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An evaluation of the effectiveness of a computer-assisted reading intervention

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Background: A cost-effective method to address reading delays is to use computer-assisted learning, but these techniques are not always effective.
Methods: We evaluated a commercially available computer system that uses visual mnemonics, in a randomised controlled trial with 78 English-speaking children (mean age 7 years) who their schools identified as needing reading support. School-based individual tutorials usually took place 2–3 times/week. Only the experimental group received the intervention in the first 10 months; thereafter, both the experimental and control groups received the intervention for 6 months.
Results: After 10 months, the experimental group had significantly higher standardised scores than the waiting list control group of decoding, phonological awareness, naming speed, phonological short-term memory and executive loaded working memory.
Conclusions: The computer-assisted intervention was effective, and this suggests that this medium can be used for reading interventions with English-speaking children.

What is already known about this topic

- There are comparatively few randomised controlled trial evaluations of computer-based reading interventions.
- Meta-analyses report small positive effect sizes for such interventions with English-speaking children.
- The use of visual mnemonics to improve reading has rarely been investigated.

What this paper adds

- The findings suggest that computer-based interventions for English-speaking, struggling readers can be effective.
- The effects extended beyond the targeted abilities, and a longer intervention was more effective than a shorter one.
- Apart from spelling, the mean reading and reading related standardised scores for children at the end of the intervention were above or just below 100.

Implications for theory, policy or practice

- Computer-based interventions can be used to support English-speaking, struggling readers, and their effects can go beyond targeted abilities.

- The use of visual mnemonics and the development of the intervention programme over a number of years could have contributed to this success.
- The role of visual mnemonics as a help for struggling readers deserves further investigation.

Abbreviations:

BAS	British Abilities Scale
ELWM	executive loaded working memory
PSTM	phonological short-term memory
RCT	randomised controlled trial
TOWRE	Test of Word Reading Efficiency

Education and employment prospects are often impaired in children with delays in reading (Dugdale & Clark, 2008). There is a range of interventions to assist these children (Carroll, Bowyer-Crane, Duff, Snowling & Hulme, 2011). Slavin, Lake, Davis and Madden (2011) have reviewed *non-computer interventions* designed to help struggling readers (see also Blanchman et al., 2014). They concluded that one-to-one tutoring, especially when this involves phonics (i.e., relations between letters and sounds), and involves teachers rather than paraprofessionals, usually is very effective; they also concluded that classroom wide programmes, particularly cooperative learning, can have very positive effects (see also Griffiths & Stuart, 2013). However, these interventions can be expensive in terms of teaching practitioner time. In contrast, computer-assisted interventions offer the possibility of 'expert' instruction at relatively low cost and high fidelity, with advantages such as increased motivation, immediate feedback, self-pacing, consolidation of learning and non-judgemental feedback (Lynch, Fawcett & Nicolson, 2000; Mathes, Torgesen & Allor, 2001; Torgesen, Wagner, Rashotte, Herron & Lindamood, 2010).

However, several reviews suggest that computer-based interventions are not particularly effective. Blok, Oostdam, Otter and Overmaat (2002) concluded that these interventions produced positive but small effects; their review was based on experimental studies, many of which were not randomised controlled trials (RCTs). More recently, Slavin et al. (2011) concluded that 'computer-assisted instruction had few positive effects on reading' (p. 1), and Cheung and Slavin (2012) concluded that there usually were small gains and effect sizes in computer-based interventions, especially when compared with non-computer interventions. Cheung and Slavin (2013) reviewed 20 investigations that met reasonable research rigour (13 of the studies involved randomisation, but 6 did not appear to be peer reviewed). They found that there was only a small positive effect size from a combined analysis of all the studies. Archer et al. (2014) in their tertiary meta-analysis found that overall effect sizes were positive, but small. They also suggested that training and support for practitioners was associated with greater effectiveness, but they were not able to identify particular methods of intervention that were more effective than others. Since the reviews were conducted, there have been a number of reports of positive effects from computer-based interventions (e.g., Hughes, Phillips & Reed, 2013; Kyle, Kujala, Richardson, Lyytinen & Goswami, 2013; Schneider et al., 2016; Tyler et al., 2015; see also Karemaker, Pitchford & O'Malley, 2010), but it also should be acknowledged that other investigations that were not included in the reviews have failed to find significant positive effects (e.g., Brookes, Miles, Torgerson & Torgerson, 2006; Given, Wasserman, Chari, Beattie & Eden, 2008).

Thus, the weight of available evidence suggests that most computer-based interventions are not of substantial help to children with reading difficulties. This raises questions about whether the medium of computer-based education is inherently ineffective with these children. One explanation of these findings is that computer-assisted learning fails because the subject matter does not lend itself to computer support, a very different position to that of technological determinism where it is believed that technology will help education and learning (Oliver, 2010). The absence of strong positive effects also may be part of a common historical cycle, identified by Crook and Lewthwaite (2010), where initial enthusiasms for new educational technology often fail to be supported by empirical evaluations. Consequently, given the range of findings about computer-based interventions, it is important to investigate a diversity of computer-based interventions to establish whether they fail to provide substantial help to children or whether there are techniques and approaches that are effective, an issue that is of considerable importance to practitioners and policy makers.

