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Audio-visual training in children with reading disabilities

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Abstract

This study tested the effectiveness of audio-visual training in the discrimination of the phonetic feature of voicing on the recognition of written words by young children deemed to at risk of dyslexia (experiment 1) as well as on dyslexic children's phonological skills (experiment 2). In addition, the third experiment studied the effectiveness of this word recognition training in dyslexic children who regularly used a computer at home. A traditional pre-test, training, post-test design including comparison groups (experimental vs. control) provided a base-line for assessing the training effects. In the three experiments the intervention group showed higher increases performances in phonological skills and phonological recoding than the control group did. Beyond providing evidence for the effectiveness of this audio-visual training, these results contribute to an understanding of the nature of reading difficulties and successful training. Globally, the results show the impact of the audio-visual training about voicing on performances of reading-disabled children. A such type of training leads children to connect print and phonology. Phonological representations could be specified by training which involves both phonological and orthographic units. The mapping between these two units could be easier in a computerized remedial program.

Keywords: Elementary education; Evaluation of CAL systems; Improving classroom teaching; Pedagogical issues

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1. Introduction

Bartram (1994) has observed that the use of computer-aided learning is increasing in the fields of cognitive psychology and education. The arguments in favor of the use of multimedia-based software in education and training are extensive (Perzylo, 1993). Research on emergent literacy has shown that such interactive activities can impact on children's oral and written language development (Yaden, Rowe, & MacGillivray, 2000).

The core question in this paper is whether such claims can be justified with specific reference to the development of reading skills? More precisely, the aim of the present study is to examine whether computer-based reading can promote phonological awareness and reading acquisition both in young children deemed to at risk of dyslexia and dyslexic children.

Three studies were conducted using a recently developed audio-visual training program (Danon-Boileau & Barbier, 2002) which has already been experimentally studied (Magnan, Ecalle, Veuillet, & Collet, 2004). The main finding of this earlier study was that dyslexic children's word recognition performance improved significantly after training. The aim of the present research is to evaluate the effectiveness of this audio-visual training in different educational contexts. The claims concerning the educational benefits of multimedia software are positive but largely untested (Underwood, 2000). The first study investigates the use of audio-visual training in kindergarten children. In the second study, we examine the impact of the training proposed in a specialized classroom on the performances of dyslexic children in phonological tasks. The third study explore dyslexic children's experience of computer-aided reading use both at home and in school. To introduce this research, issues relating to reading acquisition and the significance of phonological awareness for reading are reported, followed by a review of studies of software designed to improve children's reading skills.

1.1. Cognitive precursors of literacy development

There is substantial evidence that phonological processing is an important precursor of reading acquisition. The literature on the relationship between phonological skills and early reading is considerable (Castles & Coltheart, 2004 for a recent review; Goswami, 1999; Seymour, L.G, & Bolik, 1999). More precisely, phonemic awareness is an important source of variability in reading (Bradley & Bryant, 1978; Brady & Shankweiler, 1991). Phonemic awareness is defined as the ability to isolate and manipulate the segments of speech at the level of the single phoneme (Morais, 2003). For example, we measured how well children were able to delete a spoken phoneme (phoneme deletion task) from a spoken word (e.g. /r/; /prot/•/pot/). Phonemic awareness is strongly correlated with word-reading skills, particularly in young children (Wagner, Torgesen, & Rashotte, 1994). Furthermore, phonemic awareness is deficient in most children with a specific reading disability (Rack, Snowling, & Olson, 1992). Evidence of the central role of phonemic awareness in reading suggests that early interventions must massively support phonemic awareness (Blachman, 1997).

Numerous findings (see for example, Sprenger-Charolles, Siegel, & Béchennec, 1998; Sprenger-Charolles et al., 2000) suggest that learning to read requires the child to construct a system of connections between the letter strings of printed words (orthography) and the phonemic sequences that make up spoken words (phonology). The learning of grapheme–phoneme correspondences is the basis of reading in alphabetic systems. Snowling (2000, 2001) among others has shown that many dyslexics fail to develop adequate phonological skills and, more precisely, that they exhibit difficulties in recognizing printed words. The hypothesis that a phonological deficit plays a central causal role in developmental dyslexia is today widely accepted (Ramus, 2003). One hypothesis proposed to explain the reading difficulties of dyslexic children is that they come to the task of learning to read with poorly specified phonological representations (Swan & Goswami, 1997). Thus, a specific impairment in the representation of the constituent sounds of speech affects the learning of grapheme–phoneme correspondences (Brady & Shankweiler, 1991).

