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Computer-assisted learning in young poor readers: The effect of grapho-syllabic training on the development of word reading and reading comprehension

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A R T I C L E I N F O

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A B S T R A C T

Two experiments examine the effects of two computer-based interventions, one with grapho-syllabic training (GST) and another with grapho-phonemic training (GPT) on the development of word recognition and reading comprehension in French children during Grade 1 and Grade 2. In Exp 1, poor readers ($N = 27$) in second grade were selected and divided into three equal groups, one GST group, one GPT group and a control group. After the session training (10 h), the children from the grapho-syllabic training group outperformed their counterparts in word reading. In Exp 2, poor readers in first grade ($N = 18$) were divided in two groups, a GST group and a GPT group. Six sessions were conducted in order to examine the possible long-term effect of training (10 h) during 16 months. The results revealed an effect of grapho-syllabic training on silent word recognition, word reading aloud and reading comprehension. A computer-assisted learning (CAL) system based on the syllable, which is considered to be the phonological and orthographic unit that is used by French young readers, could be a promising tool to help poor readers decode words and consequently boost their word recognition and reading comprehension capabilities.

1. Introduction

The present study examined in a first experiment the short-term effects and in the second experiment the long-term effects of two computer-based interventions, one using grapho-syllabic units and the other grapho-phonemic units, on the development of word reading and reading comprehension in French children during Grades 1 and 2.

1.1. The two components of reading

The purpose of reading is to extract meaning from a text. However, many children fail to achieve this goal and the data reported over the last decade indicates that between 12% and 15% of primary school children have reading difficulties (OECD, 2004). Moreover, the standardized Program for International Student Assessment (PISA) conducted by the OECD (Organization for Economic Cooperation and Development) in 2009 revealed that 19.7% of French 15-year-old pupils have a literacy reading proficiency below level 2 (out of 6) (OECD, 2010)[1].

Two components are usually considered to be involved in the activity of reading (Aaron, Joshi, Gooden, & Bentum, 2008). The recognition of written words which is specific to reading consists of establishing a correspondence between the orthographic, phonological and semantic representations of a word in order to access the representation of it stored in the mental lexicon. The other component, which is not specific to reading, refers to the semantic and syntactic processes that are involved in the processing of sentences, as well as the higher-level processes that contribute to the integration of all the textual information in a single, coherent representation which makes it possible to construct a mental model of the read text. In "*The Simple View of Reading*" (Gough & Tunmer, 1986), reading is described as the product of the interaction between the word recognition and the comprehension process.

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[1] "Some tasks at this level 2 require the reader to locate one or more pieces of information, which may need to be inferred and may need to meet several conditions. Others require recognising the main idea in a text, understanding relationships, or construing meaning within a limited part of the text when the information is not prominent and the reader must make low level inferences" (ibid, p. 47).

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In normally reading children, the recognition and comprehension processes are linked: Written comprehension performance depends on word recognition performance. During normal learning to read, the automation of the recognition processes gradually frees up cognitive resources which then become available for comprehension (Perfetti, 1985). Some authors have suggested that a single word recognition and decoding deficit is responsible for comprehension difficulties (Torgesen, 2000). According to this hypothesis, slow or imprecise word recognition processes are thought to impair comprehension (Perfetti, Marron, & Foltz, 1996; Wolf & Katzir-Cohen, 2001). In studies conducted to identify predictors of reading comprehension, decoding ability has been found to account for the greatest amount of the variance in reading comprehension performance, especially in young or struggling readers (Vellutino, Tunmer, Jaccard, & Chen, 2007).

1.2. Phonological decoding: an essential procedure for the reading of words

One well-known model of reading acquisition is Share (1995) and (1999) phonological decoding and self-teaching hypothesis. In this model, Share argued that phonological decoding, or the translation of print into sound, functions as a self-teaching mechanism that facilitates the acquisition of orthographic representations. Share hypothesized that these orthographic representations are necessary for quick and independent skilled word recognition. Share's model has three components. The first of these lies in the developmental role of print-to-sound translation and is dependent on the frequency of exposure to words. The second is the increasing influence on phonological decoding of the print lexicon from which children acquire regularities that go beyond letter-sound correspondences, including morphemic boundaries. The third component is the involvement of two processes, phonological and orthographic, that contribute autonomously to the acquisition of skilled word recognition. In proposing his hypothesis, Share stressed that throughout reading development, the phonological component is primary and the orthographic dimension is secondary. Phonological awareness is an oral language skill that forms the basis for phonological decoding, i.e. the phonological skill described by Share (1995) and (1999).

Ehri's (2005) approach represents another prominent model of reading development in which, as in Share's (1995) and (1999) model, phonological awareness and orthographic knowledge constitute the core skills. According to this model, children pass through a series of qualitatively different phases as they learn to read. During Ehri's last phase, which is known as the consolidated alphabetic phase and is typical of readers, children begin to recognize letter patterns that recur in different words and apply this knowledge to help them read words. During this period, letter-sound associations become consolidated into larger units. Our hypothesis is that the syllable is a widely used unit in French. Two evidence-based arguments can be produced in support of this hypothesis: (a) the syllable is an oral unit that is available to French children at a very early age (Duncan, Colé, Seymour, & Magnan, 2006; Goslin & Floccia, 2007) and (b) the syllabic unit is used by French first graders during word recognition (see below).

