions began. The times of the day that the children were taught in the experimental condition during the first grade varied. The average period of time the children spent in the resource room was 66 hr. The intervention time varied according to absences and extracurricular conditions such as field trips or public holidays. Both experimental groups were trained out by the same remedial reading specialist, to exclude trainer effects. The remedial reading specialist was not aware of the study hypothesis. Adherence to the training protocols was monitored by keeping written records for each intervention session, and through observation and discussions with the special education team. In each group, the exercises were carefully planned to meet the participants' specific requirements and each involved individualized, highly structured training, embodying many current recommendations for good remedial practice (e.g., Fletcher, Lyon, Fuchs, & Barnes, 2007). At the same time, all 166 first graders in the study received phonic-based reading instruction in their classrooms.

Regular remedial reading intervention. 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 5. Each 45-min remedial intervention period was divided into four segments: (a) prereading activities linking reading, spelling and phonology (lasting 15 min), such as, games of letter–sound associations and sound synthesis into syllables and words, and fluency using flash cards, Logigo® and LUKO® plastic game boards; (b) activities of word segmentation (lasting 10 min), for example, identification and manipulation of syllables and sounds within words, rhyming words, and omission of sounds from words, sound substitutions within words, and identifying words as units within sentences; (c) activities of decoding and spelling (lasting 10 min), such as writing words and pseudoword while paying attention to letter–sound relations, 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 tale telling. The intervention package progressed from easier to more challenging activities.

Computer-assisted remedial reading intervention. 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 earlier. Thus, the students had 15-min individual time with GraphoGame at the beginning of each session. Mean time on task was 4 hr 53 min.

Three PC computers with Windows XP and an Internet connection were allocated to each group of 5 participants. The computer-assisted training and regular remedial reading training overlapped in the first segment. Two to 3 participants at a time practiced for 15 min with the computer application, while the others completed the regular remedial reading tasks allowed to the second segment. At the end of the 15 min, the participants changed over.

The GraphoGame computer-assisted intervention has been specially developed for children with learning disabilities and at risk for dyslexia. The software was developed within the Jyväskylä Longitudinal Dyslexia Study (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 et al., 2007). The GraphoGame application provides productive drill and practice in prereading and reading skills, such as the integration of letter–sound relations and phonemic awareness, decoding skills, and further practice in accuracy and fluency.

The application delivers context-free practice on specific syllable and word identification skills. The graphics used in the GraphoGame include falling balls, which 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 the 2–9 falling balls on the orthographic target. From 2 to 9 orthographic items fall as balls on the screen, one of which is correct. GraphoGame begins with exercises in letter–sound correspondence. The training of phonemic awareness is implemented by immediate exposure to letters and sound relations. After acquisition of the target letter–sound correspondence, GraphoGame progresses gradually in stages to sound synthesis in syllables, words, and pseudowords, aiming at acquisition of the alphabetic principles of the Finnish language.

GraphoGame is programmed to support the individual rate of acquisition by adapting 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.

In the present study, three aspects of implementation fidelity were expected to have an impact on the extent to which the interventions produced the intended effects on the literacy skill development of at-risk children; these were dosage, adherence, and quality of delivery. In the present study, *dosage* (see O'Donnell, 2008) was assessed on the basis of the written reports of reading specialist and the GraphoGame game server reports and graphs (the children were not permitted to finish the GraphoGame intervention until "game over"), which enabled the research team to observe the frequency and length of specific parts of the intervention. *Adherence* is defined as the "degree to which program components were delivered as prescribed" (Greenberg, Domitrovich, Graczyk, & Zins, 2005). In the present study, adherence was assessed through the written reports of a reading specialist on the lessons scripts and materials and through the GraphoGame game server reports and graphs. *The quality of delivery* (Greenberg et al., 2005; O'Donnell, 2008) in the field of education has been suggested to be synonymous with good teaching. Good teaching was ensured in the present study by using the same remedial reading specialist in both intervention groups. The reading specialist had an MA in education and was specialized in training children with reading disabilities. Furthermore, the GraphoGame intervention used in the CARRI group, which was based on the dyslexia study (Lyytinen et al., 2004), was tested in a school environment, while the intervention in the RRI group followed the nationwide literacy curriculum. Thus, it can be argued that in both cases the quality of delivery was good.

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 participating 166 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 a regular reading intervention based on reading fluency that was not enriched with any computer-assisted instruction (CAI) applications. The rest of remaining children were placed in mainstream reading groups in their home classes and they did not receive any intervention after Grade 1. In the Finnish school system, the second grade literacy curriculum focuses on fluency and reading comprehension, as nearly every child learns to decode in the first grade (Lerkkanen, 2007).

Statistical Methods

The main interest lay in progress made by the two intervention groups (RRI and CARRI) in relation to each other. The development of these two experimental groups was then contrasted to the development of the mainstream group. The mainstream group was included in the study to assess the developmental variation in the acquisition of literacy skills in at-risk and not-at-risk children. The literacy scores (letter knowledge, reading accuracy, fluency, and spelling) were obtained for all the participants and included in the analyses.

