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COGNITIVE DEVELOPMENT

The visuo-haptic and haptic exploration of letters increases the kindergarten-children's understanding of the alphabetic principle

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Abstract

This study examined the effect of incorporating a visuo-haptic and haptic (tactual-kinaesthetic) exploration of letters in a training designed to develop phonemic awareness, knowledge of letters and letter/sound correspondences, on 5-year-old children's understanding and use of the alphabetic principle. Three interventions, which differed in the work on letters identity, were assessed. The letters were explored visually and haptically in "HVAM" training (haptic-visual-auditory-metaphonological), only visually in "VAM" training (visual-auditory-metaphonological) and visually but in a sequential way in "VAM-sequential" training. The three interventions made use of the same phonological exercises. The results revealed that the improvement in the pseudo-word decoding task was higher after HVAM training than after both VAM training and VAM-sequential training (which did not differ). The sequential exploration of the letters (independently of perceptual modalities involved) was not to be sufficient alone for explaining these results. Moreover, similar improvements in the letter recognition test and in the phonological awareness tests were observed after the three interventions. Taken together, the results show that incorporating the visuo-haptic and haptic exploration of letters makes the connections between the orthographic representation of letters and the phonolog-

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ical representation of the corresponding sounds easier, thus improving the decoding skills of young children.

Keywords: Reading acquisition; Multisensory; Touch; Training; Metaphonological ability; Letters

1. Introduction

This study examined the effects of incorporating a visuo-haptic and haptic (tactual-kinaesthetic) exploration of letters in a training designed to develop phonemic awareness, knowledge of letters and letter/sound correspondences, on the understanding of the alphabetic principle among pre-reading kindergarten children. Studies on reading acquisition had primarily focused on the phonological dimension involved in the understanding of the alphabetic principle. Several studies have shown that one of the factors influencing reading success lies in the development of some skills related to spoken language and broadly referred to as metaphonological abilities (for recent reviews in English, see Ehri et al., 2001; Troia, 1999; for recent reviews in French, see Gombert & Colé, 2000; Sprenger-Charolles & Colé, 2003). These are defined as the abilities which allow children to identify the phonological components of linguistic units and to manipulate them intentionally (Liberman, Shankweiker, Fisher, & Carter, 1974). It appears that the metaphonemic abilities (the abilities to consciously manipulate the phonemes in spoken words) are the best predictor of reading in alphabetic systems (Ehri et al., 2001).

Furthermore, reading acquisition is broadly though to consist, on the one hand, in the development of phonological and orthographic representations and, on the other, in the establishment of connections between (or indeed the fusion of), these two types of representation (Metsala & Ehri, 1998). Then, the body of research devoted to the way in which these connections or this fusion come about is very slight and tends to consider that this is an "implicit" process which is triggered by the learning of letter/sound correspondences (e.g. Plaut, MacClelland, Seidenberg, & Patterson, 1996). Reading training programs adhere strictly to this conception and make use of metaphonological and letter discrimination exercises which are associated with the learning of the letter/sound correspondences (Bus & Van Ijzendoorn, 1999). For example, Byrne and Fielding-Barnsley (1991) evaluated the efficiency of this kind of training program on 5-year-old pre-readers. The performances in phonemic awareness and in a forced-choice word reading tasks improved significantly more after this "experimental" training than after the "control" training which only made use of semantic activities. However, although this type of intervention really has a positive effect on reading, its acquisition generally remains slow and difficult because several months of formal instruction are necessary before young children grasp the logic of the alphabetic principle and use it (Colé, Magnan, & Grainger, 1999; O.N.L., 1998; Sprenger-Charolles, Siegel, & Bonnet, 1998; Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003).

In the light of Bryant and Bradley's work (1985), we assume that one of the difficulties involved in learning to read relates in part to the task of establishing connections between the orthographic representation of a word and the corresponding phonological representation.

More precisely, it lies in a difficulty in establishing a connection between the visual image of a word and its auditory image. In an attempt to overcome this difficulty, a “multisensory” learning method calling not only on the visual and auditory modes as is traditionally the case, but also on the manual haptic modality can be used. Indeed, our hands do not simply possess the motor function of moving or transforming the objects in our environment, but also have a highly efficient active perceptual function (e.g. Gibson, 1962; for recent reviews, see Hatwell, Streri, & Gentaz, 2000, 2003; Heller, 2000; Millar, 1994).

Thus, Fernald (1943) employed a “multisensory” technique (largely based on Montessori’s principles) with children exhibiting reading difficulties. This technique, known as the “multisensory trace” involves the children in tracing a written word with their index finger while pronouncing it and looking at it. In line with this, Ofman and Shaevitz (1963) compared the effectiveness of the “multisensory trace” with that of the “visual trace” and “reading only” in a task involving the learning of new words. The “visual trace” task consists in asking the children to track with their eyes a word which is gradually written in front of them. The results revealed that poor readers (aged 13 years) were significantly better able to learn new words using the “multisensory trace” and the “visual trace” techniques (which are identical) than with the “reading only” technique. Using an exploratory movement (visuo-haptic or only visual) in the apprehension of a written word thus seems to facilitate the learning in this type of readers.