Consequently, the phonological deficit in dyslexic children may be partly due to impairments in the phonetic organization of phonemes. There is evidence that dyslexics may have a poorer categorical perception of certain phonemic contrasts, as in/ba/ versus/da/ (Adlard & Hazan, 1998; Mody, Studdert-Kennedy, & Brady, 1997; Serniclaes, Sprenger-Charolles, Carré, & Démonet, 2001). Indeed, dyslexic subjects exhibit an impairment in speech perception tasks (e.g. ba/da discrimination) which specifically focus on the sub-lexical phonological level.

1.2. Computer-aided learning and reading

Computer-assisted instruction is a relatively new and promising approach for learning phonemic awareness (Torgesen & Barker, 1995). The learning value of the computer-based tuition of early reading skills has recently been investigated (Chera & Wood, 2003; Hecht & Close, 2002; Segers & Verhoeven, 2002). The main features of computers that are relevant to teaching phonemic awareness include spoken instructions by a high-quality digitized voice, corrective feedback, high quality graphics and the gamelike presentation of training (Mioduser, Tur-Kaspa, & Leitner, 2000). Determining whether phonemic awareness training will be of value for any given child is a difficult matter because very little is known about variability in response to the training (Torgesen, 2000).

Many studies of computer software have shown its potential to enhance phonological awareness in children with reading difficulties. The existing literature has shown that segmented speech feedback is often effective in increasing phonological awareness (Olson, Wise, Ring, & Johnson, 1997; Van Daal, Reitsma, & Van Der Leig, 1994). These studies have compared children who have been exposed to different forms of speech segmentation (whole word feedback or segmented word (onset-rime) feedback). The most common method of training phonological skills (Mitchell & Fox, 2001; Wise, Ring, & Olson, 1999) involves different sub-lexical units such as rime, syllable or phoneme.

However, the results of research designed to train children in phonological awareness in order to improve their reading ability have been mixed. Some computer-based interventions have not proved to be particularly successful. For instance, Olson et al. (1997) and Wise and Olson (1995) both report improved phonological awareness but poor results in word recognition.

In a previous experimental study, Magnan et al. (2004) demonstrated the impact of the audiovisual training of voicing on the performances of dyslexic children in a word reading test. This type of training leads children to connect print and phonology. Thus, the phonological impairment of voicing which characterizes dyslexic children might be alleviated by means of audio-visual training which requires children to process the phonetic features both in the visual and auditory modalities. Phonological representations could be specified by training involving both phonological and orthographic units. The mapping between these two units could be made easier if implemented in a computerized remedial program.

This interpretation is consistent with other studies. The impact of phonological awareness training on phonological awareness and reading skills has been examined in two recent quantitative meta-analyses (Bus & van Ijzendoorn, 1999; Ehri et al., 2001). They demonstrate that speech-only approaches have only a minimal impact on reading abilities. The results of the meta-analyses conducted by Ehri et al. (2001) show that the scale of the reading improvement effect after phonological awareness training with letters was roughly twice that obtained using similar speech-only activities. The assumption that the presence of letters might serve to anchor perceptually elusive phoneme sounds has been advanced (Adams, Treiman, & Pressley, 1998). Thus, specific training in grapheme–phoneme associations might directly impact reading abilities.

In this study, we hypothesize that specific audio-visual training supporting phonetic feature perception could help children with reading disabilities to specify phonemic representations. Accordingly, they should not confuse phonemes with similar voicing features and this could facilitate their written word processing. To our knowledge, no computer-based training using the simultaneous presentation of phonological units with orthographic units has been used with children with reading disabilities and we further hypothesize that audio-visual training will boost matching between visuo-orthographic patterns and phonological units.

1.3. The audio-visual training of voicing

This audio-visual method is part of the "Play-On" program developed by Danon-Boileau and Barbier (2002). This training focuses on the voicing opposition between two items in six pairs of phonemes: /p/-/b/; /t/-/d/; /k/-/g/; /f/-/v/; /s/-/z/ et /ch/-/j/. Three types of items are used: mono-, bi- and tri-syllabic. The position of the phoneme is manipulated (initial vs. final). The participants listen to a CV syllable (/pa/) and decide between two printed alternatives (*pa* or *ba*) differing only in their voicing. Immediately after the participants have listened to the syllable, a basket-ball falls from the top of screen and the child presses one of two keys (left or right) to place the ball in the basket corresponding to *pa* or *ba*.

The child, who is wearing headphones, is placed in front of the computer screen. Initially, the ball appears red or green (see Appendix A). These are the colors of the baskets and, consequently, the children can resolve the task only on the basis of color. After this familiarization phase, the falling ball is always gray and the child is able to discriminate on the basis of the stimuli. No corrective feedback is given. However, the ball appears green or red again for five further trials whenever the child makes a mistake.

In this program, only joystick control is required, thus allowing kindergarten children to use the program without difficulty. The keyboard may be used with older children. Actions by the user are monitored and appropriate responses are given by the computer using a feedback system.