1.3. The importance of mapping between letter patterns and sounds

The two-way links between the ability to process and manipulate word sounds, or phonological skills, and learning to read have been well documented (for a review, see Castles & Coltheart, 2004; Ziegler et al., 2010). The different phonological skills are not homogeneous in nature and evolve within a developmental continuum (Anthony & Lonigan, 2004) in which it is possible to distinguish between two developmental strands: the units that are processed (syllables, phonemes) and the processing that is performed (manipulation of the unit at a greater or lesser level of cognitive cost). The learning of the alphabetic code is based on the ability to break words down into phonemes. Many different ways of training phonemic analysis have been developed in order to facilitate the learning of this code.

In support of this view, a meta-analysis of 52 experimental training studies found the overall effect size of phonological awareness instruction on reading to be moderate ($d = .53$) (Ehri, Nunes, Willows, Schuster, Yaghoub-Zadeh, & Shanahan, 2001; National Reading Panel, 2000). However, training in phonological awareness has generally been shown to be more effective when it is combined with the teaching of reading (Bradley & Bryant, 1983). This view is also supported by the findings of the National Reading Panel which reported that the mean effect size on reading of training that explicitly established letter associations ($d = .67$) exceeded that of phonological awareness training used in isolation ($d = .38$).

Since the publication of the results of the meta-analysis conducted by Ehri et al. (2001), systems designed to assist in learning to read have explicitly focused on the links between orthographic and phonological units. To date, numerous studies have focused on intensive training programs administered individually or in small groups and involving letters sounds correspondences (e.g., Byrne & Fielding-Barnsley, 1995; Levy & Lysynchuk, 1997; Magnan, Ecalle, Veuillet, & Collet, 2004; Magnan & Ecalle, 2006; Ecalle, Magnan, & Calmus, 2009a; Santa & Hoien, 1999; Torgesen, Wagner, & Rashotte, 1997). Moreover, a connectionist simulation has been performed in order to examine the effectiveness of this type of training. Comparing a series of training simulations, Harm, McCandliss, and Seidenberg (2003) observed that the most effective measure consisted of focusing on the correspondences between graphemes and phonemes. The simulated data was found to be compatible with the behavioral data and indicated that the most effective techniques were those based on the matching of orthographic and phonological units. Much experimental software has therefore been developed with the aim of enhancing both the level of phonological skills and grapho-phonological correspondences.

1.4. Audio-visual training with poor readers

Recent advances in computer-aided learning (CAL) environments offer new support in the task of reading acquisition. Digitized, high-quality synthetic speech is incorporated in programs designed specifically to address phonological awareness and issues related to letter-name and letter-sound knowledge, phonological decoding, and spelling, and provide support for word decoding and comprehension during the reading and writing of stories. Computer speech, along with interesting graphics, animation, and speech recording capabilities, has made it possible to develop programs that children find highly motivating (Mayer & Moreno, 2002). Numerous studies have investigated the use of computer-based training as an aid to reading instruction (for reviews, see Blok, Oostdam, Otter, & Overmaat, 2002; MacArthur, Ferretti, Okolo, & Cavalier, 2001). Moreover, Torgesen (2004) clearly showed that intensive grapho-phonological training administered individually over a short period has a greater effect than long-term training programs.

Many programs both include phonological awareness activities and provide practice in the learning of sound-symbol correspondences. McCandliss, Beck, Sandak, and Perfetti (2003) examined the reading abilities of children with deficient decoding skills in the levels following first grade, and traced their progress over 20 sessions of a decoding skills intervention program called Word Building. At the start of the program, the children exhibited deficits in decoding, reading comprehension and phonemic awareness skills. The intervention directed attention to each grapheme position within a word by means of a procedure involving the *progressive minimal pairing* of words that differed by one grapheme. In English, Macaruso, Hook, and McCabe (2006) showed that the software products *Phonics Based Reading* (PBR) and *Strategies for Older Students* (SOS) (Lexia Learning Systems, 2001) had a positive effect on written word identification in children in the first year of primary school. Segers and Verhoeven (2005) demonstrated the effects of training software on riming skills and graphemic knowledge in both native and immigrant children in the Netherlands. In Spanish, Jiménez et al. (2007) have assessed the effects of different spelling-to-sound units (whole word, phoneme, syllable, onset-rime) on computer speech-based reading for the remediation of children with reading disabilities. The results indicated that there was an improvement in the phoneme and syllable conditions in phonological decoding (word and pseudoword reading). More recently, in a study involving Finnish children in Grade 1, Saine, Lerkkanen, Ahonen, Tolvanen, and Lyytinen (2010) showed that a computer-assisted intervention program focusing on grapho-phonological connections (*GraphoGame*) is a valuable tool for the remedial teaching of children at risk of reading failure.

All of these studies have revealed the effectiveness of early grapho-phonological training in the school environment (1st and 2nd years of primary school) on the abilities of poor readers. To be effective, this type of training must: (1) focus specifically on phonological abilities and the assembly route (audio-visual training); (2) be conducted in small groups or individually; (3) be explicit, repetitive, intensive and provide positive reinforcement.