In a similar vein, Hulme (1979) examined in younger children (8–9 years) the effect of the haptic exploration of abstract graphical figures on their memorization. The figures were explored either by looking at each of them (“Visual” condition), or by looking while simultaneously tracing them with the finger (“Visuo-Haptic” condition). The results indicated that the children in the “Visuo-Haptic” condition achieved significantly better performances in a subsequent recognition task than those in the “Visual” condition. Similar results were obtained with alphabet letters, in children with reading difficulties and normal-reading children of nine (Hulme, 1981).

Recently, Gentaz, Colé and Bara (2003) investigated, in kindergarten children, the effects of adding a visuo-haptic and haptic exploration of letters in a reading training program, designed to develop phonemic awareness and knowledge of letters and letter/sound correspondences. Two interventions, which differed in the perceptual mode they address, were compared. The haptic-visual-auditory-metaphonological training (HVAM) involved the haptic, visual and auditory mode whereas the visual-auditory-metaphonological training (VAM) only exploited the visual and auditory modes. Both interventions made use of the same phonological exercises. However, whereas the work on letter identity was based on a visuo-haptic and haptic exploration (the shape of the letters was actively traced with the finger) in the HVAM training, only the visual exploration was exploited in the VAM training. Performances were assessed before and after interventions by means of pseudo-word decoding, letter recognition and phonological tasks (rhyme and phoneme identification). The results revealed that the improvement in the pseudo-word decoding task was greater after HVAM training than after VAM training. Similar improvements between HVAM and VAM were observed in the letter recognition and in the phonological tests. These results showed that incorporating the visuo-haptic and haptic exploration of letters increases the positive effects of the interventions on the understanding and use of the alphabetic principle in young children and thus on their decoding level (see also Bara, Gentaz, & Colé, 2004).

This positive effect of the haptic exploration was explained in terms of the functional specificities of the various sensory modalities in question (Gentaz & Rossetti, 1999; Hatwell et al., 2000, 2003; Lederman & Klatzky, 1987). Indeed, vision is characterized by its quasi-simultaneity and is therefore more suitable for processing and representing spatial stimuli such as letters. On the other hand, listening is sequential in nature and is more suitable for processing temporal stimuli such as the sounds of speech. This functional difference could explain why young children have some difficulties in establishing the association between letters, which are processed visually, and sounds, which are processed auditorily. In contrast, the haptic modality shares characteristics with both the auditory and the visual modalities. Even though its functioning is highly sequential in nature, the haptic perception is also a spatial perception since the exploration in this modality is not linear and subject to a fixed order.

Within this perspective, research into the development of the visual and haptic apprehension of objects has made it possible to better identify the characteristics of haptic exploration. Since objects are multidimensional, they possess values along a number of different dimensions such as texture, location, size, shape, etc. In the case of sight, all the dimensions are perceived practically simultaneously (separated by only a few milliseconds). The same is not true in the haptic modality because, in this case, the exploration involved makes the perception very sequential (Berger & Hatwell, 1993, 1996). This is the reason why the haptic perception appears to be less “global” and more “analytical” than the visual perception. Thus, as far as our study is concerned, the incorporation of the haptic exploration should require children to process actively letters in a more sequential and therefore a more analytic way, something which they do not do “naturally” when letters are presented in the visual modality only.

The first goal of the present research was to confirm that incorporating the visuo-haptic and haptic exploration of letters in phonological and letter knowledge exercises, increases their positive effects on the understanding and use of the alphabetic principle in young children and thus on their decoding skills. The second goal was to investigate whether these positive effects observed after HVAM training could be explained by the sequential exploration of letter per se (i.e. independently of perceptual modalities involved) or by the haptic exploration of letter per se. Indeed, the haptic exploration can be distinguished by the fact that the motor system is involved in the exploratory activity of the hand which in turn can activate the whole shoulder–arm–hand system. These haptic exploratory movements are active (they may be generated internally), intentional (they are aimed at a goal) and may use the sensory reafferences produced by their execution.

In order to study these issues, we examined in kindergarten children the effect of three interventions that were different by the sensory modality requested (visual, auditory and haptic) and by the way of exploring the letters (simultaneous or sequential). Thus, we presented children with the two interventions proposed by Gentaz et al. (2003) named HVAM training (incorporating a visuo-haptic and haptic sequential exploration of letters) and VAM training (incorporating a visual simultaneous exploration of letters) respectively and with a third training. In the third training, labelled “VAM-sequential”, the letters were explored visually and sequentially (they take shape gradually on a computer screen).