Letter knowledge was measured on five successive occasions (screening test, Time 1, Time 2, Time 3, and Time 4). Development in letter knowledge was compared by means of a latent growth model within an SEM framework. These analyses were performed with the Mplus statistical package (Version 5.1; Muthén & Muthén, 1998–2007). The estimation method was maximum likelihood with robust standard errors and chi-square test value (MLR). The fit of the model was evaluated with a scaling-corrected (Δ) chi-square test (χ^2), comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). The nonsignificant chi-square test results, values higher than .95 for the CFI and TLI, and smaller than .06 for the RMSEA (Muthén, 1998–2004) indicate good fit of the model. The tested measurement models were compared via the Satorra–Bentler scaled difference chi-square test (Satorra & Bentler, 1999).

For other variables, which were measured on only two successive occasions, repeated measures analysis of variance (ANOVA) was used to test whether each of the trained groups differed from each other and whether these groups differed from the mainstream group. These analyses were performed separately using pairwise comparisons. Similarly, single measurements were tested using the *t* test. For the group comparisons in reading accuracy at Time 3 and Time 8, and spelling at Time 8, the *t* test was used.

The effect size gives an index of the improvement relative to the original performance mean and variation of the class (Cohen, 1988). In the present study, Cohen's *d* was used in comparing the mean values of the difference scores to the standard deviation of the mainstream group in the pretest. The formula was:

$$d = \frac{\mathrm{ds}_1 - \mathrm{ds}_2}{sd},$$

where ds_1 and ds_2 are the mean values (or the difference score of mean values at successive measurement points) for Group 1 (the CARRI group) and Group 2 (the RRI group) respectively, and *sd* is the standard deviation of the mainstream group in the screening test. This maneuver provides an index of improvement that is independent of the scoring system used and may therefore be used to compare across studies. The reliability sum scales were calculated by Cronbach's alpha, where possible.

Results

The aim of the study was to access the relative effectiveness of two remedial procedures in supporting children who have poor prereading skills (see Table 1). The primary data were obtained from the changes between the screening and posttests, and follow-ups. The means (standard deviations) and effect sizes for letter knowledge, reading accuracy, fluency, and spelling between the screening and posttests for the three groups are shown in Table 1 and effect sizes in Table 2. In all cases, the analyses were performed using the raw scores.

Letter Knowledge

The mainstream group identified an average of 21.22 letters in screening at the beginning of formal education (max 29), while the RRI group was able to name 6.64 letters and the CARRI group 7.60 letters. The latent growth model with second order polynomial (initial level, linear change, and quadratic change) fitted the data well, $\chi^2(7) = 11.40$, $p = .12$, $\Delta = 1.45$, CFI = .99, TLI = .98, RMSEA = .06, SRMR = .02. In this model, the latent growth factors were regressed on the two dummy-coded variables consisting of the information on each of the intervention groups. The estimates of the error variances were small, indicating rather high reliability (.70 for screening and over .84 from Subtest 1 [October, Grade 1] onward) of the observed variables. To compare the development of the intervention groups, these regression coefficients were fixed as equal. The chi-square difference test was used to test whether the fit of the model is statistically significantly reduced as a result of this procedure. When the regression coefficient was fixed as equal for initial level, linear change and quadratic change, the results of the chi-square difference tests were $\chi^2(1) = 1.60$, $p = .21$, $\Delta = 0.27$, $\chi^2(1) = 7.56$, $p = .006$, $\Delta = 1.81$, and $\chi^2(1) = 6.48$, $p = .011$, $\Delta = 2.31$, respectively, for each. These results indicate that in the first part of the repeated measures the development in the CARRI group was faster than in the RRI group and in the last part of the repeated measures slightly slower (see Table 1). The effect sizes indicate that the standardized progress of the CARRI group was about 0.32 (or 0.89) faster than in the RRI group (or mainstream group) between screening and Subtest 1 (October, Grade 1). The progress of the CARRI group was even faster than that of the mainstream group between all measurement points (0.71 between Subtest 1 [October, Grade 1] and Subtest 2 [December, Grade 1], 0.53 between Subtest 2 [December, Grade 1] and Subtest 3 [January, Grade 1], and 0.35 between Subtest 3 [January, Grade 1] and Subtest 4 [March, Grade 1]) and −0.24 slower between Subtest 3 (January, Grade 1) and Subtest 4 (March, Grade 1) is than in the RRI group (for more details, see Table 2). At the end of the