Another issue concerning computer-assisted interventions is the rarity of rigorous investigations that demonstrate significant improvements with English-speaking children (Campuzano, Dynarski, Agodini & Rall, 2009; Dynarski et al., 2007). Several of the recent reviews of computer-based reading interventions have highlighted the very small evidence base especially when taking into account the potential importance of the topic, the rarity and desirability of RCTs and the small increases in literacy abilities in the meta-analyses. For example, Slavin et al. (2011) only identified 14 relevant studies (three were RCTs). A more extensive review by Cheung and Slavin (2012) concerned 84 studies using computer-assisted applications to support reading in typically developing and struggling readers, but only 16 of these studies appeared to have been subject to peer review and published since 2000. Thus, there continues to be a need for rigorous evaluations such as those provided by RCTs.

Although reviewers have concluded that computer-assisted interventions involving English-speaking children produce small positive effects, there are a number of reports of effective interventions with children who speak other languages. A review by Blok et al., in 2002 indicated that computer interventions involving English-speaking children were more effective than those with non-English-speaking children (mostly Dutch speakers). However, since then a number of computer interventions with non-English speakers have been found to be very effective. These include Finnish (Saine, Lerkkanen, Ahonen, Tolvanen & Lyytinen, 2010; Heikkila, Mikko, Narhi, Westerholm & Ahonen, 2013; Lyytinen, Ronimus, Alanko, Poikkeus & Taanila, 2007), Spanish (Jiménez et al., 2007) and French (Ecalle, Kleinz & Magnan, 2013; Magnan & Ecalle, 2006). Because these non-English languages have more consistent relations between graphemes and phonemes, this may explain their effectiveness in contrast to computer interventions with English-speaking children which face the challenge of inconsistent grapheme–phoneme relationships. This connects with extensive literature about the central role played by letter–sound connections in the development of reading (Hulme & Snowling, 2009). Relevant to this issue, Kyle et al. (2013) successfully implemented a computer intervention that had been found to be effective with Finnish children (Lyytinen et al., 2007); the U.K. intervention involved a fine grained mapping of graphemes to phonemes that may have addressed issues of lack of transparency in English.

A long-standing technique to facilitate letter–sound mappings is the use of visual mnemonics, particularly embedded picture mnemonics, as used in books for initial readers (e.g., the Letterland series, Wendon, 2007; Alphafriends, 2001). The mnemonics contain both an object whose name begins with the target letter (e.g., snake) and an object whose shape can be drawn so that it resembles the target letter (e.g., a snake looks like the letter S). Furthermore, the technique appears to help the learning of letter–sound relationships. Schmidman and Ehri (2010) gave English-speaking children unfamiliar Hebrew letters to compare the benefits of pairing the novel letter with an embedded picture of the letter or a picture of an object whose first letter corresponded to the sound of the letter to be learnt (e.g., a picture of a key when *k* had to be learnt). The embedded pictures were more effective in helping children learn the new letter–sound relations.

The importance of learning letter–sound correspondences suggests that interventions should use mnemonic devices, as these are more helpful than the simple pairing of letters and sounds, although the technique does not appear to have been previously studied in computer-based learning. Partly for this reason, it was decided to investigate an innovative computer-based system for children with reading delays using what is termed Trainertext (Easyread, 2014). At the core of this system is the use of visual mnemonics that appear above the text to supply relevant clues about each phoneme, including long vowels, so that a child can decode words without other help. The visual cues consist of characters that have amusing names, which often provide an extra mnemonic to help remember the phoneme (see Figure 1). This key part of the computer intervention provides scaffolding as children can access the visual mnemonics when they have difficulties decoding a written word, rather than being provided with explicit feedback containing the correct answer (Muis, Ranellucci, Trevors & Duffy, 2015). As children are able to decode words that they would be unable to read without the support of visual mnemonics, they are operating in their zone of proximal development. Furthermore, in Trainertext, visual mnemonics are provided for letters that have both normal and irregular phonetic rules, so the word ‘gas’ has the visual mnemonic of the Ant in Pink Pants available above the ‘a’, whereas the word ‘was’ has the visual mnemonic of the Octopus who Knocked a Puss (or the Ook with a Book in some dialects). In this way, if a word is a barrier to reading, the learner can look above the letter and see, in this case, that the middle sound is /o/.

