How can low-skilled 5-year-old children benefit from multisensory training on the acquisition of the alphabetic principle?

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A B S T R A C T

This study aimed at evaluating the effect on letter knowledge and writing of a multisensory exploration of letters as a function of the child's skill level (low vs high-skilled). Five-year-old children were tested on letter–sound knowledge and on letter writing before and after training. Four matched groups were formed: A Control group (C, no contact with letters), a Visual group (V, the child watched the letter), a Visuo-Haptic group (VH, the child touched the letter with the forefinger) and a Visuo-Graphomotor group (VG, highlighting). Results indicated a significant gain percentage in trained letter sounds in the V, VH and VG groups compared to the C group. With regard to letter writing, the pattern of results suggests that highlighting the letter shape could constitute a good classroom teaching method, particularly in the case of low-skilled children. These results are discussed in the light of the different modes of letter exploration.

1. Introduction

Learning to read and spell requires children to discover the alphabetic principle which, in turn, requires the ability to connect phonological and orthographic representations. Longitudinal studies have revealed two powerful predictors – phonological skills and letter knowledge – on the future acquisition of reading (Castles & Coltheart, 2004; Lyytinen et al., 2006; Puolakanaho et al., 2007).

Consequently, various types of training designed to encourage the learning of letter–sound correspondences have been evaluated in young children with the aim of promoting future literacy skills. The study of multisensory letter knowledge training is an important issue for teaching practice (e.g., Bara, Gentaz, Colé, & Sprenger-Charolles, 2004; Longcamp, Zerbato-Poudou, & Velay, 2005). From the beginning of the 20th century onwards, education specialists worked on the basis of empirical evidence to develop multisensory teaching methods (Montessori, 1915). In their review, Ritchey and Goeke (2006) stressed the fact that the Orton-Gillingham method (OG; based on Orton’s (1937) work) was more efficient (9/12 studies) than a classical teaching method. This reading instructional program is a “systematic, sequential, multisensory, synthetic and phonics-based approach to teaching reading. Explicit instruction is provided in phonology and phonological awareness, sound–symbol correspondence, syllables, morphology, syntax, and semantics. A key characteristic of OG reading instruction is that it is multisensory, involving visual, auditory, and kinesthetic/tactile learning pathways (“)” (p. 171). On the one hand, only a small number of studies have shown the positive impact of multisensory training on learning to read in the case of non-readers (Fernald & Keller, 1921) and retarded readers (Bryant & Bradley, 1985; Hulme & Bradley, 1983) with an experimental design. On the other hand, the design of most of the studies presented in the review conducted by Ritchey and Goeke (2006) was quasi-experimental and concerned children already receiving formal instruction. Therefore, further studies seem necessary in order to gain an understanding of the impact of multisensory training. The present experiment aimed at evaluating the effect of a multisensory exploration of letters (auditory, visual and haptic or graphomotor) on the acquisition of letter–sound knowledge and letter writing in 5-year-old low-skilled children (i.e., particularly at risk of future difficulties).

1.1. Positive effect of visuo-haptic exploration of the shape

Behavioral evidence indicates the positive effect of multisensory letter training. The exploration can be auditory (i.e. phonological), visual and haptic (i.e., active manual movement on the shape). Bara et al. (2004) observed a greater improvement following HVAM training (Haptic–Visual–Auditory explorations and Metaphonological training)
than VAM training (Visual–Auditory exploration and Metaphonological training) on pseudo-word reading in 5-year-old children (see Gentaz, Colé, & Bara, 2003; Hillairet de Boisferon, Bara, Gentaz & Colé, 2007 for similar results). In other words, visuo–haptic exploration outperformed conventional training based on the audio–visual exploration of letters. Haptic exploration is also more efficient than handwritten exploration to promote the alphabetic principle in 3-year-old children (Labat, Écalle, & Magnan, 2010). Bryant and Bradley (1985) demonstrated the efficacy of multisensory and phonological training in improving connections between the visual image of a word and its auditory form among preschoolers with reading difficulties. Similarly, Bara et al. (2007) found that 5-year-old children at risk of future reading difficulties obtained better scores in letter recognition and reading after HVAM training than VAM training. Furthermore, their results suggested that these children first acquired letter knowledge (i.e., because of their low-level of letter recognition at the pre-test) and then used this knowledge to boost their awareness of letter–sound correspondences. Finally, haptic exploration has a “bond effect” between orthographic and phonological representations (Fredembach, Hillairet de Boisferon, & Gentaz, 2009). Moreover, visuo–haptic letter exploration has also been found to increase both the fluency of handwriting (Palluel-Germain et al., 2007), the quality of handwriting in 5-year-old children (Bara & Gentaz, 2011) and the fluency of visuo–manual tracking trajectories in adults (Bluteau, Coquillard, Payan, & Gentaz, 2008).