The training methods presented above are underpinned by knowledge acquired from fundamental research which, however, has not been conducted among French-speaking populations. Inter-language studies have revealed an effect of language on the nature of grapho-phonological decoding. "*Grain size theory*" (Ziegler & Goswami, 2005) explains the inter-language differences observed during learning to read. This theory takes account of the interaction of two factors that are liable to influence learning to read, namely the *regularity* of the grapheme–phoneme correspondences and the *size* of the psycholinguistic units (the granularity). While the links between orthography and phonology are fundamental in all alphabetic languages, the size of the units involved differs from language to language. The difficulty as far as learning is concerned lies in the fact that the units that are most salient at the phonological level are also the largest units (syllable, rime) whereas the orthographic units that are the easiest to remember are small in size (letters, graphemes). Ziegler and Goswami (2005) describe learning to read as a process of convergence on an optimum mapping between written and spoken words. The speed of learning depends on the effectiveness and level of automation of this coupling. Arguments based on a series of experiments (Colé, Magnan, & Grainger, 1999; Chetail & Mathey, 2009; Doignon & Zagar, 2006; Ecalle, Magnan, Bouchafa, & Gombert, 2009b; Maïonchi-Pino, Magnan, & Ecalle, 2010a, 2010b) suggest that, in French, the correspondences between the written and oral modes are established via syllabic units. Consequently, intensive training in grapho-syllabic segmentation should help French poor readers identify written words more easily than grapho-phonemic training.

Our general objective was to test the effectiveness of two computerized reading support systems which are appropriate for addressing the phonological decoding difficulties encountered by children who are poor readers. Whereas grapho-phonemic training should stimulate phonological decoding at the level of small units, grapho-syllabic training should be more efficient in boosting the ability to decode words on the basis of larger units. In fact, in French it is easier, or less costly, to decode words on the basis of syllables (mar + di to mardi, *Thursday*) than on the basis of letter-sound correspondences (m + a + r + d + i). Secondly, once decoding skills and, consequently, word recognition are well developed, cognitive resources will be freed up and available for the reading comprehension process.

Two experiments were conducted, the first one as a pilot study with second graders with reading difficulties to examine the potential impact of grapho-syllabic training. In fact, Colé et al. (1999) gave evidence of a syllabic processing in word reading only in good readers at the end of Grade 1. So, in Experiment 1, the aim was to determine whether a software based on grapho-syllabic training is efficient in French poor readers in Grade 2 in comparison with two groups, a grapho-phonemic training group and a control group. In Experiment 2, the aim was to examine the long-term effect of grapho-syllabic training proposed to French 1st graders and followed to the end of second grade. Evolution of performance in word reading and reading comprehension was compared with a grapho-phonemic training group.

2. Method

2.1. Experiment 1

A classical training design involving three phases (pre-test, training, post-test) was used to compare the short-term progress of three groups of poor readers in 2nd grade sharing the same reading level at pre-test. The first group received audio-visual training in grapho-syllabic segmentation; the second group received audio-visual training in phonemic discrimination, while the third (control) group performed conventional classroom reading activities. We predicted that training in grapho-phonological correspondences should help reinforce decoding skills in children independently of the unit they are required to process in a word (i.e. grapho-syllabic training or grapho-phonemic training). We therefore predicted that the reading skills of the two groups of children receiving computer-assisted (CA) training based on the simultaneous presentation of orthographic and phonological units would improve more than those of the children in the control group.

2.1.1. Participants

Twenty-seven 2nd grade poor readers were selected from a population of 110 children attending three primary schools. The children who were selected were those who had obtained the lowest scores in the standardized word recognition test (Timé2; Ecalle, 2003; see below in Experiment 2 for a description). They had normal or corrected-to-normal vision and audition abilities and no intelligence deficiency. They were randomly divided into three groups, an experimental group which received CA grapho-syllabic training (GST), a group receiving CA grapho-phonemic discrimination training (GPT) and a control group that received conventional classroom reading instruction without any CA training. The children in the control group did not receive any other special intervention. They were included in the study as a benchmark to

Table 1
Mean chronological age and mean reading scores for the three groups before the training phase at *t*0.

Groups	*N*	Chronological age mean (SD)	Reading scores (/36) mean (SD)
GST group[a]	9 (2g + 7b)[c]	92m (3m)	23.2 (4.6)
GPT group[b]	9 (1g + 8b)	91m (3m)	22 (4.4)
Control group	9 (1g + 8b)	93m (4m)	22.8 (5)

[a] GST: grapho-syllabic training group.
[b] GPT: grapho-phonemic training group.
[c] Girl; boy.