Using the audio-visual program, the child can work independently of the teacher, who is then free to devote attention to other children. The user is presented with the instructions by a high-quality digitized voice.

2. Experiment 1: Kindergarten children deemed to at risk of reading failure and computer-assisted reading

When children enter the first year of primary school (first grade) it is already apparent that they differ in levels of emergent literacy skills (Whitehurst & Lonigan, 1998). Phonemic awareness is the best predictor of early reading skills (Hulme et al., 2002).

The aim of this first study was to examine how five year-old children from kindergarten can acquire initial reading skills by means of computer-assisted practice. The main difference between past studies and this present study is the nature of the sample, i.e., most previous studies focused on older children with reading difficulties and few have examined computer-based reading practice in young children. However, two studies have reported that phonemic awareness training has a positive effect on average levels of phonemic awareness among kindergarten children (Foster, Erickson, Foster, Brinkman, & Torgersen, 1994; Reitsma & Wessling, 1998). Kindergarten children with poor phonologicals skills are more likely to develop reading and spelling impairments. In this experiment, we study the effect of the audio-visual training of voicing on a word recognition task among children with phonological disabilities.

2.1. Methods

2.1.1. Participants

Sixty seven children from a kindergarten (mean age 5.4 years; range: 5.5–5.9) were tested in order to identify a group of children with poor phonological awareness. A screening battery consisting of phonological tasks such as unit common detection, tapping, judgment of phonological similarity (see Ecalle & Magnan, 2002 for a detailed presentation) and teacher questionnaires was designed to select the children. A phonological score was measured (max = 40) and the 16 children with the poorest phonological skills were included in the present study. The scores of the experimental group (mean score = 7.5) and the control group (mean score = 10.5) did not differ significantly, $t(14) = 1.51$, $p = 0.15$. All the pupils regularly used a computer at school.

2.1.2. Design and procedures

The participants individually performed a test designed to access word recognition. The eight children with the poorest decoding skills (mean: 11.4) were assigned to an experimental group (mean age: 5.6 years; range: 5.1–6.1) and the others (mean: 14) were assigned to a control group (mean age: 5.8 years; range: 5–6). A significant effect of group was observed on decoding performance (see later).

The children in the control group received no special intervention. In line with the Torgersen and Davis study (1996), a control group was included in this study primarily as a benchmark against which to compare changes in the results obtained from the training group. Training was administered for a period of five weeks, four days a week. Each training session lasted 20 min.

The trained children received the computer-assisted tuition as part of their normal classroom routine for five weeks. The control group received the traditional teaching method. During the training periods, all the children were not exposed to any other phonological training program. The teachers were already familiar with the principles on which the audio-visual program was based and were therefore able to incorporate the software easily in their regular classroom activities.

2.1.3. Tests

The aim of these tests was to examine phonological recoding skills. In a word recognition test, a forced-task choice was used in which the children had to find a target word among five items consisting of the orthographically correct word (e.g., lapin, *rabbit*), and four pseudowords, namely a homophone (lapain), a visually similar item (lapiu), an item sharing the same initial letters (laver) and an item containing an illegal letter sequence (lpina). Two types of words were presented, small functional words (et, de, dans, avec, etc...) and familiar words (lapin, pomme (*apple)*, etc...). The target words were presented in two conditions: orally for functional words and with a picture for familiar words. The target word and homophone scores were combined to create a composite phonological coding score (max: 32).

2.2. Results

An Anova was conducted on the results with the between-factor Group (control vs. experimental) and the within-factor Testing session (t1 vs. t2). We observed no effect of Group ($F < 1$) and a significant effect of session, $F(1,14) = 11.82$, $p < 0.004$, $\eta^2 = 0.46$, performances were higher in second testing session. This revealed also a significant interaction between group and testing session, $F(1,14) = 4.26$, $p < 0.058$, $\eta^2 = 0.23$. This interaction is shown in Fig. 1. In testing session 1, the pattern of results differed between groups, with the control group outperforming the experimental group, $F(1,14) = 11.42$, $p < 0.004$, $\eta^2 = 0.45$. No difference emerged between the two groups in testing session 2 ($p > 0.10$). At time 2, although the scores had improved for both groups, those of the experimental group had increased significantly more (+5.5, $F(1,7) = 8.39$, $p < 0.023$,

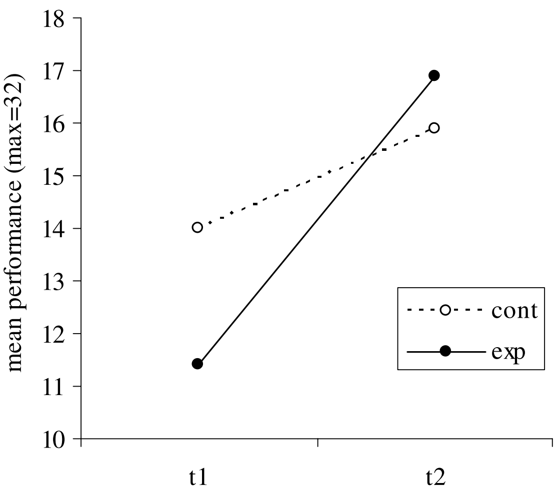

Fig. 1. Mean phonological coding performance in two groups of kindergarten children (control group and experimental group) in two testing sessions (t1, t2).