1.2. Positive effect of visuo–graphomotor exploration of the shape

Numerous behavioral, brain imaging and neuropsychological studies have provided evidence of the beneficial effect of visuo–graphomotor exploration (i.e., sequential writing movement). Firstly, the studies conducted by Longcamp and her colleagues observed a higher level of letter knowledge when the motor learning stage required the children to copy letters by hand rather than type them on a computer. However, the effectiveness of this training was dependent on the age of the participants. Learning with handwriting promoted letter knowledge in adults (Longcamp, Boucard, Gilhodes, & Velay, 2006; Longcamp et al., 2008) and in 5-year-old children, whereas it did not result in any improvement in 3-year-old children (Longcamp et al., 2005; see Labat et al., 2010 for similar results). Using an IRMf design, Longcamp et al. (2008) observed an activation of motor areas during visual letter recognition after training which required the participants letters by hand. Vinter and Chartrel (2010) found that visuomotor training (observing and copying moving models) appears to be the most efficient way to improve handwriting movement execution. Other studies have also revealed the positive effect of handwriting training in children at risk of reading difficulties. For instance, Graham, Harris, and Fink (2000) compared two kinds of training among 6-year-old children with writing difficulties: phonological awareness training and combined handwriting and phonological awareness training. The addition of handwriting instruction was found to lead to a greater improvement in handwriting both immediately after the training and 6 month later.

Secondly, neuropsychological studies conducted with alexic patients have provided further evidence of the importance of kinesthetic information for letter knowledge. In a study of two alexic patients, Seki, Yajima, and Sugishita (1995) evaluated a method of treatment based on “kinesthetic information” (tracing and copying a letter with a finger and then read it aloud) and identified a significant improvement in the reading of the trained letters but no improvement in the reading of other letters. In another case report, Bartolomeo, Bachoud-Levi, Chokron, and Degos (2002) presented a patient with an uppercase letter imagery task. The patient V.S.B. was asked to say whether letters named aloud contained curved lines. When he traced the outline of the letter with his finger, his responses were faultless. Finally, the patient M.S. of the Mycroft, Hanley, and Kay (2002)’s study was able to name 8/9 letters correctly after a reeducation in which M.S.’s finger was guided across the table-top to trace the letter-form.

1.3. Aim and hypotheses

Multisensory training could be particularly valuable for children at risk of future difficulties in the acquisition of the alphabetic principle. The aim of the present study, which took account of individual differences, was to assess the effect of three kinds of uppercase letter training (Audio–Visual training, Audio–Visual–Haptic training and Audio–Visual–Graphomotor training) on the learning of letter–sound knowledge and letter writing abilities in 5-year-old children as a function of their individual performance levels. Two groups of children were formed based on their performances in the pre-test: a low- and a high-skilled group. Within each group, we compared the effect of three types of training involving a multisensory approach with a control group (C), which received no letter training. A classical design pre-test/intensive training/post-test was used and we compared improvement on trained vs untrained letters.

We assumed that training would have a different effect depending on the children’s initial performance levels. We expected the gain percentage on trained letters (vs untrained letters) to be higher in the low-skilled than the high-skilled children (1) after V, VH and VG trainings (compared to the C group) in the letter–sound knowledge task (Hypothesis 1) and (2) after the VG training (compared to the C, V and VH groups) in the letter writing task (Hypothesis 2). We did not expect to observe any difference in the level of improvement on untrained letters between the different groups. In the letter writing task, both VG and VH explorations involve the extraction of kinesthetic feedback. Nevertheless, the saliency of visual feedback is greater than in the case