Table 1
Variable Means and Standard Deviations in 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	87.40 (4.43)	81	101	86.20 (5.76)	77	102	88.00 (3.72)	80	98
IQ estimation									
WISC–III[a]	101.44 (11.80)	85	126	102.68 (11.45)	78	122	103.15 (12.70)	75	136
April, Grade 2 (IQ estimation)									
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]									
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 1)	11.28 (3.04)	7	20	14.60 (3.56)	8	24	23.44 (4.59)	12	29
December, Grade 1 (Subtest 2)	17.60 (3.18)	13	23	20.88 (3.23)	12	26	25.38 (3.51)	15	29
January, Grade 1 (Subtest 3)	22.16 (3.64)	15	28	24.64 (2.86)	18	28	26.62 (2.53)	17	29
March, Grade 1 (Subtest 4)	27.24 (1.74)	22	29	28.88 (0.44)	27	29	28.64 (0.79)	25	29
Reading accuracy[d]									
January, Grade 1 (Subtest 3)	10.28 (3.35)	5	18	9.88 (4.00)	1	16	30.76 (11.70)	4	50
August, Grade 3 (Follow-up 2)	8.76 (2.88)	5	19	12.52 (3.59)	6	19	11.20 (3.76)	3	19
Reading fluency[e]									
May, Grade 1 (posttest)	26.44 (10.86)	6	50	35.80 (11.42)	6	50	47.51 (14.10)	12	78
May, Grade 2 (Follow-up 1)	48.28 (12.14)	24	70	60.68 (11.97)	24	74	64.32 (12.27)	31	88
Spelling[f]									
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 1)	18.12 (7.05)	7	32	28.08 (7.99)	4	40	31.93 (6.39)	16	40
August, Grade 3 (Follow-up 2)	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; Mainstream = mainstream reading group.
[a]IQ was estimated by the vocabulary, similarities, digit span, and block design tests of WISC–III. [b]Maximum score 10. [c]Maximum score 29. [d]Standard score instead of RAW score. [e]Items read correctly in 2 min. [f]Maximum score 40.

measurements, the CARRI group showed a slightly higher level of achievement than that of the mainstream group and higher achievement than that of the RRI group (see Figure 1).

When the achievement of the experimental groups was studied by using a cutoff value of 10th percentiles of the achievement in the mainstream group, the results indicated that in letter knowledge (Subtest 4, March, Grade 1), 19 children (76%) in the RRI group and 2 children (8%) in the CARRI group were in the lowest 10th percentile. The cutoff value was set to as low as the 10th percentile because of the high transparency of the Finnish orthography. Some other studies have used higher cutoff values (see, e.g., Torgesen, 1998), but these studies have also been conducted in more opaque orthographies such as English, or their focus has been on younger children (e.g., Torgesen, 1998).

The Reading Accuracy test was carried out 5 months after school began and a similar accuracy test for the third graders was carried at Follow-up 2. As the tests in the first and third grade were not the same, the statistical analyses were performed separately for each of the two measurements. In the Reading Accuracy subtest, Subtest 3 (January, Grade 1), the results indicated that the groups differed significantly from each other, $F(2, 163) = 74.29$, $p \leq .000$, while no significant difference was

Table 2
Effect Sizes for Intervention Attainment Measures of Letter Knowledge, Reading Accuracy, Reading Fluency, and Spelling in Three Groups (N = 166)

Measures	CARRI versus RRI (*d*)	RRI versus mainstream (*d*)	CARRI versus mainstream (*d*)
Letter knowledge			
Subtest 1–Screening	0.32[a]	0.57[b]	0.89[c]
Subtest 2–Subtest 1	0.13	0.58[b]	0.71[b]
Subtest 3–Subtest 2	−0.05	0.58[b]	0.53[b]
Subtest 4–Subtest 3	−0.24	0.59[b]	0.35[a]
Subtest 4	2.08[c]	−1.77	0.30[a]
Reading accuracy			
Subtest 3	0.23[a]	−1.69	−1.46
Follow-up 2	1.07[c]	−0.82	0.25[a]
Reading fluency			
Follow-up 1–posttest	0.22[a]	0.36[a]	0.57[b]
Follow-up 1	1.01[c]	−1.31	−0.30
Spelling			
Follow-up 1–posttest	0.90[c]	−0.80	1.70[c]
Follow-up 2	1.68[c]	−1.88	−0.20

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

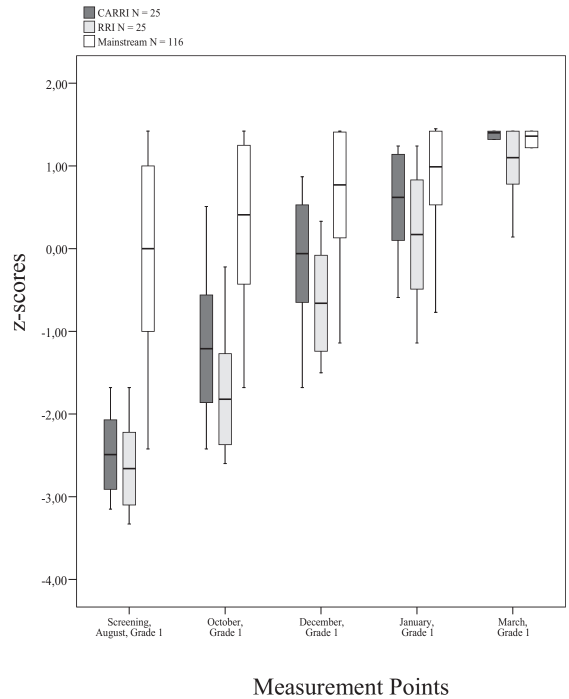

Figure 1. The achievements of the three groups in letter knowledge.
Note. The number the letters named correctly is standardized using the mainstream mean and standard deviation of screening. RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention; Mainstream = mainstream reading group. The box between mean value line described standard deviation and the endpoint of lines showed the minimum and maximum values.

found between the two experimental groups. Although the groups differed significantly in their mean values for reading accuracy, when controlled for the test of letter knowledge used in the screening procedure, $F(2, 162) = 3.38$, $p \leq .037$, the results were not statistically significant when the groups were compared two by two.