$\eta^2 = 0.54$) than those obtained by the control group with a trend that did not meet significance (+1.9, $F(1,7) = 4.84$, $p < 0.064$, $\eta^2 = 0.41$).

2.3. Conclusion

These results suggest that, overall, the intervention improved the pre-reading skills of the experimental group. The children made progress in word recognition and enjoyed working with the program. This study provides evidence that audio-visual training prior to formal schooling is advantageous for children deemed to at risk of developing a reading disability.

The fact that this audio-visual program can lead to substantial improvements in word recognition has important educational implications. Computer-assisted instruction requires much less teacher or aid time in order to deliver equivalent amounts of phonemic instruction (Foster et al., 1994). Thus, computer-assisted instruction provides a cost-effective way for education authorities to provide consistently effective phonemic awareness instruction to at-risk children.

Practice shows that child–computer interaction in kindergartens brings clear learning benefits. Qualitative studies show that many of the young children playing in a computer environment develop an understanding of the computer as a communicative tool (Labbo, 1996; Olson, 1994).

Moreover, the ergonomic aspects of the program must also be taken into consideration. Kindergarteners cannot read and are not very skilled computer users. This audio-visual program has a very clear structure, easy-to-understand buttons and no written text.

We think we have demonstrated that the use of a computer program at kindergarten level is feasible. Multimedia language programs can be designed to support specific aspects of early literacy and are thus suitable for use in a kindergarten class. However, the teacher plays an important role when the computer is implemented as part of the classroom curriculum. The teacher himself must be confident about using a computer. The introduction of technological innovations into classrooms has often been unsuccessful because they have created extra burdens for teachers (Van Daal & Reitsma, 2000).

3. Experiment 2: Dyslexic children and computer-assisted reading use in the school

Dyslexic children have great difficulties in acquiring reading skills, even though they are intelligent enough, receive normal tuition, and exhibit no obvious neurological or sensory disorders. Both phonological and surface dyslexics have impaired phonological skills (Sprenger-Charolles, Colé, Lacert, & Serniclaes, 2000). However, the origin of these disabilities is controversial. The temporal processing theory of dyslexia, according to which these children are thought to be specifically unable to process brief and rapidly changing auditory stimuli, has resulted in the proposal of training using temporally modified speech (Tallal et al., 1996). The speech modifications include both the artificial slowing of natural speech stimuli and the amplification of brief, unstable portions of the speech signal. According to the linguistic theory (Nittrouer, 1999; Rosen, 2003; Rosen & Manganari, 2001), auditory deficits and phonological impairments may be associated but are not causally related. In line with the phonetic model, the deficit in rapidly changing sound processing may be speech-specific (Serniclaes et al., 2001). Whatever the origin of linguistic disorders in dyslexic children, it is generally agreed that the core deficit is phonological (Ramus, 2001, 2003). In this study, we assume that the phonological impairment relates to the phonetic organization of phonemic representations. This experiment is concerned with the use of the audio-visual program in a specialized school for dyslexic children.

3.1. Methods

3.1.1. Participants

Fourteen dyslexic children were selected from a dyslexic population in a specialized school. They had normal or corrected-to-normal vision and no neurological deficits or overt physical handicap. From this group, all the children who met the following two criteria were selected: an overall IQ score of 70 or more on the French version of the WISC-R and reading retardation of at least 18 months behind their chronological age. These children were separated into two equal groups (see procedure), group A (mean age: 9.10 years) and group B (mean age: 10.4 years). No significant difference was found on the chronological age of the two groups, $t(12) = 0.13$, $p = 0.89$.

The two subgroups were strictly matched on educational and cognitive levels as well as for their reading level which was assessed just before the training using two standardized word reading tests (Ecalle, 2003; Lefavrais, 1986) (Table 1).

A battery of neuropsychological, phonological and visual tests was administered to each individual before the experiment. These tests are routinely used to assess reading-impaired children in French dyslexic centers. The statistical analyses confirmed that before the training period there were no significant differences in the scores on the two reading-skill tests ($F < 1$). The "*La pipe et le rat* " Test (Lefavrais, 1986) measures the speed and accuracy of word recognition, and has proved to be a reliable and valid test of isolated word decoding efficiency (Ecalle, 2003).