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**Table 1**


<table>
<thead>
<tr>
<th>Training groups</th>
<th>C</th>
<th>V</th>
<th>VH</th>
<th>VG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>65</td>
<td>68</td>
<td>67</td>
<td>68</td>
</tr>
<tr>
<td>Gender</td>
<td>9 boys</td>
<td>11 boys</td>
<td>9 boys</td>
<td>8 boys</td>
</tr>
<tr>
<td>Gender</td>
<td>9 girls</td>
<td>9 girls</td>
<td>11 girls</td>
<td>10 girls</td>
</tr>
<tr>
<td>Mean scores (standard deviations)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Letter–name recognition (/4)</td>
<td>TL 4 (0)</td>
<td>3.94 (0.24)</td>
<td>3.89 (0.47)</td>
<td>3.78 (0.55)</td>
</tr>
<tr>
<td>Letter–sound knowledge (/4)</td>
<td>unTL 4 (0)</td>
<td>3.85 (0.38)</td>
<td>3.72 (0.46)</td>
<td>3.78 (0.55)</td>
</tr>
<tr>
<td>Letter writing (/16)</td>
<td>TL 2.11 (0.96)</td>
<td>2.50 (0.79)</td>
<td>1.83 (1.38)</td>
<td>1.78 (1.44)</td>
</tr>
<tr>
<td>Letter writing (/16)</td>
<td>unTL 1.83 (0.99)</td>
<td>2.56 (1.20)</td>
<td>2 (1.46)</td>
<td>2.33 (1.46)</td>
</tr>
<tr>
<td>Gender</td>
<td>65.5 (3.71)</td>
<td>72.8 (2.27)</td>
<td>7.94 (3.13)</td>
<td>7.67 (3.90)</td>
</tr>
<tr>
<td>Gender</td>
<td>6.8 (4.3)</td>
<td>6.89 (2.19)</td>
<td>7.22 (2.92)</td>
<td>7.44 (3.97)</td>
</tr>
</tbody>
</table>

Notes: TL: trained letters; unTL untrained letters.
of VG exploration. Consequently, these two kinds of feedback in the VG group might make a greater contribution to the development of feedforward movement control (Van Galen, Portier, Smits-Engelsman, & Schomaker, 1993) and facilitate the future development of procedural representations.

Moreover, a facilitating effect was observed between the acquisition of letter–name, letter–sound and letter–sound correspondences (Biot-Chevrier, Ecalle, & Magnan, 2008; Share, 2004; Treiman, 2006). Therefore, and in order to gain a global understanding of the results and better understand the link between these abilities, we studied the variables that predicted the level of letter–sound knowledge and letter writing at the post-test.

2. Method

2.1. Participants

Seventy-two monolingual French children (mean age: 5.6 y-o; range: 60–73 months; 39 girls and 33 boys) took part in this study. These children were attending four kindergarten classes in the South of France, came from middle-class socioeconomic backgrounds and had not yet received any specific alphabet teaching or phonological awareness training. They were randomly assigned to a group: – control (C), visual (V), audio-visual exploration), visual-haptic (VH; auditory-visual and haptic exploration) and visuo-graphomotor (VG; auditory-visual and graphomotor exploration) – matched on age, gender, letter–name and letter–sound knowledge and letter writing performances at the pre-test (4 groups × 18 children).

The characteristics of the four groups before training are presented in Table 2. ANOVAs were conducted on scores to check the matching of the four groups before the training. No difference between the performances of the four groups (C, VH, VHG and VG) and the scores on the different types of letters (trained vs untrained) was identified (F < 1).

In the pre-test, two profiles of children (low versus high-skilled) were formed for each task with automatic classification (K-means clustering) being performed on the scores in the letter–sound knowledge task (i.e., trained and untrained letters). The same procedure was also applied for the letter writing scores (see Table 2a and b). This analysis aimed at identifying homogeneous subgroups by maximizing the inter-variation between groups and minimizing the intra-variation inside each group.

2.2. Material and procedure

This study was conducted at the beginning of the second trimester of the school year (January). The children were tested individually before and after the training sessions (pre-test and post-test) on two tasks: letter–sound knowledge and letter writing. The children were assessed on letter–name knowledge only at the pre-test. The performances of four groups were compared. The control group (C) did not perform any activities relating to letter learning. The three training groups – Visual (V), Visual-Haptic (VH) and Visual-Graphomotor (VG) – were taught the letter–sound correspondences for the letters B, S, U and I (two vowels and two consonants).