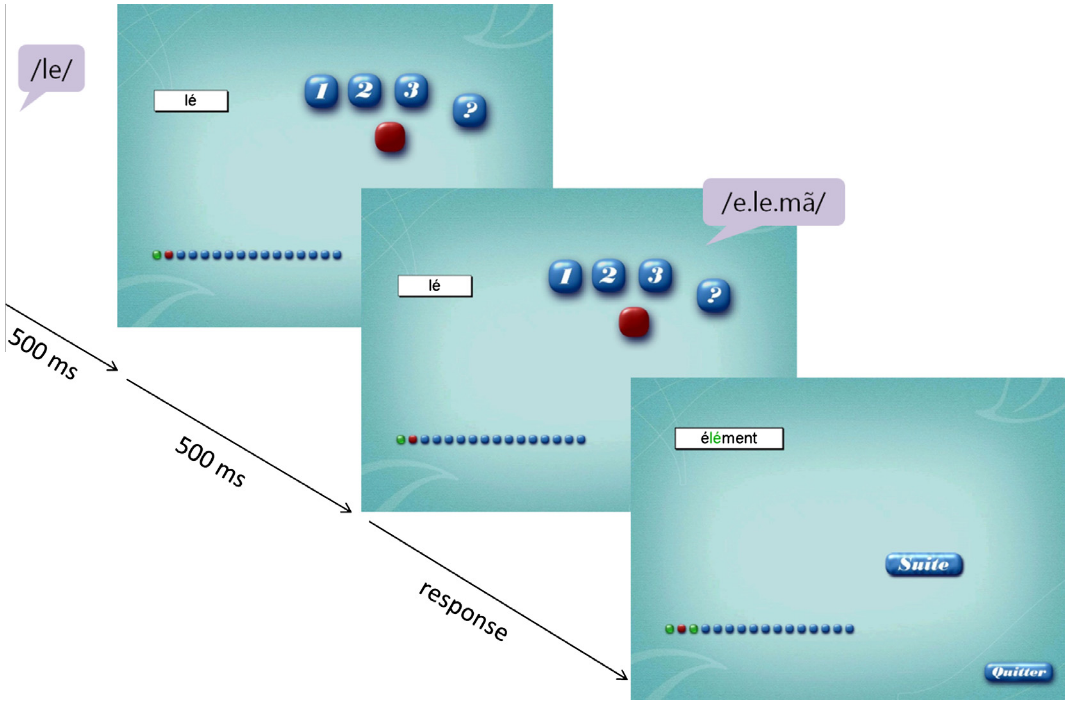

Fig. 1. Screenshots of software used in the grapho-syllabic training group.

enable us to compare the improvement in the reading skills of the trained children (see Torgesen and Davis, 1996). The groups were strictly matched on age and reading level (see Table 1) just before the training phase.

2.1.2. Pre- and post-test

A word reading aloud task was administered before and after the training period. This task is intended to connect letters and sounds. The children had to read out 30 words, 10 from the grapho-syllabic software, 10 from the grapho-phonemic software and 10 from the Odédys French reading test version 2 (Jacquier-Roux, Valdois, & Zorman, 2005). The dependent variable was the number of correctly read words. Internal consistency coefficient[2]: .90.

2.1.3. Training

During the training phase, the trained groups worked with two different CA programs. The "Chassymo" software (Ecalle, Magnan, & Jabouley, 2010) encouraged grapho-syllabic word processing: The children first heard a syllable, then saw the syllable 500 ms later and finally heard a word after another 500 ms (see Fig. 1). They had to use the mouse to click on the number corresponding to the seen and heard syllables in the word (initial, median, final) or click on a red button if the syllable was not present in the word. If they were not able to answer, they could click on a question mark.

Corrective feedback appeared on the screen: The word was displayed with the syllable highlighted in green. An indication of response quality was presented at the bottom of the screen. If the answer was correct, a green dot appeared in the progress bar, while a red dot was displayed if the answer was wrong and a yellow dot if the pupil had clicked on the question mark.

Moreover, the linguistic material used in the Chassymo software was carefully controlled. It consisted of 24 lists of 25 words, making a total of 600 words. Half of the items were bi-syllabic words (12 lists) and the other half were tri-syllabic words (12 lists). The 12 lists of bi-syllabic words each consisted of 5 items having consonant–vowel-type syllables (CV), 5 with CCV-type syllables and 2 with CVC-type syllables. The 12 tri-syllabic lists were controlled in the same way. The series were rated from 1 to 5 as corresponding to words from high to low frequency in the MANULEX database (Lété, Sprenger-Charolles, & Colé, 2004). During training, each child saw all the experimental material which was randomly presented.

The "Oppositions Phonologiques" software (Revy, 2005) trained the children in grapho-phonemic word processing. This program encourages word identification, on the one hand, and visual and auditory phoneme discrimination, on the other. Two words differing by one phoneme appeared on the screen (for example /bɔʁ/ vs. /pɔʁ/; see Fig. 2).

The children heard one of the two words and had to click on the corresponding written word. The correct word was highlighted in green and corrective feedback was provided: If the answer was correct, a green dot and an "*Exact, bravo!*" message appeared on the screen, otherwise a red dot was output and the message "*inexact*" was displayed. Ten types of phonological oppositions could be chosen: p/b, t/d, c/g, ch/j, f/v, b/d, m/n, ou/u, p/t or s/z. For each type of phonological opposition, approximately 50 pairs of words were presented. The pupils saw a total of 500 different pairs, presented in a random order.

In the two CA groups, each child was equipped with headphones and sat alone in front of a computer screen. An assistant was present to help any children who experienced a technical problem with the computer and/or the software. The children were trained for 30 min, 4 days a week over a period of 5 weeks (February–March in Grade 2). They therefore received a total of 10 h of training.