Although Trainertext is a key process in the intervention we investigated, it contains other activities, such as games, to help with motivation and help consolidate reading-related abilities. In addition, if the system detects signs of a specific cognitive weakness, such as visual tracking a moving target, the teacher is alerted to this with coaching on how to help the child overcome that specific difficulty. Consequently, our investigation involves a question about whether the use of computer-assisted intervention that uses visual

Figure 1. An example of the visual mnemonics used in Trainertext.

mnemonics as a key part of the tutorial process helps the development of reading abilities. In previous research, it has been rare for the effects of reading interventions to be evaluated beyond the key abilities targeted by an intervention (Slavin et al., 2011). In other areas of research, there has been interest in *near* and *far* effects of interventions (Dunning, Holmes & Gathercole, 2013). Consequently, our investigation was designed to assess whether the effects of the intervention extended from targeted reading abilities, to non-targeted reading-related abilities (near effects), or even to more general cognitive abilities (far effects). This methodology provides useful information about the generality of any intervention effects.

Two abilities that were targeted by this computer intervention involved decoding and phonological awareness so that these were seen as key indicators of success. In addition, assessments were made of two near abilities not targeted by the intervention, but may have benefitted from it. These were spelling, which is important aspect of literacy, and naming speed, which is highly related to literacy abilities (Kirby, Georgiou, Martinussen & Parrila, 2010), although there are still uncertainties about the reasons for these associations (Stainthorp, Stuart, Powell, Quinlan & Garwood, 2010). Lastly, it was decided to assess two aspects of the working memory system that are usually seen as less directly associated with decoding. The two were phonological short-term memory (PSTM) and executive loaded working memory (ELWM). These were chosen as it has been suggested that PSTM is a phonological ability associated with reading (Hulme & Snowling, 2009) and EWLM is often impaired in children who have literacy difficulties (Booth, Boyle & Kelly, 2010), with evidence that training in this ability helps children's reading (Loosli, Buschkuehl, Perrig & Jaeggi, 2012).

Thus, our investigation was designed to contribute to the limited evidence base involving RCTs about the effects of computer-based interventions with children who have reading delays. The research questions were the following:

1. Can the decoding abilities of English-speaking children be improved by a computer-assisted intervention that uses visual mnemonics? And is there evidence of an effect of intervention duration?
2. Do any positive effects extend beyond the targeted abilities (decoding and phonological awareness) to near, non-targeted reading-related abilities (spelling and naming speed), and to far abilities involving the working memory system (PSTM and ELWM)?

Method

Design

A RCT was conducted with a pre-test and 13 months later post-test1; during this period, only the experimental group received the intervention, and the waiting list comparison group received teaching and support as normal in the school. Thereafter, both groups received the intervention with the post-test2 assessments 7 months later, allowing evaluation of the effects of shorter versus longer interventions in what has sometimes been termed a dose–response analysis (Morrison & McDonald Connor, 2002; the actual duration of school-based tutorials was slightly shorter because of school holidays).

Similar RCT designs to this with waiting list control groups have been used in a number of important evaluations of reading interventions as it addresses questions about the added value of the intervention beyond any existing and usual support that is available. Moreover, comparing an intervention with 'teaching as usual' does not invariably result in large or lasting effects (Magnan & Ecalle, 2006; Duff et al., 2014). As in previous evaluations, regression analyses were used to investigate group differences (e.g., Hatcher et al., 2006), and effect sizes were calculated so that our findings can be compared with the effectiveness of other interventions.

Participants

Six schools agreed to take part in the research, and this was an opportunity sample. Within each school, the children were randomly allocated to the experimental and control conditions to minimise any effects of school on the findings. The schools were located within Greater London and had mixed socioeconomic status catchment areas. There was no evidence of an overrepresentation of social deprivation in the sample.

All children, who were identified by these schools as needing support because of their poor progress in reading-related activities, were invited to take part (parental permission was first obtained), as a result, the participants corresponded to the target population of concern to many schools. These children were most likely to have delays in decoding, but in some cases, the children may have had other reading-related delays such as poor comprehension, which could have made an intervention, which targeted decoding less effective (Potocki, Magnan & Ecalle, 2015). Details of the children's reading-related abilities are given in the pre-test scores in Table 1; the mean standardised scores were in the low typical range for decoding, phonological awareness, PSTM and ELWM. All the children had percentile scores above 30 on the British Abilities Scale (BAS) II Matrices Scale of nonverbal intelligence (Elliot, Smith & McCullough, 1996).

The identification of children with reading difficulties by the six schools followed U.K. national guidelines involving three levels of need and support. At the levels of *school*

Table 1. Means and standard deviations at pre-test, post-test1 and post-test2 of reading-related abilities in the experimental and waiting list control groups.