The letters were explored sequentially in each training group (as indicated in Fig. 1, i.e. from the blue to red dots following the arrows). We compared the acquisition of trained and untrained (V, D, O and A) letters. To help the low-skilled children, we chose uppercase letters in order to focus their attention on the learning of letter knowledge and letter–sound correspondences. The letters we chose had straight lines and induced sweeping motions that were easy to reproduce compared to the other fonts (Ecalle, 2004; Worden & Boettcher, 1990). The shapes of cursive or script letters could complicate their learning. Moreover, the trained letters had low graphophonemic frequencies (Veronis, 1986). For all these reasons, uppercase letters seemed particularly suitable for low-skilled children.

A training session was scheduled on school days. One letter–sound correspondence was studied in each training session (4 training sessions – 25 min per session – 3 groups + 6 children in each group). The same kind of training was administered for each letter. To summarize, this experiment was intensive and scheduled on seven successive school days (first day: pre-test/from second day to fifth day: four training sessions/sixth day: revision session/seventh day: post-test).

Table 2

<table>
<thead>
<tr>
<th>Training groups</th>
<th>Level</th>
<th>(a) Letter–sound knowledge</th>
<th>(b) Letter writing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>V</td>
</tr>
<tr>
<td>(a) Letter–sound knowledge</td>
<td>High-skilled</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Low-skilled</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>(b) Letter writing</td>
<td>High-skilled</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Low-skilled</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>

2.2.1. Pre-tests and post-tests

2.2.1.1. Letter knowledge: letter recognition and letter–sound knowledge. Letter knowledge was assessed in two successive tasks. In the pre-test, each child was first asked to recognize each target letter (i.e., letter recognition) and then to pronounce the corresponding letter–sound (i.e., letter–sound knowledge). Letter–sound knowledge was also assessed in the post-test, and therefore the improvement in the scores. Nevertheless, we evaluated letter–name knowledge because this facilitates the acquisition of letter–sound knowledge and the links between orthographic and phonological representations (Biot-Chevrier et al., 2008; Share, 2004; Treiman, 2006). Letter recognition was measured only in order to help us match the training groups. As expected, the children exhibited a high level of letter recognition prior
### Table 3
Description of the three trainings.