All the pupils regularly used a computer at school. The teachers expressed the view that the computer's role in their classroom was to support learning and teaching and perceived their own role as being one of targeted intervention. Moreover, they reported that the most frequently used item of software was the reading program.

In this specialized school, reading was taught with an emphasis on grapheme-to-phoneme conversion and reading out loud rather than whole-word recognition and silent reading for comprehension. Our sample of 14 dyslexic has been selected by their education authority as recipients of the same type of remedial teaching. This remedial instruction was an extension of the mixed approach to reading instruction.

Table 1
Group characteristics

		Group A		Group B	
Lefavrais (1986) test	Word reading time	87	81–93	88	81–93
	Word reading accuracy	86	78–90	86	78–93
Ecalle test	Word reading accuracy	84	79–92	85	77–94

Mean reading age and range in months.

Table 2
Design of testing and training sessions

	Testing session 1	Training session 1	Testing session 2	Training session 2	Testing session 3
Week	1	2, 3, 4, 5, 6	7	8, 9, 10, 11, 12	13
Group with training	A and B	A	A and B	B	A and B
Group without training		B		A	

3.1.2. Procedure

The experiment was conducted over a 13-week period as Table 2 illustrates.

In the first training session, the children in group A received the audio-visual training whereas the seven other children formed the control group (B). An improvement in the performances on the phonological tasks was expected for group A. After a second training session for group B only, it was expected that the training effect would persist in group A and the difference between the groups would disappear.

The training was administered over a period of five weeks, four days a week. Each training session lasted 15 min twice a day. The trained children received the computer-assisted instruction as part of their normal classroom routine for five weeks.

3.1.3. Assessment material

The participants in both samples were individually administered tests that assess phonological skills. There were four measures of phonological awareness:

- a phonological similarity judgment task in which the children had to designate two words (out of four) that shared the same phonological unit (eight items with syllables and eight items with phonemes);
- a common unit detection task (Duncan et al., 1997) which consisted of extracting the unit (eight items with syllables and eight items with phonemes) that was shared by two different words;
- a syllable permutation task in which the children listened to a pseudoword (*bano*) and were asked to provide a new pseudoword (*noba*) (max = 24);
- a phonemic segmentation task in which the children had to give the number of phonemes in eight words.

The score was the total number of correct responses (max: 64).

3.2. Results

A first Anova was conducted on the results with the between-factor Group (group A vs. group B) and the within-factor Testing session (t1 vs. t2). We observed no effect of Group ($F < 1$) and a significant effect of session, $F(1,12) = 6.17$, $p < 0.029$, $\eta^2 = 0.34$, performances increased from t1 to t2 (Fig. 2). Only, the performances of group A tended to increase, $F(1,6) = 4.94$, $p < 0.068$, $\eta^2 = 0.45$. In testing session 2, the performances did not differ between the two groups ($F < 1$). A second Anova with the between-factor Group (group A vs. group B) and the within-factor

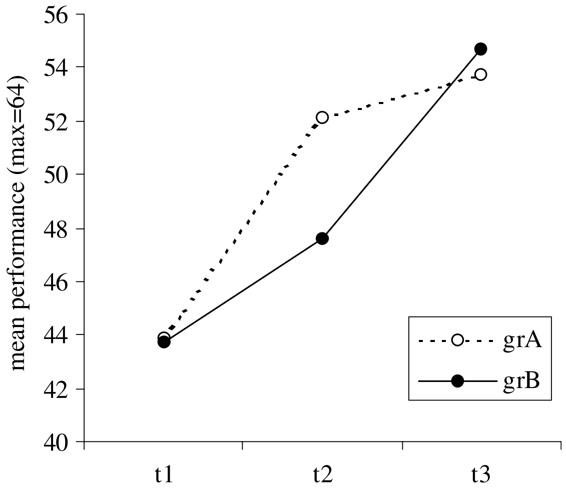

Fig. 2. Mean performance in two groups of dyslexic children in three testing sessions (t1, t2, t3).

Testing session (t2 vs. t3) did not show any effect of group ($F < 1$). We observed a significant effect of session, $F(1,12) = 13.71$, $p < 0.003$, $\eta^2 = 0.53$ and a significant interaction between the group and session factors, $F(1,12) = 5.61$, $p < 0.036$, $\eta^2=0.32$. Now, only group B improved significantly between sessions 2 and 3, $F(1,6) = 17.44$, $p < 0.006$, $\eta^2 = 0.74$.

3.3. Conclusion

The results reveal significantly greater increases in phonological skills accompanied by a positive effect of training. In fact, between sessions 1 and 2, the trained group A progressed more than the group B. When group B was trained in its turn between sessions 2 and 3, its phonological skills increased significantly.