2.1.4. Results

An ANOVA was performed on the scores with Group as a between-factor (grapho-syllabic training vs. grapho-phonemic training vs. control group; GST, GPT, contG), and Session as a within-factor (pre-test, $t0$ and post-test $t1$). We expected to observe a Group $*$ Session interaction which would indicate that the

[2] Split-half reliability measures were calculated at pre-test.

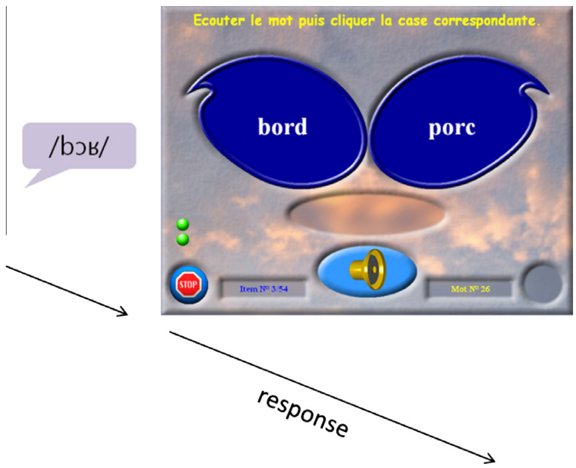

Fig. 2. Screenshot of software used in the grapho-phonemic training group.

performance of the grapho-syllabic training group had progressed more than that of the grapho-phonemic training group and of control group. We then calculated Cohen's *d* between sessions to obtain the effect size in each group.

We observed a significant Group effect, $F(2, 24) = 5.96$, $p = .008$, $\eta_p^2 = .33$, (GST: mean = 25.5; GPT: 21.1; contG: 24.4), a significant Session effect, $F(1, 24) = 7.43$, $p = .01$, $\eta_p^2 = .24$ ($t0$: 22.9; $t1$: 24.5) and a significant interaction Group * Session, $F(2, 24) = 5.95$, $p = .008$, $\eta_p^2 = .33$ (Fig. 3). Post hoc tests (Tukey) revealed that only performance in GST significantly differed ($p < .05$) from session 1 to session 2. The Cohen' *d* were 1.82 in GST group, 0.53 in GPT group and −0.41 in control group.

2.1.5. Discussion

In this Experiment, three groups of French 2nd graders with reading difficulties were formed and two of these were trained with two different software programs. While a first group received grapho-syllabic training, the second group received grapho-phonemic training. The third group was a control group. After the session training, the children from the grapho-syllabic training group outperformed their counterparts in the grapho-phonemic training group and in the control group in the word reading aloud task. This result was not totally in line with our predictions as far as we expected better performance in grapho-phonemic training group than in control group at *t*2. This pilot study showed that grapho-syllabic training seems more efficient in comparison to grapho-phonemic training and to a control group without any specific intervention. This was encouraging to conduct a second experiment to examine the long-term effect of grapho-syllabic training on word reading and reading comprehension.

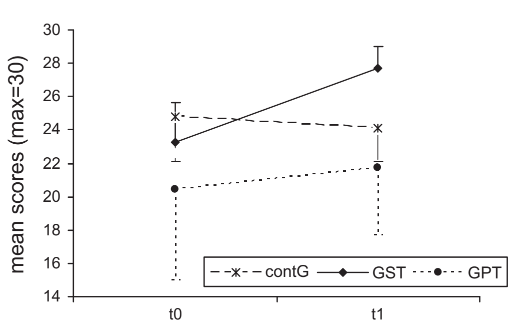

Fig. 3. Mean scores in word reading aloud at pre- (*t*0) and post-test (*t*1) in the three groups, one with grapho-syllabic training (GST), one with grapho-phonemic training (GPT) and the control group (contG).

2.2. Experiment 2

The same design was carried out with again three phases: After a pre-test and a session training, five post-tests were administered to examine the possible long-term effect of grapho-syllabic training.

2.2.1. Participants

Eighteen poor readers in first grade were selected from a large population of 101 children attending five primary schools in urban areas. All the children were French-speaking. They were from low and medium SES backgrounds and had no specific problems. They had normal or corrected-to-normal vision and no neurological deficits or overt physical handicaps. To perform the selection, a standardized word reading test (Timé2; Ecalle, 2003; see below for a description) was administered to the 101 children and only the 18 with the lowest scores were retained (from 4 to 16/36 correct responses). For all the children, agreement to participate was obtained from their parents, education authorities, the school principal and teachers.

The selected children were divided into two equal groups: one group (four girls and five boys; mean age: 6 years 6 months) which received grapho-syllabic training and another (five girls and four boys; mean age: 6 years 9 months) which received grapho-phonemic training. Just before the training phase, the two subgroups were strictly matched on age, reading scores (correct responses and errors obtained in the standardized word recognition test) and cognitive level by means of a non-verbal intelligence sub-test, similar to the well-known Raven matrices, taken from an academic achievement battery (ECS-2; Khomsi, 1997).