<table>
<thead>
<tr>
<th>(1) Letter identification</th>
<th>(2) Phonological exercises</th>
<th>(3) Sensory exercises</th>
<th>Revision session</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual training</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Each target letter was printed on a sheet of paper (Times new Roman, size: 200, i.e., 5 cm high). The experimenter presented the target letter to the child in the conventional reading orientation and asked him/her to name it. If the child made a mistake, the experimenter provided the correct answer. Then, the experimenter pronounced the sound corresponding to the letter.</td>
<td>Same exercises for all training groups. Two games involving different equipment were used. During these exercises, children were encouraged to explore the shape of the target letter (i.e., sensory explorations in each training group, see letter identification). A poster game (50 cm × 65 cm) and a card game (12 cm × 9 cm), were presented. In each trial, the pictures corresponded to familiar bisyllabic words, namely three target words (sharing phonological features with the target sound). Each child had to find a word starting or ending with the sound learned during the session. For instance, for the target letter B, the child had to identify the target words beginning with /b/ among the words “bague (ring), poisson (fish), hateau (boating), oiseau (bird), bébé (baby) and dragée (sugared almond)”. The children whispered the answer to the experimenter. All the children’s answers were then announced to the group and discussed in order to identify the correct responses.</td>
<td>Visual training Phase 1: letter exploration The experimenter presented the trained letter, printed on a sheet of paper to the child. The child then had to look at the letter eight times in accordance with the fixed exploratory instructions spoken aloud during the child’s exploration of the letter (e.g., “look at the blue point, then look at the arrows that come down…”). The purpose of these instructions was to reinforce the visual exploration of the letter through a global processing mode compared to analytical processing in the case of haptic and graphomotor explorations. Similarly, the number of explorations was greater than in the VH and VG training groups. While the children explored the letter, the experimenter checked that the exploratory movements respected these instructions and corrected them if necessary. Phase 2: letter recognition A sheet of paper containing two lines of six letters was each presented to the child. Each line contained target letters and three kinds of filler letters (sharing graphic and phonological similarities with the trained letter). Children were asked to circle target letters. If they made a mistake, the experimenter told them to take their time and look for the correct letter again.</td>
<td>Same session for all trainings Letter knowledge recall The experimenter reminded the children of the letter name, letter sound and the shape of each target letter. The shape was reactivated using the letter identification exercise specific to the training group involved (see above). Consequently, the exploration of the shape was performed in the visual, visuo-haptic or visuo-graphomotor experiences. <strong>Phonological exercise</strong> As in the phonological exercises used in the training sessions, the children were asked to identify the target sound. The words began or ended with the target sound. All the trained sounds were mixed together in a game of dominos. Each game consisted of twelve dominoes (12 cm × 9 cm), each of which contained two familiar pictures, which the children had seen before on the posters and in the card games. The pictures represented words beginning with one of the four trained letter sounds. Participants had to match words with the same starting sound (First game: e.g., sabot-balai (hoof-brown) ballon-idée (balloon-idea)) or ended with the target sound (Second game: e.g., toit-brosse (crooked-hairbrush) casse-crabe (checkout-crab)).</td>
</tr>
<tr>
<td><strong>Visuo-haptic training</strong></td>
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<tr>
<td>The child had to identify the name of a foam target letter presented in relief in the correct orientation (5 mm thick + 5 cm high). If the child made a mistake, the experimenter provided the correct answer. He then spoke the corresponding letter–sound aloud.</td>
<td>Visual training Phase 1: Letter exploration The same foam target letters, accompanied by filler letters, were presented to the child. The experimenter guided each child’s forefinger to help him or her to discover the shape and outline of the letter in the fixed order. The first two explorations were visuo-haptic and the second two only haptic. While children explored the letter, the experimenter checked that the exploratory movements respected the instructions and corrected them if necessary. Phase 2: Letter recognition In the manual recognition test, children were blindfolded and had to recognize the target letter in the presence of a distractor letter (5 cm high) following haptic exploration (i.e., D–B, U–V, S–R, and I–J). This phase was performed individually. If the children failed to identify the letter correctly, the experimenter told them to explore the letter again.</td>
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<tr>
<td><strong>Visuo-Graphomotor training</strong></td>
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<tr>
<td>Same as the V training</td>
<td>Visual training Phase 1: letter exploration The experimenter guided each child’s hand individually to highlight the outline of the “complete” letter with a pencil in a fixed exploratory order. The child was then asked to carry on and highlight the four stippled letter in his/her own. Children had an eraser to correct their writing movements if they made a mistake. While the child was highlighting the shape of the target letter, the experimenter checked that the highlighting movements respected the fixed order and corrected them if necessary. Phase 2: letter recognition Same as V training.</td>
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</table>
to instruction. The corresponding scores are reported in Table 1. Twelve letters printed on a board were shown to the child (4 trained letters, 4 untrained letters and 4 distractor letters). First of all, the experimenter named the letter aloud and the child had to recognize the target letter. Next, the child had to say the corresponding sound aloud. In each task (letter recognition and letter–sound knowledge), one point was awarded for a correct answer (maximum score in each experimental condition (2 conditions): Trained and untrained letters) = 4 points).

2.2.1.2. Letter writing. The child was asked to write eight pseudo-words corresponding to imaginary individuals with a pencil. The pseudo-words were bisyllabic and half of them used trained letters (e.g., BUSI) while the other half used untrained letters (e.g., DAVO). The presentation of the pseudo-words was randomized across the children. Each target letter appeared in the first (e.g., BUSI) second (UBIS), third (SIBU) and fourth position (SIBU) in each pseudo-word. The number of correctly written letters was assessed without regard to position (e.g., “BSI” and “SIB” for “BUSI” both scored 3 points). One point was awarded for each correctly written letter (maximum score in each condition (2 conditions): Pseudo-words made from trained or untrained letters) = 4 pseudo-words × 4 letters = 16 points).

2.2.2. Training sessions

The control group received no letter training. Instead, the children constructed objects in two or three dimensions using a variety of materials (e.g., paper, glue). Session duration was the same as for the other training groups. Table 3 illustrates the training session for the V, VH and VG groups. The V, VH and VG training session used the same design (see Bara et al., 2004 for similar training): (i) letter identification, (ii) phonological exercises (posters and card games) and (iii) a sensory exercise consisting of two phases: letter exploration (phase 1) and letter recognition (phase 2). One training session began with the letter identification and the poster-based phonological exercises, continued with the sensory exercise and ended with card game-based phonological exercise. The children were seated around a table and each child was asked to contribute individually during each exercise.