		Experimental group			Control group		
		Pre-test	Post-test1	Post-test2	Pre-test	Post-test1	Post-test2
Decoding	Mean	87.2	100.3	101.9	91.1	93.1	97.5
	SD	11.5	12.4	13.8	9.7	11.3	11.2
Phonological awareness	Mean	86.2	94.9	94.7	87.4	89.8	96.0
	SD	7.3	9.5	14.1	6.2	6.5	13.5
Naming speed	Mean	93.7	103.6	103.0	97.6	99.8	101.6
	SD	12.7	12.1	13.1	11.9	13.2	14.8
Spelling	Mean	95.2	95.0	95.3	96.6	95.5	94.5
	SD	11.1	10.2	11.2	12.8	11.9	12.1
PSTM	Mean	90.5	103.1	105.2	88.2	87.6	89.5
	SD	14.9	15.4	17.4	13.8	12.7	13.5
ELWM	Mean	87.0	99.3	104.7	90.2	93.7	97.7
	SD	13.6	14.9	17.2	11.1	13.2	12.1

ELWM, executive loaded working memory; PSTM, phonological short-term memory.

action or *school action plus*, teachers identified children who were making slower progress in reading than their peers. School action involved support within the school, and school action plus involved professionals from outside the school providing additional advice or assistance; no information was systematically collected about the role of these professionals although our impression was very few if any children received additional provision from outside the schools. For some children, clinical assessments had resulted in a formal *statement of special educational need* that constituted the third level. Two additional children were included in the sample because an independent assessment had indicated that they had poor decoding abilities (they had standardised scores on the Test of Word Reading Efficiency [TOWRE] below 86; Torgesen, Wagner & Rashotte, 1999). Five children had initial TOWRE standardised scores above 115; these children took part in the intervention, but were not included in the analyses. The research received approval from the relevant University Ethics Committee, and informed consent to participate in the current study was obtained from parents and from the participants.

At the beginning of the study, there were 57 children in the experimental group and 49 in the waiting list control group. By the end of the study, there were 45 children (27 males) in the experimental group and 33 children (17 males) in the control group (for these groups, the mean age at start of testing was for the experimental group 91.4 months [*SD* 4.5] and for the control group 91.5 months [*SD* 3.9]); the analyses concerned these children. An analysis of variance failed to identify any significant effects on the TOWRE scores at pre-test according to whether or not the children remained in the study or whether or not the children were in the control group.

Assessments

The following assessments were administrated using the guidelines provided by the test manuals. The sessions were conducted by a very experienced assessor in a quiet room at the schools.

Decoding. Decoding was assessed using the TOWRE (Torgesen et al., 1999), a test of the ability to read and pronounce lists of words with accuracy and fluency. There are two subtests, each with two alternate forms (A and B). One subtest assesses the accurate decoding of real words, and the second assesses the decoding of pronounceable nonwords. After the practice items, the children read the test items. Assessment starts when the child reads the first word and ends after 45 seconds. Any words/nonwords skipped or read incorrectly are marked, and only those read correctly are scored. The manual gives the average test–re-test (time sampling) coefficient for the same form and for alternate forms as above 0.90.

Phonological awareness. Phonological awareness was assessed using three tests from the Phonological Assessment Battery (Frederickson, Frith & Reason, 1997). The tests of rhyme and alliteration awareness were used at pre-test and post-test1. The rhyme test involved identifying the two words that rhymed out of a choice of three (one irrelevant word and two that rhyme), and in the alliteration test, the two of the three chosen words needed to have the same beginning sound. The Spoonerism test was used at post-test2 to avoid ceiling effects. There were two tasks. A word was spoken, and the child was asked to replace the beginning sound with another one (e.g., cat with an /f/ gives?); the other task involved transposing the beginning sounds of two words (e.g., King John gives Jing Kohn). The manual reports the internal consistency as being above 0.8.

Naming speed (rapid automatised naming). Naming speed was assessed using a subtest from the PhAB (Frederickson et al., 1997). The children had to name as quickly as possible 50 pictures of 5 objects (e.g., hat, ball and door), which were presented in five rows with there being no discernible sequence to their order. The time taken and any errors were recorded. The internal consistency is reported as being above 0.8.

Spelling. The BAS II Spelling Scale (Elliot et al., 1996) was used to assess the spelling of single words. The experimenter dictated the words one at a time, and the children wrote these down. The words were grouped into age-related blocks of 10, and starting and stopping points are according to age and ability. The manual gives test–re-test reliability as 0.93.

Phonological short-term memory. The word recall test from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001) was used to assess PSTM. Children had to repeat the single syllable words spoken by the experimenter immediately and in the correct order. Children started with a set of six single words; the number of words was increased by 1 until there were three errors within a set. The children's word span was used in the analyses. Test–re-test reliability is reported as 0.8.

Executive loaded working memory. The ELWM was assessed using the listening recall test from the Working Memory Test Battery for Children. The experimenter read a sequence of short sentences, which did, or did not, make sense (e.g., *pineapples play football*). The child said whether the sentence was *true* or *false*. Then the child recalled the final word of the sentence(s) in the correct order. As with PSTM, trials started with single item sequences and increased until there were three errors made within a set. Listening span was used in the analyses. Test–re-test reliabilities of 0.38–0.83 are reported for relevant ages.

Nonverbal intelligence. The BAS II Matrices Scale (Elliot et al., 1996) was used to assess nonverbal intelligence. The child was shown an incomplete abstract matrix; they had to select from six choices, the figure that correctly completed the matrix.