The VAM-sequential training allowed testing the role of the sequentiality of exploration. On the one hand, the exploration of letters was sequential and supervised by the experimenter (the exploratory order of the letter, corresponding to its writing, was imposed) in the HVAM training and the VAM-sequential training whereas it was simultaneous and without fixed order in the VAM training. This comparison allowed evaluating the role of sequential versus simultaneous exploration of letters, independently of the perceptual modalities involved. On the other hand, the letter was perceived by an active and intentional haptic exploration of children in the HVAM training whereas it was passively explored in the VAM training and in the VAM-sequential training. This comparison allowed evaluating the role of haptic exploration per se. The three interventions have in common the use of exercises involving phonemic awareness and exercises bearing on letter recognition and on the learning of letter/sound correspondences.

Regarding the incorporating of the haptic exploration effect (first goal), we should observe an improvement in performances on both the tasks designed to evaluate the understanding and use of the alphabetic principle (pseudo-word decoding and letter recognition tests) following HVAM and VAM training, but this improvement should be greater after HVAM training than VAM training. Regarding the role of the sequentiality of exploration (second goal), we should observe whether the sequential exploration of letters explained the improvements in reading observed after the HVAM training: (1) similar improvements (in pseudo-word decoding and letter recognition tests) in the HVAM and VAM-sequential training and (2) lower improvements in the VAM training. By contrast, if haptic exploration of letters per se was responsible for these improvements, we should observe greater performances after the HVAM training than after both the VAM-sequential and the VAM training. Finally, we also measured children's metaphonological abilities and we expected to observe similar improvements after the three interventions.

2. Method

2.1. Participants

Sixty monolingual French children (25 girls and 35 boys) with a mean age of 5 years 7 months (from 5 years 2 months to 6 years 1 month) took part in this study. These children were attending three different kindergarten classes at schools in Grenoble (France). All the children and the whole classes participated in the study. All the children belonged to average socio-economic status. They were pre-readers and had never been trained to phonological tasks in class. Only the children who had attended all the training sessions were taken into account in the results analyses. In each classroom, children in the three training groups were matched on the following criteria: age, vocabulary level (EVIP), non-verbal performance level (Kohs block from WIPSI), metaphonological ability, knowledge of the alphabet letters and pseudo-word decoding (see Table 1). Globally, there were 20 children in each training group.

2.2. Material and procedure

The selection of the phonemes and the order in which they were studied were based on their frequency of appearance in the French oral language (Rondal, 1997). Thus the sessions

Table 1
Characteristics of the children in each group before the interventions

	EVIP M (S.D.)	Khos block M (S.D.)	Alphabet letters (/26) M (S.D.)	Letter recognition (/6) M (S.D.)	Pseudo-word decoding (/12) M (S.D.)	Mean age
HVAM	68.3 (16.7)	25.7 (4.6)	15.2 (6.3)	5.2 (4.0)	0.5 (1.6)	5 years 6 months
VAM-sequential	66.9 (15.0)	23.7 (4.4)	16.5 (6.9)	3.6 (4.4)	0.4 (1.2)	5 years 7 months
VAM	71.8 (16.8)	26.2 (5.3)	13.2 (5.45)	2.7 (3.5)	0.6 (1.9)	5 years 7 months

started with the study of the sounds /a/, /i/ (amongst the most frequent), continued with the sounds /r/, /l/ and ended with the sounds /t/, /p/ and /b/ (less frequent). The typography of each letter resembled lowercase handwriting (Fig. 1) and was used in all the exercises which required the use of the letters.

2.2.1. Pre- and post-tests

Each child's understanding and use of the alphabetic principle (a) and her/his metaphonological abilities (b) were individually assessed between 1 and 2 weeks before and after the interventions. These assessments were carried out by the same experimenter who remained blind to training assignments of each child.

(a) The understanding and use of the alphabetic principle were measured using a pseudo-word decoding test and a test requiring the recognition of the alphabet letters. In the pseudo-word decoding test, the experimenter told the children that words were made-up and meant nothing in their language. Three of these pseudo-words consisted of two letters, six of three letters and three of four letters (score out of 12). These pseudo-words were composed of the letters studied during the training sessions.