The aim of the letter identification phase (i) was to learn the letter–name and letter–sound. The purpose of the phonological exercises (ii) was to improve segmentation abilities. Finally, the sensory exercises (iii) were specific to the various types of training. In the letter exploration phase, the V, VH and VG training groups differed in terms of the number and the nature of sensorimotor explorations involved. In the dual-mode V training, the letters were explored in the visual and auditory modalities. In the three-mode VH and VG training groups, an additional kinesthetic exploration, not present

3 The French Ministry of Education specifies that letter name knowledge is a required competence in kindergarten.

4 Gain percentages (g en %) were calculated with \((M (\text{post-test}) - M (\text{pre-test})) / \max \text{imum in each experimental condition} \times 100\).

in the audio-visual group, was used. The time taken to explore the shape (phase 1) was the same for the three groups. The letter was touched (VH group) or was highlighted (VG group). Finally, the children were reminded of the acquired letter–name, letter–sound knowledge and the corresponding shape concerning the target letter at the end of the training session.

The revision session was scheduled at the end of the four training sessions. This session had the same design as the corresponding training sessions. For the control group, the task was to reproduce a new object. For the three training groups – V, VH and VG –, the aim of the revision session was to recall, on the one hand, knowledge of each target letter (letter–name, letter–sound and shape) on the basis of the specific sensory-motor exploration undertaken by each training group (i.e., see training above) and, on the other, to promote phonological abilities (i.e., game of dominos).

3. Results

ANOVA were conducted on gain percentages with two between-factor, Training Group (Control – C, Visual – V, Visuo-Haptic – VH and Visuo-Graphomotor – VG) and Level (low and high-skilled) and one within-factor, Letter (trained and untrained letters). When a significant effect and interaction emerged, the effect size was calculated using partial eta-squared (\(\eta^2\)). Moreover, post-hoc Tukey comparisons were conducted and Cohen’s d values were also calculated when a priori hypotheses were planned (Howell, Rogier, & Yzerbyt, 1998). A stepwise multiple regression analysis was then conducted on the scores obtained in the various tasks (letter recognition, letter–sound knowledge and letter–writing) at the pre-test and post-test.

3.1. Letter–sound knowledge

The ANOVA revealed a number of main effects: a Training Group effect, \(F (3, 64) = 19.27, p = .0001, \eta^2 = .47\), a Level effect, \(F (1, 64) = 72.09, p = .0001, \eta^2 = .53\), and a Letter effect, \(F (1, 64) = 51.64, p = .0001, \eta^2 = .45\). First of all, the gain percentages observed in the V, VH and VG groups (gain (V) = 19%; g (VH) = 26%; g (VG) = 35%) were greater than in the C group (g = 5%; comparison of C and VG groups: \(p = .001\) d = 7.5; comparison C-VH: p = .02, d = 5.25; comparison C-V: p = .04, d = 3.5). Furthermore, the gain percentage in letter–sound knowledge among the low-skilled children (g = 36%) was greater than among the high-skilled children (g = 2%). Finally, trained letters–sounds (g = 31%) were better recognized than untrained letter–sounds (g = 6%).

A Group × Letter Interaction, \(F (3, 64) = 4.37, p = .007, \eta^2 = .17\), was observed (Fig. 2). Post-hoc Tukey comparisons indicated a significant gain percentage on trained letter–sound with the V (d = 6), VH (d = 7.8) and VG trainings (d = 9.8) compared to the C group (ps = .0001). No difference between the four groups was observed on untrained letter–sound gains (ps > 1). Moreover, the gain percentage on trained letter–sounds was greater than that for untrained letter–sounds in the V, VH and VG groups. This comparison was not significant in the C group (p > 1).

The other interactions were not significant (F < 1).

3.2. Letter writing

The ANOVA conducted on the gain percentages indicated a number of main effects, a Training Group effect, \(F (1, 68) = 6.47, p = .0007, \eta^2 = .23\), a Level effect, \(F (1, 68) = 16.01, p = .0002, \eta^2 = .2\), and a Letter effect, \(F (1, 68) = 18.76, p = .0001, \eta^2 = .23\). First of all, the gain percentages observed in the V, VH and VG groups (gain (V) = 9.7%; g (VH) = 9.4%; g (VG) = 13%) were better than in the C group (comparison C-VG;
p = .001, d = 6.5; comparison C–VH groups: p = .02, d = 4.7; comparison C–V: p = .04, d = 4.85). In addition, low-skilled children achieved greater gain percentages in letter writing (g = 36%) than high-skilled children (g = 2%). Finally, the gain percentages were superior for the correctly trained letters (g = 13%) than for the untrained letters (g = 3%).