The word recognition test, which was group-administered, comprised three forced-choice tasks calling on silent word reading abilities: in the first task, the target words were named by the examiner; the second consisted of pictures; and the third took the form of a semantic categorization task in which the children had to associate two words. In each of the tasks, the target word was present in a list of five items consisting of the orthographically correct word (e.g., *bateau*, boat), and four pseudowords, namely a homophone (*bato*), a visually similar item (*baleau*), an item sharing the same initial letters (*batte*) and an item containing an illegal letter sequence (*btaeua*). Thirty-six target words were proposed (12 in each task). The children had to find the target in each list. The dependent variable was the number of correct words. Internal consistency coefficient: .82.

The word recognition test allowed us to match the groups precisely on reading abilities and no less than five indicators were used. At pre-test, no significant difference between the two groups was observed in terms of chronological age, word recognition test or performance in the non-verbal intelligence test (Table 2).

2.2.2. Pre- and post-tests

Two other tasks (in addition to the standardized test) were administered: The same word reading aloud task as in Experiment 1, listening comprehension and reading comprehension. Six sessions were required in order to examine the possible long-term effect of training during Grades 1 and 2 (G1, G2): A pre-test session (G1-February; *t*0) just before the training phase, and five post-test sessions, one in G1-April (just after training; *t*1), one 2 months later in G1-June (*t*2), one 4 months later in G2-October (*t*3), one 4 months later in G2-February (*t*4) and the last one 4 months later in G2-June (*t*5). The children were assessed on word reading, text comprehension, and listening comprehension at *t*0 and reading comprehension from *t*1 to *t*5.

2.2.2.1. Listening comprehension. This task was administered to control for the level of comprehension before training. The

Table 2
Mean scores (standard deviations) for the two groups before the training phase at $t0$.

	Age[a]	Word recognition test (/36)					LC (/28)	nvInt (/15)
		CW	Ho	Vs	Sil	Ils		
Grapho-syllabic training	78.4 (3.2)	10 (3)	7.2 (3)	6.9 (2.8)	5.3 (1.7)	5.6 (2.9)	17.9 (3.6)	4.8 (1.6)
Grapho-phonemic training	81.2 (3.3)	9.8 (3.1)	7.7 (1.5)	5.8 (1.9)	6.9 (2.8)	5.3 (1.3)	19 (2)	5.3 (2.1)

[a] Chronological age in months; CW: correct word, Ho: pseudoword homophone, Vs: pseudoword, visually similar, Sil: same initial letters, Ils: pseudoword with an illegal letter sequence; LC: listening comprehension; nvInt: non-verbal intelligence.

participants individually completed a short version of the French ECOSSE test (Lecocq, 1996) which was constructed on the basis of the TROG (Test for the Reception of Grammar; Bishop, 1983; 2003). During this task, the children heard a sentence and were asked to choose one picture out of four which represented the situation described in the given sentence (max = 28). Internal consistency coefficient: .82.

2.2.2.2. Silent word reading. This forced-choice task (Timé2; Ecalle, 2003) has already been presented in the Participants section. The dependent variable used in the analyses was a composite score involving the orthographically correct word and the pseudoword homophone. This composite score has the advantage of taking account of both the level of the orthographic lexicon and the participants' ability to use the phonological procedure when the correct response was not provided. Internal consistency coefficient: .81.

2.2.2.3. Word reading aloud. The same task was administered as in Experiment 1. Internal consistency coefficient: .91.

2.2.2.4. Reading comprehension. A standardized test (Khomsi, 1999) was used to assess this ability: The children had to read a sentence written under four pictures and they were asked to choose one picture out of four which represented the situation described. The maximum score was 20. Internal consistency coefficient: .76. Because the children were poor readers with difficulties in word recognition, this task was not administered at $t0$.

2.2.3. Training

During the training phase, the groups worked with the two CA programs presented above. The training was set up in the same conditions as in Experiment1. Each child was equipped with headphones and sat alone in front of a computer screen. An assistant was present to help any children who experienced a technical problem with the computer and/or the software. The children were trained for 30 min, 4 days a week over a period of 5 weeks (February–March in Grade 1). They therefore received a total of 10 h of training.

2.2.4. Results

An ANOVA was performed on the scores in the three tasks with Group as a between-factor (grapho-syllabic training vs. grapho-phonemic training; GST vs. GPT), and Session as a within-factor (pre-test, $t0$[3] and post-tests $t1$, $t2$, $t3$, $t4$, $t5$). We expected to observe a Group $*$ Session interaction which would indicate that the performance of the grapho-syllabic training group had progressed more than that of the grapho-phonemic training group. We then calculated Cohen's d between sessions to obtain the effect size in each

[3] No reading comprehension scores were available for this session. Consequently, only the scores for the five post-test sessions from t1 to t5 were introduced in the ANOVA.

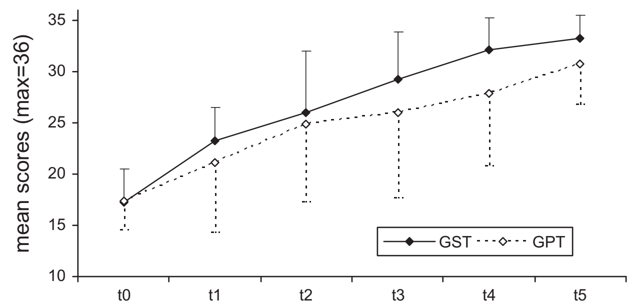

Fig. 4. Mean scores (with standard deviations) in silent word reading for the six sessions in the grapho-syllabic training (GST) group and the grapho-phonemic training (GPT) group.