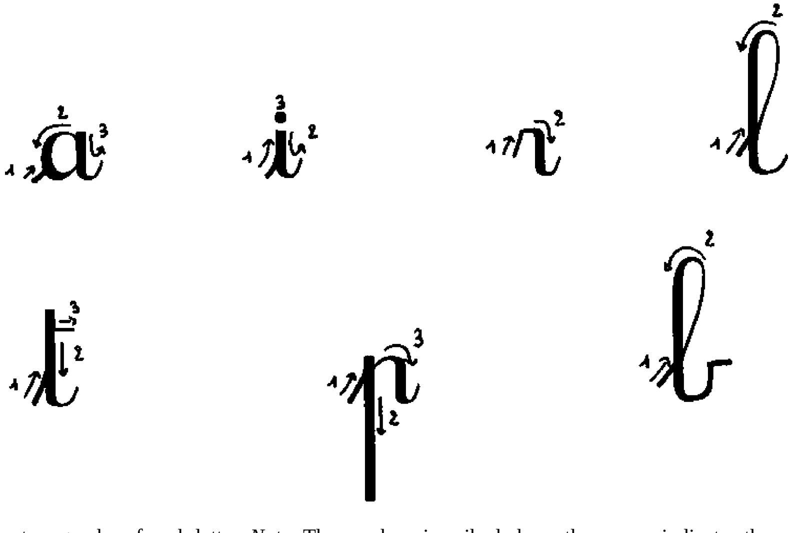

Fig. 1. The typography of each letter. *Note*: The numbers inscribed above the arrows indicates the exploratory order of each letter.

In the letter recognition test, the experimenter said the name of a letter and the child had to indicate on a presentation card (composed of six letters) the letter he had just heard. Each correct response was scored 1. Before the interventions, all the 26 letters were tested (score out of 26) whereas in the post-test, only the letters involved in the training sessions were tested (score out of 7).

(b) The children's metaphonological abilities were measured using three tests: a rhyme identification test, and two phoneme identification tests (in initial and final position in the words). In these three tests, pictures corresponding to familiar, easily depicted words were presented and the children were asked to perform a specific task. In our tests, the children were asked to look for the seven phonemes which had been included in the training sessions.

Each test consisted of three training trials, during which we made sure that the children had correctly understood the task, and six or seven trials on the basis of which a score out of six (for the rhyme test) or seven (for the two phoneme identification tests) was obtained. In the rhyme test, the child saw three pictures and had to indicate those corresponding to the two words "that sound the same at the end" (for example: *bulle* [bubble], *pull* [pull over], *four* [furnace]). In the test requiring the identification of the phonemes in initial position, four pictures were presented to the child in each trial. The experimenter chose a first picture and said the word. This first word was then used by the child to find, among the other three pictures, the one corresponding to the word "that starts with the same sound" (for example: *bague* [ring] was the first word and the child had to choose between *bouée* [buoy], *chemise* [shirt], *stylo* [pen]). In the test requiring the identification of phonemes in final position, we used the same principle with the difference that the child had to find the word "that ends with the same sound" (for example: *lit* [bed] was the first word and the child had to choose between *toupie* [spinning top], *pomme* [apple], *clé* [key]; in the French oral language, the letter /t/ of /lit/ and the letter /e/ of /toupie/ are silent). In each test, the order of presentation of the pictures was controlled. Thus, in each trial, we changed the position of the target word with reference to the word that acted as the starting point for the child in order to prevent the establishment of retrieval strategies based on the order of picture presentation.

2.2.2. Training sessions

Three equivalent groups of 20 children each were formed using eight criteria: age, vocabulary level (EVIP), non verbal IQ (Khos blocks), three metaphonological abilities tests, letter recognition and pseudo-word decoding (Table 1). A specific training (namely: HVAM, VAM or VAM-sequential) was administered to each of the three groups by the same experimenter. Each intervention consisted of seven sessions, conducted in the same way (the same exercises were performed in the same order) and one revision session. A different sound (and the corresponding letter) was learned in each session. By the end of the interventions, the children were familiar with the sounds/letters -a-, -i-, -r-, -l-, -t-, -p- and -b-. One session was conducted each week. As a consequence, each intervention took 8 weeks (seven training sessions and one revision session). The interventions were conducted from February to May. The context in which the different groups were asked to work was identical. Each training session lasted for approximately 25 min and took place in an acoustically insulated room in order to optimise the children's attention. The children sat in groups of five or six around a table in order to encourage their interactions. The experimenter involved each of them during the different exercises.

The three interventions used the same metaphonological exercises which included the nursery rhyme, the posters and the card games. The basic difference between the three lies in the sensory modes that were requested and in the manner of exploring the letters (simultaneous or sequential).

2.2.2.1. The HVAM training sessions

The identification exercise. At the start of each session, the experimenter gave a small, movable letter (made of foam with a thickness of 5 mm) to each child and showed the correct orientation of the letter. The experimenter asked them to guess its identity. The small letters -a-, -i- and -r- were 2.5 cm high and the letters -t-, -l-, -p- and -b- were 4.8 cm high. The children held the letter between their hands during the two following activities (the nursery rhyme and the posters) and were free to touch it during this period.