This experiment took place in a specialized school for dyslexic children who also benefited from phonological awareness training with a speech therapist. This is probably the reason why, in session 2, the difference between the two groups was not significant.

4. Experiment 3: Dyslexic children and computer-assisted reading at home and school

This experiment seeks to examine the effect on children of computer-assisted training at home and school. Numerous studies have provided evidence of the growing gap between computer experience in the home and school environments, with children making more use of the computer at home than at school (Shoffner, 1990). However, the way computers are used at home and at school seems to be different. Computer games represent the most frequent activity on home computers (Cunningham, 1994; Downes, 1999; Durkin, 1995; Kirkman, 1993). Moreover, the importance of parental involvement in children's computer use at home has been revealed by Giacquinta, Bauer, and Levin (1993). However, the positive effect of access to a home computer on children's attitudes seems irrefutable (Colley, Gale, & Harris, 1994; Mumtaz, 2001).

Numerous studies have either focused on home use or school use of computers but not many of these studies compare the two environments. The aim of this study is to examine how dyslexic children can benefit from using an audio-visual training program for learning to read at home and school. We hypothesized that the dyslexic children who were allowed to practice using a home computer would learn more than children who had no access to a computer.

4.1. Methods

4.1.1. Participants

The study involved 14 dyslexic children. These children were separated into two equal groups, a "home" group (mean chronological age: 138 months; range: 122–154; mean reading age: 95 months; range: 81–103) and a "school" group (mean chronological age: 135 months; range: 124–146; mean reading age: 98 months; range: 87–112). None of these children used regularly a computer in their classroom, because the school did not possess some computer. Their teachers expressed the view that the computer's role in a classroom is only to support the development of computer awareness. They did not consider computer-aided reading as a tool for developing literacy skills.

4.1.2. Procedure

All "home group" participants reported that they had access to a computer at home. These children used their computers at home for playing games every day and they clearly perceived the home computer as a games machine. The parents were instructed how to switch the apparatus on and off. The only other instruction to the parents was to allow their children to practice every now and then. An experimenter visited the families weekly, made a copy of the practice results and inspected the results. All the parents of these children were intensively involved in this experiment and followed the training attentively.

None of the "school group" participants did not used a computer at home. After the children had completed a pre-test, two computers were allocated in the school for a period of five weeks. The trained children did not receive the computer-assisted instruction as part of their normal classroom routine. An experimenter visited the school every day and provided the training during the break. The teachers were not involved in the training.

The training was administered for a period of five weeks, four days a week. Each training session lasted 15 min twice a day.

No significant difference was found between the chronological age of the two groups ($p > 0.10$). These two subgroups were matched on educational and cognitive levels as well as for their reading level which was assessed just before the training using a standardized word reading test (Lefavrais, 1967). The statistical analyses confirmed that before the training period there were no significant differences in the scores on the reading-skill test (lexical age of "home group": 94.6 months; lexical age of "school group": 98 months; $t(12) = 0.79$, $p = 0.44$.)

4.1.3. Tests

The participants were tested individually over two sessions, both held during normal school hours. The aim of these tests was to examine phonological recoding skills. In a word recognition test, a forced-choice task was used in which the children had to find a target word among five items consisting of the orthographically correct word (e.g., chapeau, *hat*), and four pseudowords, namely a homophone (chapo), a visually similar item (chapeou), an item sharing the same initial letters (chameau) and an item containing an illegal letter sequence (cpaheua). The target words were presented in three conditions: orally, with a picture, and in a categorization task. No analysis was run on the conditions. The normative data for these tasks were obtained from first, second and third graders (Ecalle, 2003). The target word and homophone scores were combined to create a composite phonological coding score (max: 36).

4.2. Results

An Anova was conducted on the results with the between-factor Group (home vs. school) and the within-factor Testing session (t1 vs. t2). This revealed a significant effect of the main factor group, $F(1,12) = 6.54$; $p < 0.025$, $\eta^2 = 0.25$ and no effect of session ($F < 1$). Globally the performances of the "home group" were better than those of the "school group" (Fig. 3). Moreover, the results indicated a significant group * session interaction, $F(1,12) = 5.03$, $p < 0.045$, $\eta^2 = 0.29$. In testing session 2, the pattern of results differed between groups, $F(1,12) = 11.44$, $p < 0.005$, $\eta^2 = 0.49$, with a training effect appearing for the home group. Between the two sessions, only the performances of the home group tended to improve, $F(1,6) = 4.5$, $p < 0.078$, $\eta^2 = 0.43$.