A similar Reading Accuracy subtest for third graders (Follow-up 2, August, Grade 3) was completed 16 months after the intervention had ceased. The results indicated that the groups differed significantly from each other, $F(2, 163) = 7.17$, $p \leq .01$. The pairwise comparison revealed that the RRI group differed from the CARRI ($p < .01$) and the mainstream group ($p < .01$). As shown in Table 2, the achievement level in effect size was 1.07 higher in the CARRI group than in the RRI group. When the achievement of the experimental groups was studied by using a cutoff value of the 10th percentile of the achievement in the mainstream group, the results for the reading accuracy (Follow-up 2, August, Grade 3) indicated that 6 children (24%) in the RRI group and 2 children (8%) in the CARRI group were in the lowest 10th percentile.

The Reading Fluency test was first completed 9 months after formal schooling began (posttest, May, Grade 1). At the posttest measurement, the CARRI and RRI groups differed significantly from each other, $t(48) = 2.97$, $p \leq .005$. Furthermore, the CARRI and RRI groups also differed significantly from the mainstream group, $t(139) = -3.88$, $p < .001$; $t(139) = -7.03$, $p < .001$. Improvement in the CARRI and RRI groups was faster than that in the mainstream group, $F(1, 139) = 83.02$, $p < .001$; $F(1, 139) = 26.17$, $p < .001$, respectively. As shown in Table 2, the achievement level in effect size was 0.22 faster in the CARRI group than in the RRI group (and 0.57 faster than in the mainstream group).

At the Follow-up 1 (May, Grade 2) measurement, the RRI group differed significantly from the CARRI and mainstream groups, $t(48) = 3.64$, $p \leq .001$, and $t(139) = -5.94$, $p < .001$, respectively, whereas no statistical significant difference between the CARRI and mainstream groups emerged (see Figure 2). As shown in Table 2, the achievement level in effect size in the CARRI group was 1.01 higher than in the RRI group (and −0.30 lower than in mainstream group). When the achievement of

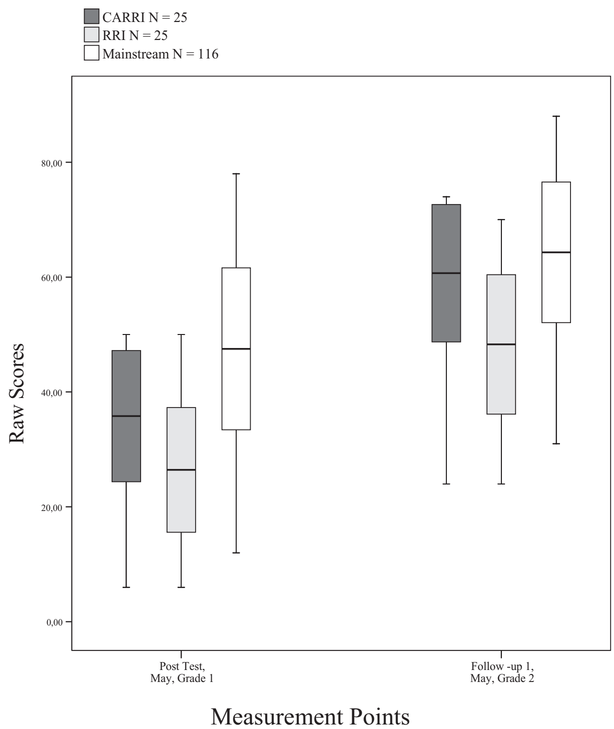

Figure 2. The achievement of the three groups in reading accuracy.
Note. RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention; Mainstream = mainstream reading group. The box between mean value line described standard deviation and the endpoint of lines showed the minimum and maximum values.

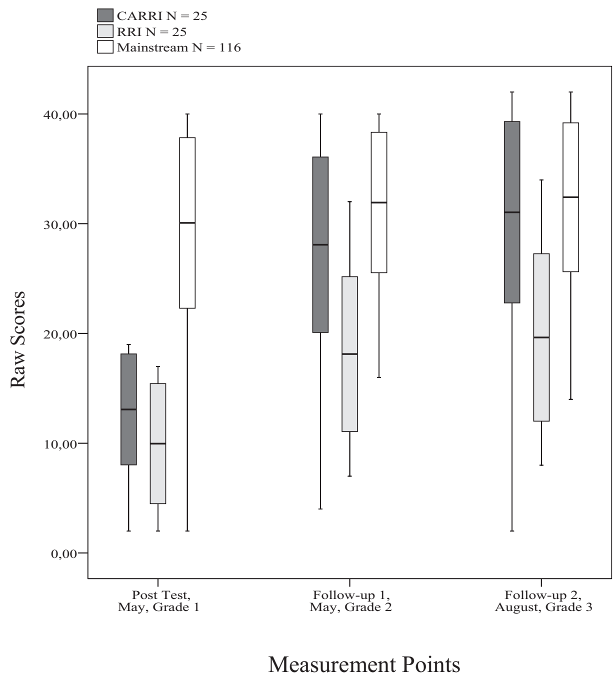

Figure 3. The achievement of the three groups in spelling.
Note. RRI = regular reading intervention; CARRI = computer-assisted remedial reading intervention; Mainstream = mainstream reading group. The box between mean value line described standard deviation and the endpoint of lines showed the minimum and maximum values.

the experimental groups was studied by using the cutoff value of the 10th percentile of the achievement in the mainstream group, the results for fluency indicated (Follow-up 1, May, Grade 2) that 11 children (44%) from the RRI group and 3 children (12%) from the CARRI group were in the lowest 10th percentile.