The intervention

The tutorials were usually 10–15 minutes long and usually took place two–three times a week during the school terms. An adult, usually a teaching assistant, was present during the tutorials, which often involved a small group of children (two–three) working on their own individual computer. The adults had taken part in an online training package. A pre-test occurred in October/November of the first year, and a post-test1 occurred 13 months later; during this period, only the experimental group received the intervention. Additionally, both groups could receive the intervention for 7 months after post-test1 and before post-test2. During this second phase of 7 months, the tutorials could be terminated for children in the experimental group if the teachers considered they were no longer necessary; this usually happened if children had made good progress and there were other demands made on the time of teaching assistants. Because of holidays, the children had school-based sessions for 10 months between pre-test and post-test1 and for 6 months between post-test1 and post-test2. In the experimental group, the average number of tutorials between pre-test and post-test1 was 110.2 (*SD* 24.9), the number between post-test1 and post-test2 was 50.2 (*SD* 28.0); in the waiting list control group, the corresponding number was 55.0 (*SD* 15.8).

The intervention and waiting list control groups continued to receive the usual support that the schools deemed appropriate; most of the support involved additional reading-related activities provided by teaching assistants. The intervention was designed to have high fidelity; adults were always present; they checked that the children were engaging in the tasks and that the tasks were completed. Regular visits confirmed that the intervention was administered appropriately.

The core feature of the computer tutorials was the use of Trainertext and interactive, multimedia materials. As already described, different, amusing, visual characters are linked to the same grapheme (see Figure 1). It also should be noted that Trainertext involves an allophonic approach, by giving the children a single character for certain phoneme pairs. An example is the *Star in a car*, to represent the phonemes /s/ and /t/. This type of presentation is different to conventional phonics instruction in the U.K. because it uses implicit instruction (Easyread, 2014) rather than explicit decoding rules.

The tutorial experience involved two key reading activities with Trainertext. This was the time when the facilitator was most likely to provide assistance by overseeing effective decoding of the Trainertext materials and inputting a child's performance into the computer:

Activity 1. Four phrases of five–six words are presented as Trainertext images with no letters, thereby ensuring children decode each word phonetically.

Activity 2. In the next session, children read aloud the same phrases in plain text and can click on letters so as to view the Trainertext mnemonics when needed. An important part of the adult's role is to ensure they are able to decode the word with fluent accuracy. When this is achieved, the children return to activity 1 with a different set of words, and the sequence is repeated for 5–10 minutes. Once the learner has finished these activities, there is a final game, which is randomly picked from 14 different games in the system. The games are fun and provide a reward at the end of the lesson, but also involve some decoding for successful performance. As the adults are working with small groups of children, it is possible to provide individual attention during the important activities as the children were usually progressing at different rates, and it was possible to and/or briefly delay the activities of one child while focusing on another.

Thus, children learn by decoding words for a few minutes each day to establish procedural knowledge (Messer & Pine, 2000). After 95 tutorials, by which time this decoding approach has become very familiar, the amount of text is gradually increased, until the learner is reading around 150 words per day (recorded by the adult facilitator).

The intervention is structured to maximise initial success with, and mastery of, basic reading-related tasks. The first 14 lessons give a foundation with gaming activities to build the child's confidence, particularly in relation to decoding. Then there are reading activities with Trainertext, with a game before and after the activity to help maintain motivation. The early games are simple decoding-related activities to help children become comfortable with these tasks. For instance, children changed a word into another word (e.g., *lamb* to *limb*) by choosing one of several graphemes that are positioned above the word and dragging the grapheme onto the letter that needs to be replaced. The learners are supported through these gamified exercises with audio instructions and affirmations. These are suitably randomised to give a natural feel to the experience. When a mistake is made in one of the gamified exercises, spoken feedback generated by the computer is given to the learner, along with some guidance on completing the task correctly. In most instances, this involves a friendly spoken response (e.g., 'Oops, it wasn't that one') and spoken encouragement from the computer to attend to relevant information.

The computer tutorials involve a multifaceted approach to reading difficulties and are designed to deal with a range of challenges that children can face, such as weaknesses with processing sounds, memory for sounds, fluency, ability to follow a moving target and convergence. The system also has been designed to reduce stress and anxiety about reading. Usually, the progress is monitored centrally so individual assistance can be provided if needed, but no such assistance was provided during the investigation.

Data checking and inspection

The children's nonverbal ability in the two groups as assessed by the BAS II Matrices Scale (Elliot et al., 1996) was similar at the beginning of the study (mean and *SD*; at pre-test, experimental 52.2, 5.6; control 53.8, 4.6; at post-test1, experimental 53.7, 5.2; control 53.7, 5.4). A 2 (groups) × 2 (times pre-test, post-test1) repeated analysis of variance failed to identify any significant effects of group, time or interaction. This suggests that any improvements are not attributable to a change in general nonverbal ability.