4.3. Conclusion

The positive effect of access to a home computer on dyslexic children's reading performance is very clear. The greater use of a computer at home boosted the effect of the audio-visual training. These results suggest that attitudes formed at home dominate children's attitudes towards computers. The effect of access to a home computer has been already reported (Colley et al., 1994; Kirkman, 1993; Underwood et al., 1994). Attewell and Battle (1998) examined the

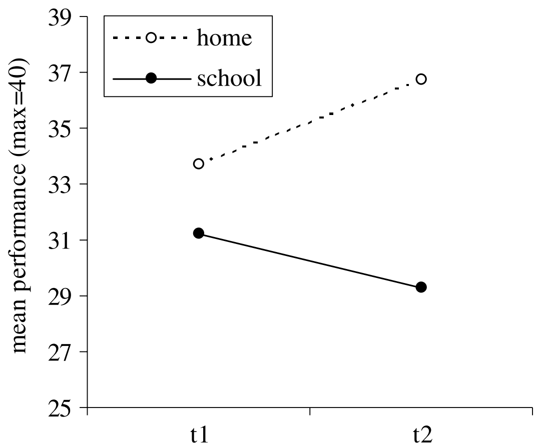

Fig. 3. Mean phonological coding performance in two groups of dyslexic children ("home" group and "school" group) in two testing sessions (t1, t2).

effects of home computers on school performances and found that having a home computer is associated with higher scores in mathematics and reading. Another reason for the difference between the two groups could be parental involvement in the case of the "home group" participants.

5. Discussion

Three separate studies were successively carried out to investigate the usefulness of intensively training children with reading disabilities using daily exercises based on voicing contrasts. The newly developed audio-visual program is an innovative instructional system that provides beginning readers and children with reading problems with exercises designed to stimulate skills identified as important for successful reading acquisition. This audio-visual training focused on voicing contrasts. It was similar for the three studies and was based on the "linguistic theory" (Rosen, 2003).

Beyond providing evidence for the effectiveness of this audio-visual training, these results contribute to an understanding of the nature of reading difficulties and successful training. More precisely, why might training that focuses children's attention on spelling-sound mappings have an impact on reading-related skills beyond decoding ability? Our audio-visual training improved children's reading skills by helping them to develop *ortho-phonological representations*. The effectiveness of phonological awareness based on methods that emphasize orthographic to phonological mappings has also been recently demonstrated (MacCandliss, Beck, Sandak, & Perfetti, 2003). Finally, our empirical observations and our position are consistent with reading interventions simulated with a recent connectionist model of reading development (Harm, McCandliss, & Seidenberg, 2003). These authors present the mapping hypothesis which "*holds that phonological awareness interventions influence word recognition processes via the quality of the letter-sound mapping representations (rather than by the quality of the phonological representations per se*)" (Harm et al., 2003, p. 162). The simulations replicated the empirical findings, thus indicating that the remediations that include training on spelling-sound regularities are more effective than those targeting phonological awareness alone.

In another study, a connectionist model of reading acquisition intended to simulate detailed aspects of developmental dyslexia (Harm & Seidenberg, 1999) was used to explore why certain kinds of remediations are more effective than others. This model represents a further extension of the theoretical framework developed by Seidenberg and MacClelland (1989) in order to understand normal and impaired reading acquisition. It differs from previous simulations of reading in that it incorporates a trainable phonological system as the output of the model. This phonological system was implemented as a set of low-level phonetic features such as voicing, plosives with a set of weighted connections between these features.

To summarize, the effectiveness of the present training method during a relatively short training period might be attributed to two factors. First, we trained the children in voicing. In line with the phonetic model, we think that the phonological deficits in dyslexic children may be partly due to impairments in the phonetic organization of phoneme detectors (Bedoin, 2003; Krifi, Bedoin, & Mérigot, 2003; Serniclaes et al., 2001). Second, this training required the children to process this phonetic feature both in hearing and reading. In line with a connectionist model of reading development (Harm & Seidenberg, 1999; Harm et al., 2003), we think that trainings involving spelling-sound regularities are more effective than those including phonological awareness alone. If knowledge of phonemes is closely connected to knowledge of orthography then training methods that emphasize this connection should be more effective.

This audio-visual training has been used in an experimental study of dyslexic children (Magnan et al., 2004). The results revealed a positive effect of the training on the recognition of written words. As far as the application of the experimental results is concerned, this study was designed to investigate the effectiveness of this training in both an educational and a family context.

The first experiment, conducted in kindergarten among children deemed to at risk of dyslexia, highlights the positive effect of the training on word recognition. This study illustrates the possibility of using hypermedia tools with young children. The use of software in kindergarten could make it possible to attenuate individual differences and help combat illiteracy. Indeed, if we consider that implicit knowledge and in particular phonological knowledge, plays a fundamental role in the explicit learning of reading, it appears necessary to provide young children with effective tools to remedy their phonological deficits at a very early age. However, the children who took part in this experiment regularly used a computer at school and their teachers were highly motivated by this experiment and encouraged the children during the training. Thus the effectiveness of the training is highly dependent on the attitudes developed by the children towards computer use and on the place their teachers accord to hypermedia.