A Group x Letter Interaction, $F (3, 64) = 4.18, p = .009, \eta^2_p = .16$, was observed. Post-hoc Tukey comparisons indicated a significant gain percentages on the trained letters ($p < .002$ = with the V ($d = 5.93$), VH ($d = 5.6$) and VG groups ($d = 8.27$) compared to the C group). No difference on untrained letters was revealed between the four groups ($p > .1$). Moreover, the gain percentage on trained letters was greater than that on untrained letters only with the VG training ($p = .003; d = 6$). This difference was not observed in the C, V and VH groups ($p > .1$).

Furthermore, a marginally significant Letter x Level x Group interaction was observed, $F (3, 64) = 2.29, p = .08, \eta^2_p = .1$ (Fig. 3). Tukey comparisons indicated a greater gain percentage on trained than on untrained letters after VG training in the low-skilled children ($p = .003; d = 7.5$). The other comparisons were not significant ($p > .1$). In the case of the high-skilled children, no significant difference between types of letter was identified in response to any of the training modes. In addition, the gain percentage on trained letters among the low-skilled children was greater in the VG group than in the C group ($p = .0001; d = 8.33$). None of the comparisons between training groups for the trained and untrained letters was significant among the high-skilled children ($p > .1$). Finally, the low-skilled children achieved a greater gain percentage than the high-skilled children on the trained letters only after the VG training ($p = .01, d = 6.25$).

The other interactions were not significant ($F < 1$).

### 3.3. Correlation and regression analyses

Firstly, a correlation matrix (Pearson product–moment correlation coefficient, $r$) was used to examine the relationships between the performance obtained by the 72 children at the pre-test (letter recognition, letter–sound knowledge and letter writing) and performance at the post-test (letter–sound knowledge and letter writing). The results are presented in Table 4. Positive correlations were identified between letter–sound knowledge at the post-test and performance at the pre-test in: (a) letter recognition ($r = .23$), (b) letter–sound knowledge ($r = .28$) and (c) letter writing ($r = .28$). As far as the letter writing task is concerned, performance in the post-test was associated with the prior ability to write letters ($r = .84$) and to pronounce their sounds ($r = .24$).

Stepwise multiple regression analyses were then performed to examine the unique contribution of all these measures at the level of (a) letter–sound knowledge and (b) letter writing. In the first analysis, the dependent variable was the letter–sound knowledge score at the post-test, while scores in all other tasks at the pre-test were considered as potential distal predictors. The variables were entered as a function of their level of correlation in the tested model (i.e., procedure with forward stepwise at each step – 3 steps in this study). The analyses are presented in Table 5 and the models accounted for a lower amount of variance because the children were evaluated in only a small number of tasks at the pre-test. Firstly, the scores in the pre-test accounted for 14% of variance in letter–sound knowledge (distribution: 8% letter writing, 4% letter–sound knowledge and 2% letter recognition). Second, in the letter writing task, model 1 indicated that the measurements in the pre-test accounted for 70% of variance. Model 2 showed that 8% of the variance was explained by letter–sound knowledge ($6\%$) and letter recognition ($2\%$) when prior knowledge of letter writing was controlled for.

### 4. Discussion

The aim of the present study was to assess the effect of three multisensory trainings (compared to a control group) on the learning of letter–sound knowledge and letter writing in 5-year-old children as a function of their level of performance (low vs high-skilled). These training programs differed in terms of the kind and number of sensory modalities involved in the exploration of the shape of uppercase letter (Visual group (V), Visuo-Haptic group (VH) and Visuo-Graphomotor group (VG)).

In the letter–sound knowledge task, the gain on the trained letters was better after V, VH and VG training than in the C group. Moreover, this gain appeared to be larger than the gain on the untrained letters. An intensive training course implies an improvement in letter–sound knowledge. Nevertheless, no difference in the rate of acquisition between low vs high-skilled children emerged since a substantial level was already identified in the two clusters at the pre-test (Hypothesis 1 partially confirmed). This experimental task was not sufficiently sensitive due to the restricted number of items. Standardized tests would appear to be more appropriate in a future study in order to assess the possibility of generalizing the results. In the letter writing task, the improvement on trained letters was superior compared to the untrained letters after the VG training in low-skilled children. This trained letter score was better in the VG group than in the C group and was greater than the high-skilled children. Comparisons between VG and VH or V revealed no significant difference (Hypothesis 2 partially confirmed). Nevertheless, this pattern of results suggests that a VG exploration of the shape is more sensitive and enhances a higher acquisition of phono-graphemic correspondences and the corresponding graphic movement than V and VH explorations in low-skilled 5-year-old children. A subsequent post-test should be planned to test whether (1) the knowledge is maintained in long-term memory and (2) the VG training of uppercase letters is more efficient than V and VH trainings.