The nursery rhyme. After the first identification exercise, the experimenter recited a nursery rhyme which contained many examples of the sound on which the children were required to concentrate during the session. Its aim was to sensitise the children to the sound by means of short, playful stories which they found easy to remember and fun to repeat. During this nursery rhyme, the children attempted to detect the sound that corresponded to the target letter. The children then repeated the rhyme sentence by sentence. Repeating the rhyme enabled them to pronounce the target sound a large number of times and to familiarize themselves with it. We expected this familiarization to encourage the learning of the letter/sound correspondences.

The two poster exercises. The children then started working on two posters (40 cm high by 60 cm wide). The first of these contained pictures corresponding to words starting with the learned sound and distractor words. Among the six words presented (three target words and three distractors), each child had to find a word starting with the sound learned during the session and whisper the answer to the experimenter. Each child's answer was then revealed to the group and discussed in order to determine whether or not it was correct. The experimenter then moved on to the poster containing pictures corresponding to words which ended with the learned sound and repeated the above exercise accordingly.

The visuo-haptic and haptic exercises. The large letters (fixed to a 20 cm $\times$ 25 cm board) made with foam were then handed out. The letters -a-, -i- and -r- were 5 cm high and the letters -t-, -l-, -p- and -b- were 10 cm high. The children were told to explore the relief letter with their fingers and run their index finger along its outline in a fixed exploratory order corresponding to its writing (Fig. 1). The experimenter observed and checked the way each child explored the letter. Once this exercise was finished, the haptic exploration of the letter continued under a cover which was placed above the board. The children slid their hands below the cover and were told to think of the letter while exploring it haptically. The same exercise was then used with the small letters, which were fixed to a 10 cm $\times$ 13 cm board (they have the same size than the small letters used in the identification exercise). It should be noted that we used two letter sizes in order to facilitate the learning and exploration of the letters. Indeed, we know that medium amplitude movements are easier to control with precision than low amplitude movements (Hatwell et al., 2003). Thus the large letters, which induced medium amplitude movements, helped the children succeed in this visuo-haptic tracking task and give them the way of exploring the letters. This therefore facilitated the exploration of the small letters which induce low amplitude movements.

Once the haptic exploration was finished, the children performed a recognition task using the small fixed letters. They had to distinguish between the letter learned during the session and a “distractor letter” which physically resembled it. Thus we associated the training letter (TL) -a- with the distractor letter (DL) -e-, the TL -i- with the DL -u-, the TL -r- with the DL -n-, the TL -l- with the DL -t- and the TL -t- with the DL -b-, the TL -p- with the DL -q- and the TL -b- with the DL -l-. The two foam letters were arranged under the cover where the children again had to slide their hands in order to handle them. Their task was to explore both letters and to identify the target. When the children thought to have correctly identified the letter, they were allowed to remove the cover and check for themselves. However, if they failed to identify the correct letter, the experimenter advised them to take their time and explore the letters again.

The two card game exercises. The final stage of the session took the form of two card games. Pictures representing the target and distractor words were spread out on the table. In the first game, the children had to take turns to choose a picture which corresponded to a word starting with the target sound. In the second game, the chosen picture had to represent a word which ended with the learned sound. This game ended when no further target pictures remained.

2.2.2.2. The VAM training sessions

The identification exercise. The visual exploration boards were distributed to each child. Each letter, printed on a sheet of paper, was glued to a small board. The experimenter showed the correct orientation of the letter and asked them to guess its identity. The size of each letter was the same as the size of the foam letters used in the identification exercise in the HVAM training. These boards displayed the handwritten letter to be learned and remained visible throughout the two following activities (the nursery rhyme and the posters).

The nursery rhyme. The nursery rhyme was the same as in the HVAM training sessions.

The two poster exercises. The two poster exercises were the same as in the HVAM training sessions.

The visual exercises. The large letters, printed on a shit of paper, were then explored visually (their size was the same as the large letter used in the haptic exploration exercise). The experimenter asked the children to follow the drawing of the letter with their eyes and drew their attention to its shape and the lines and curves it contained. This information allowed the children to subdivide the letter into organized elements and track its contour visually in a fixed exploratory order (Fig. 1). When the children had explored the letter for long enough, the experimenter distributed the sheets containing a visual recognition test. The children were asked to cross out the target letter presented together with a number of distractors (letters sharing physical characteristics with the target). This test was presented on a sheet of paper (A4 format) containing four lines of twelve letters each (with a small size). Each line of letters contained two types of distractor letters and a variable number of instances of the target letter in order to prevent the children from using a strategy based on the number of items to be crossed out. It should be noted that we selected two distractor letters (instead of one in the haptic task) in order to increase the difficulty of the exercise (the use of a single letter makes the visual task too easy and to fast). The training letter -a- was associated with the distractor letters -o- and -e-; the TL -i- with the DL -j- and -u-, the TL -r- with the DL -n- and -s-; the TL -t- with the DL -b- and -d- and the TL -l- with the DL -t- and -h-, the TL -p- with the DL -q- and -g- and the TL -b- with the DL -l- and -k-.