Spelling

The spelling test was repeated three times during the study period. The first spelling test (posttest, May, Grade 1) was completed immediately after the intervention ceased, the second test (Follow-up 1, May, Grade 2) was carried out 12 months later, and the third test (Follow-up 2, August, Grade 3) was performed 16 months after the intervention ceased. At posttest (May, Grade 1), the CARRI group was on a higher level than the RRI group, $t(48) = 2.10$, $p \leq .041$. Both the CARRI and RRI groups had lower achievement in spelling than that of the mainstream group, $t(139) = -10.46$, $p < .001$, and $t(139) = -12.29$, $p < .001$, respectively. Progress from posttest to Follow-up 1 was faster in the CARRI than in the RRI group, $F(1, 48) = 10.15$, $p \leq .003$. The improvement in the CARRI and RRI groups was greater than in the mainstream group, $F(1, 139) = 68.27$, $p < .001$, and $F(1, 139) = 14.23$, $p < .001$, respectively (see Figure 3). As shown in Table 2, 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).

A similar spelling test for third graders was carried out 16 months latter (Follow-up 2). In this measurement, the RRI group differed significantly from the CARRI and mainstream groups, $t(48) = 5.07$, $p < .001$, and $t(139) = -8.36$, $p < .001$, respectively, whereas no statistical significant difference emerged between the CARRI and mainstream groups. As shown in Table 2 the achievement level in effect size in the CARRI group was 1.68 higher (or −0.20 lower) than in the RRI group (or mainstream group). When the achievement of the experimental groups was studied by using a cutoff value of the 10th percentile of the achievement in the mainstream group, the results for spelling Follow-up 2 (August, Grade 3) indicated that 15 children (60%) in the RRI group and 2 children

(8%) in the CARRI group were in the lowest 10th percentile.

Discussion

The present study investigated whether a CAI application designed for remedial reading training would enhance letter knowledge, reading accuracy, fluency, and spelling among children with low prereading skills and at risk for RDs, and the extent to which gains would be maintained 12 and 16 months after the intervention. The study showed that the children in the CARRI group made gains during the first grade and continued to progress similarly in the follow-ups conducted 12 months (second grade) and 16 months (third grade) after the intervention had ceased. At-risk children in the RRI group also gained, but to lesser extent than the computer-assisted group. More specifically, the overall gains in the computer-assisted intervention were significant, not only in letter knowledge, decoding, and accuracy, but also in fluency and spelling.

The primary focus in the study was on reading, although spelling was also examined. Previous studies (e.g., Lyon, Shaywitz, & Shaywitz, 2003; Lyytinen et al., 2004; Snowling, Gallagher, & Frith, 2003) have confirmed that the letter knowledge, phonological awareness, and letter–sound relations are of pivotal importance in beginning reading and spelling. In the shallow and regular Finnish orthography, reading and spelling skills are taught simultaneously and children usually acquire both skills confidently (Lerkkanen, 2007). Therefore, it was of interest to investigate both the reading and spelling achievement of at-risk children. In the present study, an effective way of improving the reading skills of at-risk children involved a joint computer-assisted approach that integrates the training of letter–sound association, phonological skills, and decoding along with regular remedial reading training. Spending an equivalent amount of time in computer-assisted training proved to be more effective than the more regular types of remedial reading methods.

Letter Knowledge

The computerized remedial reading intervention proved to be beneficial in the acquisition of the letter–sound association. The results of the present study are consistent with the findings of Hatcher et al. (2004), who argue that children at risk for reading failure may benefit from additional training in phoneme awareness linked to letter sounds. Both the present remedial reading groups received additional training in phoneme awareness that is linked to letter names and letter sounds. Training letter–sound correspondence with the GraphoGame application proved to be beneficial to the children at risk for reading failure. That was most likely due to intensive training in grass roots skills such as letter knowledge and decoding. The RRI intervention may also be consistent with the findings of Hatcher et al., although, the achievement level was not as high in the RRI group. In the CARRI group, children at risk most obviously received more focused and intensive drilling in the computer-assisted environment. The finding in the CARRI group is in line with that reported by Beech et al. (1994), who reported that a group of children who followed the computer tracing of letters and named the letters seemed to make better progress than children instructed in a more regular remedial environment. The consistency of the target language might have something to do with the importance of training on the level of phonics. It is noteworthy that phonological skills may not be the most efficient predictors of RDs in transparent orthographies (see, e.g., Aro & Wimmer, 2003). In the present study, 7 months was required for the CARRI group to reach the ceiling level of letter knowledge, while the children in the mainstream group knew 21 of 29 letters already at school entry. The risk children in the RRI and CARRI group needed more time to acquire letter names and letter–sound connections than children who did not have delays in prereading skills. The development of decoding, accurate and fluent reading as well as spelling was also slower in the experimental groups. Although the CARRI group was able to reach the level of the mainstreamers in all tasks by Grade 3, they clearly required more time and practice as well as remedial training to do so. This finding confirms the findings of Lyytinen et al. (2007) that children who do not acquire reading skills as expected during early school instruction need much greater exposure for learning letter names and sounds.