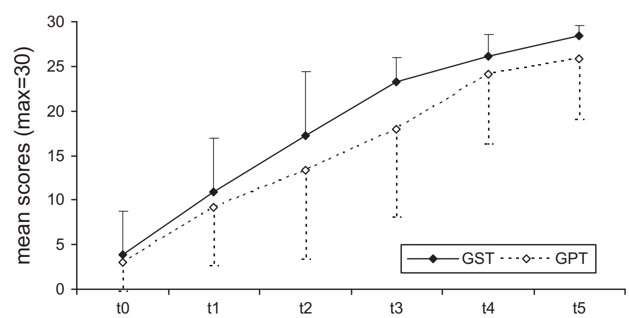

Fig. 5. Mean scores (with standard deviations) in word reading aloud for the six sessions in the grapho-syllabic training (GST) group and the grapho-phonemic training (GPT) group.

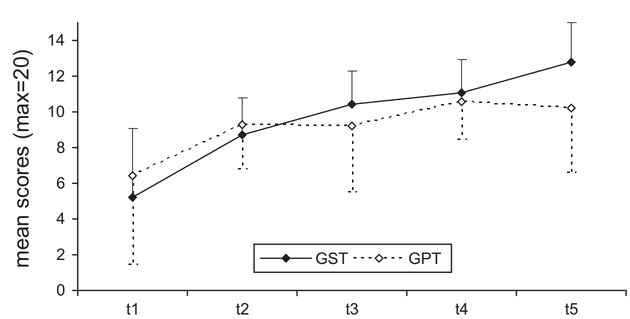

Fig. 6. Mean scores (with standard deviations) in reading comprehension for the five sessions in the grapho-syllabic training (GST) group and the grapho-phonemic training (GPT) group.

group as well as a global effect size measuring the long-term impact of training from $t0$ to $t5$.

Development of performance in each group (with means and standard deviations) are presented in Fig. 4 (silent word reading task), Fig. 5 (word reading aloud), and Fig. 6 (reading comprehension). In the *silent word reading* task, the ANOVA run

Table 3
Effect sizes (Cohen's *d*) in the two training groups between sessions.

Group	Grade 1			Grade 2		
	*t*0–*t*1 (2m)[a]	*t*1–*t*2 (2m)	*t*2–*t*3 (4m)	*t*3–*t*4 (4m)	*t*4–*t*5 (4m)	*t*0–*t*5 (16m)
Silent word reading						
GST	2.63	1.09	1.82	1.67	1.28	6.28
GPT	0.83	1.4	0.32	0.93	1.07	4.64
Word reading aloud						
GST	2.55	3.36	1.86	2.2	1.79	6.96
GPT	2	2.02	1.93	1.43	0.92	6.14
Reading comprehension						
GST	–	1.57	1.01	0.76	1.79	4.12
GPT	–	0.87	−0.03	0.46	−0.49	1.09

[a] Months; GST: grapho-syllabic training group; GPT: grapho-phonemic training group.

on composite scores showed a significant effect of Session, $F(5, 80) = 45.83$, $p = .0001$, with the scores increasing from *t*0 to *t*5 (17.3, 22.2, 25.4, 27.6, 30, 32.1). We observed (Fig. 4) that the standard deviations fell from *t*3 onwards in the GST group unlike in the GPT group in which the standard deviations remained high. Moreover, the effect sizes were greater in the GST group (except between *t*1 and *t*2) than in the GPT group (Table 3). Globally, from *t*0 to *t*5 the effect size due to training was greater in the GST group (6.28) than the GPT group (4.64).

In the *word reading aloud* task, the ANOVA revealed only a significant effect of Session, $F(5, 80) = 100.52$, $p = .0001$, with the scores increasing from *t*0 to *t*5 (3.4, 10.1, 15.3, 20.6, 25.1, 27.2). Again, we observed a fall in the standard deviations in the GST group from *t*3 onwards (Fig. 5). The effect sizes were greater in the GST group (except between *t*2 and *t*3) than in the GPT group (Table 3) and higher between *t*0 and *t*5 in the GST group (6.96) than the GPT group (6.14).

In the *reading comprehension* task, the ANOVA was run on the scores obtained for the 5 sessions from *t*1 to *t*5. Again it revealed only a significant effect of Session, $F(4, 64) = 14.15$, $p = .0001$, with the scores increasing from *t*1 to *t*5 (5.8, 9, 9.8, 10.8, 11.5). At *t*1, the mean score did not differ significantly from chance level ($p > .05$). From *t*3 onwards, we again observed a fall in the standard deviations in the GST group compared to those of the GPT group (Fig. 6). The effect sizes in the GST group were considerably higher than in the GPT group (Table 2) and, more specifically, a greater effect size was obtained between *t*1 and *t*5 in the GST group (4.12) than in the GPT group (1.09).

Finally, no interaction Group $*$ Session was revealed in each task. None of the post hoc tests between consecutive sessions was significant in each group.