In order to attempt to equalise the global duration and the number of exercises between the interventions, we proposed an additional card game. In this game, the cards were spread on the table and each child had to take one of it. Each game consisted of 12 cards amongst which there were four cards corresponding to the target letter, and four cards of each of the two distractor letters. The distractor letters used for each target letter were the same as those used in the crossing-out task. The children had to judge whether the letter they had taken corresponded to the target letter or to a distractor, in placing it in one of the two boxes placed in front of them (one for the target letter and one for the distractor letters as specified by the experimenter).

The two card game exercises. The two card game exercises were the same as in the HVAM training sessions.

2.2.2.3. The VAM-sequential training sessions

The progress of VAM-sequential training sessions was exactly the same as the VAM training sessions, except for the presentation of the letters (visually but sequentially). Indeed, the letter presented visually took shape gradually on the screen of a computer. The letter was traced sequentially on the screen by a black spot which moved while following its outlines. Once the letter was entirely drawn, it remained motionless and visible on the screen during 2 s, then disappeared during 10 ms and started again to take shape. The experimenter asked the children to follow the drawing of the letter with their eyes and drew their attention to its shape and the lines and curves it contained. This sequential drawing allowed the children to subdivide the letter into organized elements and track its contours visually in a fixed exploratory order. Then, the children performed an observation work of the letter which takes shape on the screen. They had to follow with their eyes the layout of the letter and try to memorize it.

2.2.2.4. The revision session

A revision session was planned for each group at the end of the seven training sessions. First of all, we summarized the work done during the sessions and reminded the children of the seven letters they had studied together with the corresponding sounds. In the HVAM training, the children were told to explore each relief letter with their index finger. In the VAM training, the children were asked to explore visually each letter. In the VAM-sequential training children explored the letters seeing them gradually take shape on the computer screen. The purpose of this session was to reactivate the knowledge acquired by the children during the training sessions. Then they worked with the dominos, which formed part of the metaphonological training. The dominos consisted of two pictures placed side by side. All these pictures represented words which started (or ended) with one of the seven sounds learned during the training sessions. The children's task consisted of matching the dominos in such a way that the different pictures, when placed together, corresponded to words which started or finished with the same sound. We constructed two sets of dominos. The first game contained pictures corresponding to words which started with one of the sounds learned during the training sessions, while the second contained pictures corresponding to words which finished with one of these sounds. The dominos also made it possible to check the children's knowledge of the different sounds they had learned.

3. Results

3.1. Pseudo-word decoding

The mean number (and standard deviations) of correctly decoded pseudo-words (maximum 12) before and after each of the three interventions are presented in Table 2.

A 3 (training) × 2 (period) ANCOVA, with the pre-test scores in vocabulary, Khos blocks, metaphonological tests and letter recognition as covariates, was performed on the number of correctly decoded pseudo-words. It revealed that the effect of period was significant [$F(1,57) = 62.88$, $P < 0.001$]: the performances were higher after the interventions ($M = 3.86$) than before ($M = 0.5$). The training effect was not significant [$F(2,50) = 1.53$]. The period × training interaction approached significance [$F(2,57) = 2.97$, $P = 0.059$]. In order to examine our hypothesis about the haptic exploration effect, we carried out a pre-planed comparison between HVAM and VAM training. This comparison was significant [$F(1,50) = 9.98$, $P < 0.01$]: The number of decoded pseudo-words was higher after HVAM training (M = 5.2) than after VAM training ($M = 2.75$). In order to investigate the role of the sequentiality of exploration, we carried out a post hoc analysis (Newmans–Keuls Test with a 0.01 alpha level). These comparisons revealed that the number of decoded pseudo-word in post-test was significantly higher after HVAM training than after VAM-sequential training

Table 2
Mean number (and standard deviations) of correct pseudo-words decoding (maximum 12) before and after each of the three interventions

Training	Period	
	Pre-test M (S.D.)	Post-test M (S.D.)
HVAM	0.55 (1.6)	5.2 (4.0)
VAM-sequential	0.45 (1.2)	3.65 (4.4)
VAM	0.6 (1.9)	2.75 (3.5)

Table 3
Mean number (and standard deviations) of recognized letters (maximum seven) before and after each of the three interventions

Training	Period	
	Pre-test M (S.D.)	Post-test M (S.D.)
HVAM	3.75 (1.8)	5 (1.3)
VAM-sequential	4.25 (2.0)	5.15 (1.9)
VAM	3.35 (1.7)	4.8 (1.7)

($M = 3.65$) whereas there were no differences between the three interventions in pre-test. Moreover, no significant difference was found between VAM and VAM-sequential in post-test.