It may be typical for at-risk children and children with RDs to require more training and practice to reach the level of mainstreamers (see, e.g., Torgesen, 2005). However, it seems possible to reach mainstream level with an effective early intervention that includes computerized training in initial prereading skills. Possibly, the training of phonological abilities should start earlier among at-risk children, at least in Finland where children start formal education in the year they reach the age of 7. The idea of an early start has been supported by Elbro and Petersen (2004) who argue that phoneme awareness training with preschool children at risk for dyslexia could be expected to reduce the risk of dyslexia.

Reading Accuracy

Both of the groups studied lagged behind the mainstreamers in the decoding and accuracy tasks in the midterm of the first grade. However, when the reading accuracy test for third graders was carried out, the CARRI group outperformed both groups. Similarly, in the study of Elbro and Petersen (2004) the training effects on reading were manifested in the follow-up tests. It seems that children with low prereading skills require more time for learning to decode than their not-at-risk peers with well-developed phonological awareness and letter knowledge. Early accuracy training should not only be beneficial but also be persistent and progressive among at-risk children and children with RDs. Notwithstanding, most children with RDs are not likely to receive sufficient opportunities to practice decoding skills to a level of fluency that will enable them to read adequately (e.g., Torgesen & Barker, 1995). Nonetheless, it is important to identify and target instruction at the weak areas of child's reading. A computer-assisted intervention is one instrument for raising the profile of remedial reading intervention. Computer applications may provide the kind of individual, motivating, and continuous practice and training in decoding and accuracy that will enable at-risk children to operate sufficiently during the reading process. This may require time a regular intervention regimen ought to be an essential part of daily classroom routines.

Fluency

As in decoding and accuracy skills, there seemed to be delays in the acquisition of fluency. After 9-month training in their respective remedial conditions both experimental groups had gained, but they were still behind the mainstreamers in fluency. However, within a year the CARRI group achieved the level of the mainstream group. A similar achievement span was not seen in the performance of the RRI group. The gradual gains during the follow-ups testify to the fact that children at risk for RDs can reach the level of mainstreamers; however, they require more training and practice than children with adequate reading skills. The findings are particularly significant in the area of fluency. Similar findings were reported in the study by Wise et al. (1999). The results of the present study indicated that at-risk children in the early stages of reading acquisition, who were placed in a remedial reading group enriched with a phoneme-based computer-assisted reading intervention, reached the level of mainstreamers in fluency by the end of the second school year.

The present study raises number of issues relevant to the development of reading skills, such as the extent to which phonological skills should be trained simultaneously with letter–sound connections and the extent to which phonology and reading need to be made explicit in the teaching of reading. Furthermore, notice ought to be taken of the extent to which children differ in the ease with which they acquire decoding. As well as differing in their ability to acquire decoding skill, children may also differ in their propensity and ability to acquire accuracy and their subsequent transition to fluency.

Spelling

The CARRI group reached the level of the mainstreamers in spelling skills by the third grade. It is noteworthy that similar progress was not seen among the children in the traditional remedial reading group. However, an integrated package of letter knowledge and phonological training seemed to improve both reading and spelling skills (Hatcher et al., 1994).

In general, Finnish children seem to acquire accurate decoding skills relatively fast compared to children learning to read in more opaque orthographies (e.g., Aro & Wimmer, 2003; Lerkkanen et al., 2004). However, intensive and individual training is needed for at-risk children to become adequate readers in the Finnish language context. In the present study, the gains made were progressive in both reading and spelling, but the development of these skills was delayed compared to that of the non-at-risk children who needed more training and practice to acquire core reading and spelling skills. The results supported the view (see, e.g., Bentum & Aaron, 2003; Hatcher et al., 2004) that regular remedial reading training alone is not a powerful enough tool for training the basic reading skills of children at risk for RDs up to the level of mainstream children. Remedial education may also fail to provide the kinds of intensive, closely monitored and individualized practice that children with RDs need to attain proper reading skills (see, e.g., Bentum & Aaron, 2003; Torgesen, 2005). According to Torgesen and Barker (1995), the amount of time children actually spend in individualized, carefully supervised practice in reading skills is far from optimal (see also Hatcher et al., 2004; Torgesen, 2005). The CARRI remedial approach used in this study proved to be feasible in the school environment. Bringing computer-assisted reading interventions to resource rooms might be a step toward more effective remedial practices.

In this study, the long follow-up period along with steady and cumulative results indicated educational effectiveness. A CAI itself is considered to be an educationally efficient way of training early literacy skills (e.g., Nicolson et al., 2000). An important finding in the present study was that the children in the CARRI group made gains during the study and continued to progress similarly in the follow-ups. In previous intervention studies, for example, in Nicolson et al. (2000), some children appeared not to profit as much as others from the intervention. In similar vein, some children in the present study needed continuing support. It is for a future studies to investigate variation in individual gains and differences.