For all variables, skewness and kurtosis were within acceptable limits (Field, 2009). Some outliers were identified; therefore, further statistical checks were carried out in relation to the regression analyses (Durbin–Watson, tolerance/VIF statistics and Cook's/Mahalanobis distances); all were within acceptable limits (Field, 2009).

Results

Standardised scores were used as these take account of the effects of age-related improvements. Table 1 shows the standardised scores for the two groups at the three time points. At pre-test, both groups had mean standardised scores on six reading-related abilities that were below those expected for typically developing children. After the intervention, at post-test1, the experimental group had mean scores on most of the assessments that were close to or above 100, and these were maintained over the next 7 months. In contrast, the waiting list control group made little if any progress between pre-test and post-test1. After the control group had experienced the intervention between post-test1 and post-test2, most of standardised scores increased, but not to the levels achieved by the experimental group at either post-test.

A separate multiple hierarchical multiple regression analysis was conducted to investigate whether group had a significant effect on each of the six dependent variables at post-test1, while controlling for initial abilities at pre-test1; this was similar to conducting analyses of covariance (Hatcher et al., 2006; Duff et al., 2014). In each of the six regression analyses, BAS matrices T-score was entered at step 1 to control for general cognitive ability. The standardised score at pre-test of the relevant independent variable was entered at

Table 2. Statistics from the six multiple regression analyses on reading-related abilities at post-test1 with stepwise entry of scores at pre-test from BAS matrices, the relevant independent variable and group.

Variables	Adjusted R^2	R^2 change at steps 1–3			Standardised betas		
		Step 1 (BAS matrices)	Step 2 (relevant independent variable)	Step 3 (group)	BAS matrices	Relevant independent variable	Group
Decoding	0.67	0.01	0.49***	0.17***	−0.07	0.79***	−0.42***
Phonological awareness	0.58	0.17***	0.28***	0.12***	0.21*	0.60***	−0.35***
Rapid naming	0.54	0.00	0.48***	0.07**	0.03	0.73***	−0.26**
Spelling	0.73	0.05	0.69***	0.00	0.12	0.86***	−0.03
PSTM	0.40	0.01	0.20***	0.20***	0.06	0.41***	−0.54***
ELWM	0.47	0.05	0.35***	0.08**	0.02	0.66***	−0.28**

BAS, British Abilities Scale; ELWM, executive loaded working memory; PSTM, phonological short-term memory.
*$p < .05$.
**$p < .01$.
***$p < .001$.

step 2 to control for pre-intervention ability and autoregressive effects (e.g., when the post-test1 TOWRE scores were the dependent variable, the pre-test TOWRE scores were entered at step 2 to control for initial abilities). Group was dummy coded and entered at step 3 to investigate whether the intervention resulted in group differences in reading-related abilities.

A summary of these regression analyses is provided in Table 2. The adjusted R^2 values indicate that the three independent variables entered into each of the six regression analyses together accounted for a reasonably high percentage of the variance of the dependent variable (range 0.4 to 0.7). At step 1, the matrices T-score assessment only was a significant predictor of phonological awareness and was not a significant predictor of any of the other dependent variables; this indicates nonverbal ability was not an important influence on most of the dependant variables at post-test1. In contrast, all the pre-test variables entered at step 2 resulted in a significant R^2 change; this is to be expected, as initial abilities often are the best predictor of the same later abilities because of autoregression. At step 3, group resulted in a significant reduction in R^2 in five analyses, the exception being spelling; this shows that after taking account of BAS matrices ability and initial ability, the experimental group still had a significant effect on five of the post-test1 scores (decoding, phonological awareness, naming speed, PSTM and ELWM). The size and significance levels of the standardised beta coefficients at step 3 confirmed that our findings were not simply the result of the order of entry of the variables.

A second set of regression analyses was conducted for each of the six dependent variables to investigate whether the longer exposure to the intervention in the experimental group resulted in higher gains. In each regression, the dependent variable was either the gains of the experimental group between pre-test and post-test1 or the gains of the waiting list control group between post-test1 and post-test2. The time points for the experimental group were chosen because there were no appreciable increases in the standardised scores between post-test1 and post-test2. The entry of variables into each regression was the same as in the previous analysis.

The adjusted R^2 values were lower than in the previous analysis indicating that it was more difficult to predict gain scores from the three independent variables. The findings from adjusted R^2 change and beta coefficients gave a consistent picture (see Table 3). BAS matrices were not a significant predictor of any of the gain scores, as in the previous analyses, this suggests that nonverbal ability was not an important influence on the children's gains. Nor were the pre-test scores of the dependent variable particularly good predictors of the gain scores, only pre-test rapid naming and pre-test spelling were significant predictors of the relevant gains. This suggests that the sizes of the gains were not related to the initial reading-related abilities. Group, and therefore length of intervention (10 versus 6 months), was a significant predictor of decoding, rapid naming, PSTM and ELWM. Consequently, for these variables, the intervention with a longer duration and more sessions appears to have been significantly more effective than the shorter intervention.