2.2.5. Discussion

Two groups of poor readers in 1st grade, matched on reading level, chronological age and non-verbal intelligence were trained with two softwares. The group which was trained with the grapho-syllabic software outperformed (but no significantly) the other group trained with grapho-phonemic software, in the two word reading tasks and more, in reading comprehension. Even though no significant interaction Group $*$ Session was observed, with regard to effect size (Cohen's *d*), grapho-syllabic training seems to be more efficient than grapho-phonemic training.

3. Conclusions

When children start to learn to read, they have to develop the ability to decode words that are mostly unknown to them. Phonological decoding is a self-teaching procedure that helps boost the orthographic lexicon which, in turn, makes it possible to use the direct lexical route during word reading (Share, 1999). When word recognition is properly automated, cognitive resources are freed up and more attention can be paid to text comprehension.

It is well known that teaching the alphabetic code, i.e. the letter-sound correspondences, is essential. Ehri's model (2005) states that after the full alphabetic phase, which is promoted through the teaching of letter-sound correspondences, children recognize words on the basis of letter patterns in a final phase, the so-called consolidated alphabetic phase. The nature of the linguistic units involved in word recognition depends on the language (Ziegler & Goswami, 2005). In French, numerous experimental studies have shown that the relevant letter pattern is the syllable which is a salient unit used in word recognition (e.g., Maïonchi-Pino et al., 2010a). Based on this earlier work, Ecalle et al. (2009) performed a long-term study of French poor readers in 1st grade which provided evidence that a CA training program based on grapho-syllabic word processing was more efficient than a CA training program based on whole word recognition.

The present study with two experiments extends this previous work by comparing two software programs, one of which used the grapho-syllabic unit and the other the grapho-phonemic unit in order to stimulate the decoding procedure and consequently word reading. We expected that word reading would improve more in response to grapho-syllabic training, on the one hand, and that reading comprehension would be more efficient in this training condition, on the other.

In Experiment 1 as a pilot study, poor readers in 2nd grade significantly obtained the best performance in word reading after the training session in comparison to the two other groups. Grapho-syllabic training contributes more in word reading development than grapho-phonemic training, in comparison to a control group which did not receive any specific intervention.

In Experiment 2, even though the conventional ANOVAs did not reveal any significant Group $*$ Session interaction, there are still three important main results: (1) the effect sizes underline the impact of grapho-syllabic training in the three tasks, namely silent word recognition, word reading aloud and reading comprehension, (2) the inter-individual differences diminished in the grapho-syllabic training group as of the beginning of Grade 2 (*t*3) compared to the grapho-phonemic training group in which the standard deviations remained high and stable throughout all the sessions, and finally (3) the effect of the grapho-syllabic software on reading scores seemed to increase from *t*4 (see Cohen's *d*). This latter finding indicates that the training program which used the syllable as a unit to boost phonological decoding, word reading and consequently reading comprehension had a delayed impact. In the case of reading comprehension, this delayed impact was more evident at *t*5. It would therefore be possible to hypothesize that word recognition is more automated in the grapho-syllabic training condition which frees up cognitive resources for reading comprehension. This hypothesis could be tested in future research by including the time to read words as an indicator of reading fluency.

In Section 1, we emphasized the importance of the mapping between letter patterns and sounds as a reinforcement to decoding. Audio-visual training using computer-assisted learning seems to be more effective as an aid in reading instruction. Software developed on the basis of the syllable, which is considered to be a phonological and orthographic unit that is rapidly acquired by French young readers, could be a promising tool to help poor readers learn to decode words and consequently boost their word recognition abilities. Further studies with larger samples will have to be conducted in order to confirm these findings. It would also be interesting to investigate the profiles of the children who benefit from grapho-syllabic training and those who do not. For example, it would be possible to hypothesize that a minimum amount of letter-sound knowledge would permit the effective use of grapho-syllabic training in poor readers. Another question relates to the way the children interact with the software. To examine this issue in more detail, it might be useful to investigate children's conative behavior during training sessions, i.e. the extent to which they are motivated by the training task. Finally, it is now well documented that some readers have specific comprehension difficulties even though they possess a normal word reading level (Hulme & Snowling, 2011; Oakhill & Cain, 2007). In this case, specific software should be provided for poor comprehenders whatever the modality in which the sentences or text are presented, i.e. orally (for listening comprehension) or visually (for reading comprehension). Further research is being conducted into this topic.

CAL in the form of the grapho-syllabic training program presented in this study could be used either within the framework of or as a complement to conventional classroom reading activities, either in school or at home (see Magnan & Ecalle, 2006; Experiment 3). Children nowadays are not only familiar with computers but are usually also highly motivated to use computer technology. CAL techniques which highlight phonological and orthographic syllables in printed words should therefore be developed in order to optimize the reading acquisition process, reinforce decoding skills, automate word recognition, and consequently facilitate reading comprehension (only in the case of children who do not experience difficulties in listening comprehension). Under these conditions, CAL should be considered to be one of the pedagogical devices available to combat reading difficulties at an early stage at the beginning of learning to read in order to reduce the high percentage of poor readers among adolescents revealed by OECD survey (2010).

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