Motivational aspects may also affect the results of the present study. Evidence of a bidirectional relation between reading skills acquisition and motivation has been recognized as important factors in the reading development (see, e.g., Morgan & Fuchs, 2007). At-risk children are most likely to benefit from frequent practice but are often unmotivated to read (e.g., Chapman, 1988). This lack of motivation can be seen within a year or so of school entry (e.g., Chapman, Tunmer, & Prochnow, 2000). A game-like computer-assisted reading environment, such as GraphoGame, might reduce that risk. In the computer-assisted environment provided by GraphoGame, a child presumably has a chance to learn to read in a more fun way, which probably enhances willingness to practice reading. By contrast, children who receive less stimuli in their remedial reading practices in RRI tend to find reading laborious and are thus likely to dislike reading and decoding practices (see, e.g., Morgan, Fuchs, Compton, Cordray, & Fuchs, 2008).

There are limitations that should be taken into consideration in any attempt to generalize these results. First, our subjects were middle-class children apparently presenting with some decoding problems at school entry. Many interventions are for children from less advantaged backgrounds and our findings do not apply to them. Second, our sample size was quite small and further replication, especially without research supervision, is warranted before the program is adopted in practice. Third, although Finnish children begin formal schooling in the year a child reaches the age of 7, with adequate teaching the transparency of the Finnish language enables a child to read and spell accurately very rapidly (within a year) compared to children in other languages with more opaque orthographies. Therefore, if they are to be applied more widely, CARRI intervention needs testing among children learning to read in less regular orthography. Finally, both the RRI and CARRI groups were taught by the same remedial reading specialist. This was to avoid possible trainer effects. However, the at-risk children along with the 116 mainstreamers were taught by same class teachers during lessons other than reading. This might have 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. On the other hand, there were 4–5 children in a remedial reading group in each home classroom. Therefore, individual attention from individual class teachers can hardly have been a priority. Also teachers were kept blind to the research group setting and other research practices.

In conclusion, the results indicated that children at risk for developmental reading failure would benefit from a remedial reading intervention that is enriched with the CAI application like GraphoGame in the very beginning of the first grade, at least in an opaque orthography like Finnish. The remedial reading enriched with GraphoGame might reduce the risk of later RDs among at-risk children. The reading and spelling attainment such children should nevertheless be carefully followed until the third grade, to ensure that they who continue to lack success have acquired fluent reading and spelling skills. Furthermore, children still failing to succeed in reading should be provided with individually targeted reading support enriched a computer application, as accurate and fluent reading and spelling skills are the springboard to later academic success.

References

Ahonen, T., Tuovinen, S., & Leppäsaari, T. (1999). *Nopean sarjallisen nimeämisen testi* [The Automatized Serial

Naming]. Lievestuore: Haukkarannan Koulu and Niilo Mäki Instituutti.

Aro, M., & Wimmer, H. (2003). Learning to read: English in comparison to six more regular orthographies. *Applied Psycholinguistics*, *24*, 619–634.

Beech, J. R., Pedley, H., & Barlow, R. (1994). Training letter-to-sound connections: The efficacy of tracing. *Current Psychology*, *13*, 153–164.

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.

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.

Borman, G. D., Slavin, R. E., Cheung, A. C. K., Chamberlain, A. M., Madden, N. A., & Chambers, B. (2007). Final reading outcomes of the national randomized field trial of success for all. *American Educational Research Journal*, *44*, 701–730.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read: A causal connection. *Nature*, *30*, 419–421.

Chapman, J. W. (1988). Cognitive–motivational characteristics and academic-achievement of learning-disabled children—A longitudinal-study. *Journal of Educational Psychology*, *80*, 357–365.

Chapman, J. W., Tunmer, W. E., & Prochnow, J. E. (2000). Early reading-related skills and performance, reading self-concept and the development of academic self-concept: A longitudinal study. *Journal of Educational Psychology*, *67*, 145–152.

Cohen, J. (1988). *Statistical poweranalysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

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., & McCormick, S. (1998). Phases of word learning: Implications for instruction with delayed and disabled readers. *Reading and Writing Quarterly*, *14*, 135–163.

Elbro, C., & Petersen, D. K. (2004). Long-term effects of phoneme awareness and letter name training. An intervention study with children at risk of dyslexia. *Journal of Educational Psychology*, *96*, 660–670.

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.

Finnish Central Statistical Office. (2009). Osa-aikaista erityisopetusta lukuvuonna 2007–2008 saaneet peruskoulun oppilaat erityisopetuksen ensisijaisen syyn mukaan [Students receiving remedial training 2007–2008—according to the primary cause]. Retrieved September 16, 2009, from http://www.stat.fi/til/erop/2009/erop_2009_2010-06-11_tie_001_fi.html

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

Foorman, B. R., Francis, D. J., Fletcher, J. M., Schatschneider, C., & Mehta, P. (1998). The role of instruction in learning to read: Preventing reading failure in at-risk children. *Journal of Educational Psychology*, *90*, 37–55.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. E. Patterson, J. C. Marshall, & M. Colthart (Eds.), *Surface dyslexia neuropsychological and cognitive studies of phonological reading* (pp. 301–330). Hillsdale, NJ: Erlbaum.