3.2. Recognition of the seven target letters

The mean number (and standard deviations) of correctly recognized target letters (maximum seven) before and after each of the three interventions are presented in Table 3.

A 3 (training) × 2 (period) ANCOVA, with the pretest scores in vocabulary, Khos blocks and metaphonological tests as covariates, was performed on the number of correctly recognized target letters. It revealed a significant effect of period [$F(1,57) = 54.41$, $P < 0.001$]: the performances were higher after the interventions ($M = 4.98$) than before ($M = 3.78$). The training effect and the interaction were not significant (all $P > 0.25$).

3.3. Metaphonological abilities

The mean scores (and standard deviations) obtained in the three metaphonological tests before and after each of the three interventions are presented in Table 4.

Table 4
Mean performances (and standard deviations) obtained in the three metaphonological tests before and after each intervention

Test × training	Period	
	Pre-test M (S.D.)	Post-test M (S.D.)
Rhyme (maximum six)		
HVAM	5.15 (1.0)	5.55 (1.1)
VAM-sequential	4.8 (1.3)	5.75 (0.6)
VAM	5.3 (1.2)	5.65 (0.7)
Initial phoneme (maximum seven)		
HVAM	3.7 (1.9)	5.5 (1.5)
VAM-sequential	3.35 (1.8)	5.25 (1.4)
VAM	3.65 (1.8)	5 (1.9)
Final phoneme (maximum seven)		
HVAM	3.4 (1.4)	5.5 (1.6)
VAM-sequential	3.8 (1.2)	5.6 (1.2)
VAM	3.9 (1.7)	5 (1.8)

3.3.1. The rhyme test (score out of 6)

A 3 (training) × 2 (period) ANCOVA, with the pre-test scores in vocabulary, Khos blocks and letter recognition as covariates, was performed on the scores in the rhyme test. It showed a significant effect of period [$F(1,57) = 18.21$, $P < 0.001$]: the performances were higher after the interventions ($M = 5.65$) than before ($M = 5.08$). The training effect and the interaction were not significant (all $P > 0.25$).

3.3.2. The initial phoneme test (score out of 7)

A 3 (training) × 2 (period) ANCOVA, with the pre-test scores in vocabulary, Khos blocks and letter recognition as covariates, was performed on the scores in the initial phoneme identification test. It showed a significant effect of period [$F(1,57) = 51.67$, $P < 0.001$]: the performances were higher after the interventions ($M = 5.25$) than before ($M = 3.56$). The training effect and the interaction were not significant (all $P > 0.25$).

3.3.3. The final phoneme test (score out of 7)

A 3 (training) × 2 (period) ANCOVA, with the pre-test scores in vocabulary, Khos blocks and letter recognition as covariates, was performed on the scores in the final phoneme identification test. It revealed a significant effect of period [$F(1,57) = 73.66$, $P < 0.001$]: the performances were higher after the interventions ($M = 5.36$) than before ($M = 3.7$). The training effect and the interaction were not significant (all $P > 0.25$).

4. Discussion

This study attempted to show that the addition of the haptic mode in a preparatory reading training program with kindergarten children can help in their understanding of the alphabetic principle and is likely to induce an improvement in their decoding skills. Moreover, the role of the sequential exploration of letters in these positive effects was investigated. We measured the children's abilities before and after the HVAM, VAM and VAM-sequential interventions using two tests evaluating the understanding and use of the alphabetic principle (pseudo-word decoding and letter recognition tests) and three tests involving phonological awareness (rhyme, initial and final phoneme identification tests).

First, we observed an improvement of performances after each measure. These results are in line with previous studies and mean that any intervention that focuses on phonemic awareness and knowledge of letters and letter/sound correspondences is efficient and help the children to understand the alphabetic principle and use it to decode written words (cf. Bus & Van Ijzendoorn, 1999). However, the amplitude of these improvements depends both on the kind of intervention, more particularly on the way of exploring the letters, and on the test used. More precisely, in the latter case, it was the same in the metaphonemic and letter recognition tests after the three interventions but it was function of the kind of intervention in the pseudo-word decoding test.

It is clear that the pseudo-word decoding test is of central interest because it is a good indicator of children's understanding of the alphabetic principle. Indeed, success in this test requires the application of the letter/sound correspondences with which the children were familiarized during the training sessions. This can only be effective if the children have understood the principle by which the sounds are represented by the letters. The results observed are consistent with those reported previously by Gentaz et al. (2003) and confirmed our hypothesis.