The second experiment, conducted in a specialized school for dyslexic children, made it possible to highlight the positive effect of training on the children's phonological skills. This experiment was carried out in partnership with the teachers and the training was integrated into their classroom activities. Moreover, all the children who took part in the experiment regularly used the school computer.

The third experiment was intended to compare the effects of training on word recognition in two groups of dyslexic children who differed on a number of dimensions. One group of children was trained at home with the participation of their parents who were all highly motivated to take part in this experiment. Moreover, these children all regularly used a computer at home, in particular for playing games. A second group of children was trained in a specialized school for dyslexic children, outside of classroom hours (during the break). The teachers did not take part in the experiment. Their role was limited to authorizing the conduct of the training in the school. The training was carried by a neutral experimenter who was unknown to the children. This school did not have a computer and the children did not use a computer at home. Consequently, they did not have any experience of computer use before the experiment. The results clearly reveal a significant difference between the performances of the two groups, with the children trained at home achieving significantly improved performances after training.

This last result considerably relativizes the effects of computer-assisted reading. It seems that the effectiveness of such training depends on the attitudes developed by the children towards the computer during operation and on the educational context in which the training is carried out. Indeed, in the first two experiments, the teachers were convinced of the value of the training and the trained children received the computer-assisted instruction as part of their normal classroom routine. The children trained at home were also placed in a positive motivational context that favored the training, with the parents being greatly involved in the experiment. The absence of a training effect among the children trained at school could be explained by two facts. Children who do not use a computer cannot develop computer-related knowledge and be attracted by this type of training (weak motivation among these children). In addition, the neutrality of the experimenter providing the training and the absence of a commitment on the part of the teachers would not motivate the children to participate actively.

However, experiment 3 does not make it possible to determine in this experiment the respective roles of the factors "computer use" (frequent and regular vs. rare) and "training context" (strong motivation vs. weak motivation). The role of these factors has received little attention in research into the effects of training. It appears necessary to develop tools to evaluate the level of motivation of children and teachers, the level of computer knowledge, and the attractiveness of using a computer at school.

If children are to use this tool effectively, computers must be used regularly and frequently within the framework of school activities and the teachers must be highly motivated. If these two conditions are met, computer use in schools can be introduced as early as kindergarten. Indeed, the young children in our study quickly become able to work with a computer in an autonomous and effective way.

In conclusion, two points need to be emphasized in connection with the introduction of computer-assisted reading. Firstly, it is of value to propose training based on experimentally tested psychological and linguistic theories to both practitioners (teachers and speech therapists) and parents. Secondly, our results suggest the need to study the motivation of the children, the parents and/or the teachers as well as their ability to use a computer.

Moreover, the effectiveness of training administered at home raises the question of the role of the family in the remedial tuition of dyslexic children. Computer-aided reading could be used as link between the speech therapist and the family. More precisely, parents could participate in the remedial tuition of their children through the use of a computer.

Individual, computer-based reading seems to represent a good way of delivering literacy training adapted to the specific needs of both "reading-ready" kindergarten children and reading-disabled children. The quality of the home computer environment (availability of computer-based reading in the home and time spent using the computer with parents), parental involvement in their children's schooling and motivation to achieve may influence the growth of phonemic awareness skills.

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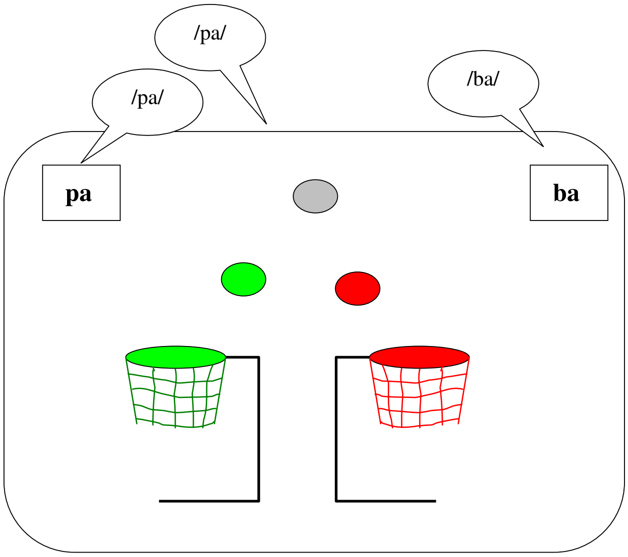
Appendix A

An example of screen (reconstituted) from phonological discrimination exercises in "Play-On" (Danon-Boileau & Barbier, 2002).



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