To provide information about the effect sizes of the increases in reading-related abilities, we calculated Cohen's *d* for the gain scores relevant to the two regression analyses (see Table 4). Between pre-test and post-test1, apart from spelling, there were large effect sizes, most above 0.80, indicating that the intervention was highly effective in changing the children's abilities; the highest effect sizes were for decoding and phonological awareness. In the comparison of the interventions that were of

Table 3. Statistics from the six multiple regression analyses with the dependant variable consisting of the gains scores for the experimental group over 10 months and for the waiting list control groups over 6 months (see text for further details).

Variables	Adjusted R^2	R^2 change at steps 1–3			Standardised betas		
		Step 1 (BAS matrices)	Step 2 (relevant independent variable)	Step 3 (group)	BAS matrices	Relevant independent variable	Group
Decoding	0.20	0.01	0.04	0.17***	−0.07	−0.13	−0.42***
Phonological awareness	0.09	0.03	0.04	0.03	0.09	0.21	−0.16
Rapid naming	0.24	0.02	0.12**	0.10**	−0.13	−0.30**	−0.32**
Spelling	0.07	0.02	0.05*	0.00	0.18	−0.23*	−0.06
PSTM	0.08	0.01	0.00	0.08*	0.05	−0.08	0.29*
ELWM	0.13	0.00	0.04	0.08**	0.01	−0.18	−0.29*

BAS, British Abilities Scale; ELWM, executive loaded working memory; PSTM, phonological short-term memory.
*$p < .05$.
**$p < .01$.
***$p < .001$.

Table 4. Effect sizes on group differences in reading-related abilities using Cohen's *d* on (i) gain scores for pre-test to post-test1 and (ii) gain scores for experimental group pre-test to post-test1 compared with control group post-test1 to post-test2.

Variables	Both groups Pre-test to post-test1	Experimental pre-test to post-test1 cf. control post-test1 to post-test2
Decoding	1.34	0.97
Phonological awareness	1.03	0.27
Rapid naming	0.84	0.80
Spelling	0.15	0.13
PSTM	0.90	0.69
ELWM	0.80	0.65

ELWM, executive loaded working memory; PSTM, phonological short-term memory.

different lengths (i.e., experimental group between pre-test and post-test1 versus control group between post-test1 and post-test2), there were large effect sizes for the improvement of the TOWRE and rapid automatised naming, with medium effect sizes for PSTM and ELWM; there were negligible or no effects for phonological awareness and spelling.

Discussion

The investigation has provided evidence that English-speaking children considered by their schools as in need of support for their reading can benefit from computer-assisted learning. After the children in the experimental group received an intervention for 10 months, they had mean standardised scores on a range of reading-related abilities that were close to or above 100, and these scores were maintained over the next 7 months. Consequently, the intervention appeared to have overcome the Matthew effect where children fail to catch up with their typically developing peers.

The first regression analysis revealed that between pre-test and post-test1, the children in the intervention group had significantly higher scores than the waiting list control group in decoding, phonological awareness, naming speed, PSTM and ELWM. The differences were present despite the earlier entry of nonverbal ability and the relevant pre-test ability into the regression to control for initial abilities and autoregression effects. Furthermore, the effect sizes for the gains between pre-test and post-test1 were large (except for spelling). This indicates that the intervention had a significant impact on the reading of the children, and these effect sizes were much higher than those generally reported in reviews (e.g., Cheung & Slavin, 2013; Slavin et al., 2011).

A comparison of the gains made by the two groups revealed that a longer 10-month intervention had more extensive and significantly higher gains in reading-related abilities than the 6-month intervention. This effect could have been due to a longer period for the consolidation of skills, or the higher number of sessions or the intensity of the sessions. This increases our confidence in the findings of the RCT analysis as there appears to have been a 'dose-related' increases. Previous informal observations suggest that there needs to be several sessions a week for the Easyread system to be effective and that noticeable gains occur between sessions 60 and 90. Somewhat surprisingly, phonological awareness failed to show an effect of duration, suggesting that the shorter intervention was equally effective as the longer one. As the standardised scores of phonological awareness at the end of both interventions remained in the mid-90s, this may reflect a difficulty in increasing children's phonological abilities even with longer interventions (Hulme & Snowling, 2009).

Our investigation also showed that the intervention had effects on near and far reading-related abilities. To our knowledge, this has not been shown before with this range of variables (Cheung & Slavin, 2013). Decoding and phonological awareness were specifically targeted by the intervention, and as might be expected, these showed the largest effect sizes in the comparison of groups between pre-test and post-test1. There were mixed findings for the two near abilities that were not directly targeted by the intervention (naming speed and spelling). The intervention group had significantly higher naming speed than the control group at post-test1. Because the intervention did not focus on speed-related tasks, the improvements might have been because children became more efficient at accessing phonological material and/or translating visual stimuli into a phonological form. It is also worth noting that Torgesen et al. (2010) have reported positive effects of a computer intervention on naming speed with children in the United States, however, Heikkila et al. (2013) failed to produce a similar effect with Finnish children.