The mean number of correctly decoded pseudo-words (close to 0 before the interventions) increased significantly after each of the intervention. However, the amplitude of this improvement depends on the kind of intervention. Indeed, the number of decoded pseudo-words was higher after HVAM training than after VAM training. This result was confirmed by a complementary research in which the HVAM and VAM interventions were evaluated in 42 kindergarten children (see Appendix A). It suggests that the addition of the haptic exploration in the type of training inspired by Byrne and Fielding-Barnsley (1991) almost makes it possible to improve the beneficial effects in pseudo-word decoding. The performances observed after the HVAM training were also higher than those observed after the VAM-sequential training and the VAM training (which did not differ). The sequential exploration of the letters (independently of the perceptual modalities involved) seems not to be sufficient alone. Indeed, a visual sequential exploration of letters did not prove more efficient than a visual simultaneous exploration. It seems that the most important component which can explain the efficiency of this intervention lies in the active motor exploration of letter lead by the children. These results showed that the haptic exploration of letters per se was responsible for these improvements observed after HVAM training.

The results in the test of recognizing the trained letters partially confirmed our hypothesis. The three interventions improved (in a similar way) the mean number of correctly identified target letters. However, as in the previous study (Gentaz et al., 2003), the improvement of the number of recognized letters was not higher after the haptic exploration than after the visual exploration. These results showed that the haptic exploration did not prove more efficient than the visual (sequential or simultaneous) exploration in the learning of letters. This means that the letter knowledge is only a prerequisite to understand and use the logic of the alphabetic principle: it is necessary but not sufficient to decode words. Indeed, children tested before the interventions recognized about four letters but were unable to decode the pseudo-words. After the interventions, children recognized about one letter more but were able to decode five pseudo-words on average after the haptic exploration of letters (HVAM) and only about three pseudo-words after the visual exploration of letters (VAM-sequential and VAM). Although children recognized the same number of letters after the three interventions, only the children trained with the haptic exploration were able to use this knowledge to decode pseudo-words. Thus, one might think that the haptic exploration specifically facilitates the connections between the letters and the sounds and not the knowledge of letters (the performances were similar after the three interventions on letter recognition).

Finally, the rhyme, initial and final phoneme identification tests make it possible to evaluate the effectiveness of the metaphonological exercises presented in the three training programs. The results were compatible with our hypotheses since the three interventions improved performances in each of the three tests in a similar way. This result could be easily explained by the fact that the metaphonological exercises were the same in the three interventions.

Taken together, the results showed that incorporating the haptic exploration in exercises involving letter and letter/sound correspondences knowledge, combined with exercises involving phonemic awareness, increase the positive effects of this type of training on the understanding and use of the alphabetic principle in young children and thus on their decoding skills. If the three interventions permit to improve the knowledge of letters and sounds, only the haptic exploration helps in establishing the link between the orthographic representation of the letters and the phonological representation of the corresponding sounds. This beneficial effect of incorporating the haptic modality could be due to various functional specificities of the sensory modalities. Incorporating the haptic exploration would lead children to process the letters in a more analytical way, something which they do not do implicitly when the letters are presented in a visual form only (simultaneously or sequentially). This would favour the association with the sound of the letter, which is processed auditorily. This hypothesis could also partially explain the beneficial effects of writing activities on the understanding of the alphabetic principle observed in some studies (see, for examples, Gentaz & Dessus, 2004; Zesiger, 1995).

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Appendix A. Control study

The main purpose of this control study was to reproduce the results observed both in the main experiment and in Gentaz et al.'s (2003) experiment. The HVAM and VAM interventions were evaluated in 42 monolingual French children with a mean age of 5 years 7 months (5 years 3 months to 6 years 1 month). Two equivalent groups of 21 children were formed (see Table A.1).

The method (pre- and post-test, the HVAM and VAM interventions) was the same as in the main experiment, except for the proposed phonemes (/a/, /i/, /r/, /l/ /t/). The results in the pseudo-word reading test confirmed the findings observed in the main experiment and by Gentaz et al. (2003), since the improvement in observed performance was greater after HVAM training than after VAM training (see Table A.2; ANCOVA revealed a main effect of training type [$F(1,40) = 17$, $P < 0.01$]). This means that the addition of the haptic

Table A.1
Characteristics of children in each group before the interventions

Training	TVAP-F M (S.D.)	Khos block M (S.D.)	Alphabet letters M (S.D.)	Mean age
HVAM	41.01 (4.3)	9.6 (0.6)	14.04 (5.5)	5 years 5 months
VAM	41.4 (6.8)	9.5 (0.9)	14.85 (4.9)	5 years 6 months

Table A.2
Mean number (and standard deviations) of correct pseudo-words decoding (maximum nine) before and after each of the two interventions in the control study

Training	Period	
	Pre-test M (S.D.)	Post-test M (S.D.)
HVAM	0.14 (0.4)	4.9 (2.3)
VAM	0.43 (0.9)	2.52 (2.6)

mode in this type of training almost makes it possible to improve the beneficial effects in pseudo-word decoding.

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