Greenberg, M. T., Domitrovich, C. E., Graczyk, P. A., & Zins, J. E. (2005). *The study of implementation in school-based preventive interventions: Theory, research, and practice: Vol. 3* (Draft). Rockville, MD: Substance Abuse and Mental Health Services Administration.

Harrington, R. C., Cartwright-Hatton, S., & Stein, A. (2002). Annotation: Randomised trials. *Journal of Child Psychology and Psychiatry*, *43*, 695–704.

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.

Hatcher, P. J., Hulme, C., Miles, J. N. V., Carroll, J. M., Hatcher, J., Gibbs, S., et al. (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.

Hatcher, J. P., Hulme, C., & Snowling, M. J. (2004). Explict phoneme training combined with phonic reading instruction helps young children at-risk of reading failure. *Journal of Child Psychology and Psychiatry*, *45*, 338–358.

Häyrinen, T., Serenius-Sirve, S., & Korkman, M. (1999). *Lukilasse* [The Lukilasse Graded Achievement Package for comprehensive school age children]. Helsinki: 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.

Jiménez, J. E., Hernández-Valle, M., Ramírez, G., del Rossario Ortiz, M., Rodrigo, M., Estévez, A., et al. (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. (2007). The beginning phases of reading literacy instruction in Finland. In P. Linnakylä & I. Arffman (Eds.), *Finnish reading literacy. When quality and equity meet* (pp. 154–173). Jyväskylä: Institute for Educational Research, University of Jyväskylä.

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.

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

Lovett, M. W., Barron, R. W., & Benson, N. J. (2003). Effective remediation of word identification and decoding difficulties in school-age children with reading disabilities. In H. L. Swanson, K. Harris, & S. Graham (Eds.), *Handbook of learning disabilities* (pp. 273–292). New York: Guilford.

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

Lyytinen, H., Aro, M., Eklund, K., Erskine, J., Guttorm, T., Laakso, M.-L., et al. (2004). The development of children at familial risk for dyslexia: Birth to early school age. *Annals of Dyslexia*, *54*, 184–220.

Lyytinen, H., Aro, M., Holopainen, L., Leiwo, M., Lyytinen, P., & Tolvanen, A. (2006). Children's language development and reading acquisition in a highly transparent orthography. In R. M. Joshi & P. G. Aaron (Eds.), *Handbook of orthography and literacy* (pp. 47–62). Mahwah, NJ: Erlbaum.

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.

Magnan, A., & Ecalle, J. (2006). Audiovisual training in children with reading disabilities. *Computers & Education*, *46*, 407–425.

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

Morgan, P. L., & Fuchs, D. (2007). Is there a bidirectional relationship between children's reading skills and reading motivation? *Exceptional Children*, *73*, 165–183.

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.

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

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

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., & Nicolson, M. K. (2000). Evaluation of a computer-based reading intervention in infant and junior schools. *Journal of Research in Reading*, *23*, 194–209.

O'Donnell, C. L. (2008). Defining, conceptualizing, and measuring fidelity of implementation and its relationship to outcomes in K-12 curriculum intervention research. *Review of Educational Research*, *78*, 33–84.

Posner, M. I., & Rothbart, M. K. (2007). *Educating the human brain*. Washington, DC: American Psychological Association.

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.

Satorra, A., & Bentler, P. M. (1999). *A scaled difference chi-square test statistic for moment structure analysis*. Retrieved February 23, 2006, from http://preprints.stat.ucla.edu/260/chisquare.pdf

Seethaler, P. M., & Fuchs, L. S. (2005). A drop in the bucket. Randomized controlled trials testing reading and math interventions. *Learning Disabilities Research & Practice*, *20*, 98–102.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*, 523–568.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, *55*, 151–218.

Snowling, M. J., Gallagher, A., & Frith, U. (2003). Family risk of dyslexia is continuous: Individual differences in the precursors of reading skill. *Child Development*, *74*, 358–373.

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 November 5, 2008, from http://eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/16/4e/22.pdf

Torgerson, C., & Torgerson, D. (2001). The need for randomised controlled trials in educational research. *British Journal of Educational Studies*, *25*, 129–143.

Torgesen, J. K. (1998). Catch them before they fall: Identification and assessment to prevent reading failure in young children. *American Educator/American Federation of Teachers*, *Spring/Summer*, 1–8.

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

Torgesen, J. K. (2005). Recent discoveries from research on remedial interventions for children with dyslexia. In M. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 521–537). Oxford, UK: Blackwell.

Torgesen, J. K., & Barker, T. A. (1995). Computers as aids in the prevention and remediation of reading disabilities. *Learning Disability Quarterly*, *18*, 76–87.

Vadasay, P. F., Sanders, E. A., & Peyton, J. A. (2006). Code-oriented instruction for kindergarten students at risk for reading difficulties: A randomized field trial with paraeducator implementers. *Journal of Educational Psychology*, *98*, 508–528.

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

Wechsler, D. (1999). *Wechlerin lasten älykkyysasteikko* [Wechsler intelligence scale for children] (Rev. ed.). New York: 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: An Interdisciplinary Journal*, *9*, 163–192.

Wimmer, H., & Mayringer, H. (2002). Dysfluent reading in the absence of spelling difficulties: A specific disability in regular orthographies. *Journal of Educational Psychology*, *94*, 272–277.

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