Spelling was the only variable not to show a significant group difference at post-test1. This was unexpected as decoding and spelling are closely associated (e.g., Christopher et al., 2012) and the failure could be due to several possibilities including the relatively high standardised scores for spelling at pre-test and the need for lengthy consolidation before decoding gains translate into spelling gains. In addition, improvements in decoding may not necessarily translate to spelling (Hughes et al., 2013) and even computer interventions that target spelling have not been successful (Bishop, Adams, Lehtonen & Rosen, 2005).

There were significant improvements in the two components of the working memory system that constituted far abilities. The increase in PSTM could have been because the learning of letter–sound relationships helped the accurate storage of words. This in itself is notable as few previous interventions have been able to increase PSTM abilities (Hulme & Muir, 1985; Henry, Messer & Nash, 2014). There also was a significant effect of group on ELWM. Given the interest in finding ways to improve ELWM, these findings deserve further attention (Melby-Lervåg & Hulme, 2012). ELWM involves the simultaneous processing of current information and the storage/retrieval of other information; consequently, it seems likely that the intervention had an effect on ELWM because the computer tasks often involved having to simultaneously process two forms of visual information (graphemes and mnemonic devices) as well as the concurrent retrieval of phonological information from memory. So as to assess whether these effects extend beyond the verbal domain and involve a general effect on ELWM, future research should include assessments of nonverbal ELWM (Pimperton & Nation, 2014).

The overall success of the intervention contrasts with many previous investigations and the general conclusions from reviews about computer-assisted interventions (Cheung & Slavin, 2012). Consequently, our findings indicate that it is possible for computer-assisted interventions to have significant effects on English-speaking children's reading-related abilities. This adds to the existing evidence that some computer-based interventions can be effective with these children. It is useful to speculate about the reasons for the effectiveness of the intervention as this can provide a basis for further research and for software developments. The most obvious possibility for the success of the intervention was the novel use of visual imagery/mnemonics involving Trainertext to help children remember the relationship between graphemes and phonemes and thereby assist decoding in the presence of a supportive adult. There is broad agreement that this mastery of the phonetic coding is a crucial aspect of the development of reading, that this mastery is particularly problematic in English (Slavin et al., 2011), and computer interventions can effectively target phonological abilities (Comaskey, Savage & Abrami, 2009; Wild, 2009). A similar technique to Trainertext has been used in books for beginning readers (e.g., the Letterland series), but this system goes beyond a single relationship between a letter and sound that occurs in many readers (e.g., the ‘s’ sound in snake), to provide for the same letter, different visual mnemonics when the letter can be pronounced in different ways in different words. In addition, previous findings suggest that interventions involving phonological awareness are more effective when these are associated with the use of letters than when confined to speech processes (Ehri et al., 2001) and other interventions that use different methods to address the diversity of grapheme–phoneme relations in English have been effective (Hughes et al., 2013; Kyle et al., 2013). Therefore, as the Trainertext technique is different from conventional phonics instruction, it deserves further evaluation.

There also are several *general* features of the intervention, in addition to Trainertext, that might have resulted in the increase in children’s reading-related abilities. Because the computer tutorials have been developed over 12 years in the light of feedback and observations, they have been fine-tuned to make the learning experience enjoyable, motivating and effective. Related to this, several of the successful interventions for non-English-speaking children have been the result of a sustained programme of research and interventions (e.g., Ecalle, Kleinz & Magnan, 2013; Lyytinen et al., 2007). It also is possible that because this computer system is designed to provide support for a range of literacy-related impairments that this contributed to its effectiveness. Furthermore, the relatively long 10-month duration and the number of sessions of the experimental intervention and of the 6-month period between post-test2 and post-test3 are also likely to have enhanced their effectiveness, and it should be noted that these are higher than in many other interventions. However, some interventions over similar periods have failed to produce significant gains (Cheung & Slavin, 2013), so it is unlikely that simply the duration and number of session were the main reason for the improvements.

A limitation of the study was that there was no assessment of reading comprehension (Lysenko & Abrami, 2014). However, related to this, it is worth noting that the intervention had significant effects on decoding and ELWM; these often are regarded as key to reading comprehension abilities (Cain, Oakhill & Bryant, 2004; but see Pimperton & Nation, 2014). Consequently, it would be worth investigating reading comprehension in future research, although there are mixed findings about the effects of interventions designed to increase this ability (Paul & Clarke, 2016; Savage et al., 2013). Another limitation was that the evaluation of the dose–response effect did not involve the same time period and so findings about this effect should be treated with caution, especially as the comparison did not involve a RCT.

To summarise, this evaluation has shown that computer-assisted interventions can be effective with children identified in need of literacy support. There are several features of the intervention that might have contributed to this success: the duration of the intervention, the fine-tuning of the tutorials over a long period and perhaps most importantly the use of visual mnemonics in the form of Trainertext. This investigation has also provided new information on the important of the duration of interventions and the way that they can influence a range of near and far reading-related abilities.

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