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5 The French Ministry of Education recommends starting the teaching of letter–sound knowledge in kindergarten.
Multiple regression analyses indicated that earlier scores in letter recognition, in letter–sound knowledge and in letter writing predicted some of the variance in the future ability to learn letter–sounds or to write these letters. These results are not in line with research conducted in English (e.g., Treiman, 2006; Share, 2004 for behavioral evidences) as well as French studies (e.g., Biot-Chevrier et al., 2008). Indeed, a high level of letter–name knowledge (observed in the pre-test) enhances the learning of the corresponding letter–sound knowledge and facilitates the acquisition of letter–sound correspondences. One explanation is that the letter–name contains clues concerning the corresponding letter–sound. Decoding skills involving the phonological mediation procedure is a good predictor of the future development of lexical orthographic knowledge (Share, 1999). Moreover, alphabet knowledge has been found to make a significant contribution to children’s letter writing skills and this letter ability predicts spelling skills in 4–5-year-old children (Puranik, Longan, & Kim, 2011).

The effects of trainings in this experiment are consistent with the findings of developmental and educational studies. For instance, Byrne, Fielding-Barsley, and Ashley study (2000) indicating that training involving the visual-auditory exploration of letters and phonological exercises also promotes letter–sound knowledge. Multisensory training involving visual–auditory and haptic explorations has also been found to enhance the acquisition of reading (Bara et al., 2007, 2004; Gentaz et al., 2003; Hillairet de Boisfaron, Bara, Gentaz, & Colé, 2007) and writing movements (Bara & Gentaz, 2011; Bluteau et al., 2008; Fredembach et al., 2009). Moreover, behavioral studies (e.g., Graham et al., 2000; Longcamp et al., 2005), as well as neuropsychological case reports involving alexic patients (e.g., Seki et al., 1995), suggest that handwriting training improves letter recognition and reading performances. Labat et al. (2011) showed also that a visuo-graphomotor exploration of shapes led to a greater increase in spelling scores than visuo-haptic exploration. In the present study, the pattern is similar. A phonological and multisensory training program based on visual and graphomotor exploration was found to constitute a particularly effective training method and helps young children who are struggling with the alphabetic code. It is therefore important to grasp the optimum conditions for letter learning in greater depth and gain an understanding of how the early training of letter knowledge can help children to master the alphabetic principle.

More generally, our results further reinforce the emphasis placed on the development of multimodal letter knowledge. Motor experience seems to play an important role in the emergence of knowledge in the field of education (letter knowledge, reading, spelling and graphic movements). In addition, a visuo-haptic intervention relating to the properties of the shapes also resulted in better geometrical performances than a visual intervention in kindergarten children (Kaline, Pinet, & Gentaz, 2011; Pinet & Gentaz, 2008). Multisensory experience (visual, haptic and motor) implies simultaneous multiple codings in memory and creates a more distributed trace in memory, which may facilitate the emergence and the reactivation of knowledge (Versace, Labeye, Badard, & Rose, 2009; Longcamp et al., 2008). Indeed, the same motor areas are activated when executing and observing actions (Kosslyn, Thompson, & Alpert, 1997).

5. Conclusion

This study suggested that learning through the visuo-graphomotor exploration of uppercase letters seems to boost low-skilled 5-year-old children in the acquisition of the alphabetic principle. Our results suggest that a multimodal letter representation facilitates the emergence of alphabetic knowledge (see Labat et al., 2010, 2011; Longcamp et al., 2008, 2005; Seki et al., 1995). The experimental research reported in this paper confirms the results of previous studies, most of which have been quasi-experimental in design (see Ritchey & Goike, 2006 for a review). Highlighting the shape constitutes an effective classroom teaching method and helps young children who are struggling with the alphabetic code. It is therefore important to grasp the optimum conditions for letter learning in greater depth and gain an understanding of how the early training of letter knowledge can help children to master the alphabetic principle.

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