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Visual and proprioceptive recognition of cursive letters in young children

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ABSTRACT

Two experiments investigated visual and proprioceptive recognition of cursive letters in young children. In Experiment 1, children aged 3–5 years were asked to recognize a visually presented target letter after a 3 s inspection time, from among two distracters: a highly and a moderately similar letter. Visual letter recognition improved rapidly between 3 and 5 years and was a function of the "uniqueness" of letter shape and of letter frequency. In Experiment 2, children aged 4–6 years were asked to recognize a target letter from among 2 distracters, after having traced over the letter in a "blind" condition, with their hand guided by the experimenter. Proprioceptive recognition developed more slowly than visual recognition, and was not a function of letter frequency. The results are discussed in terms of integration versus differentiation of perceptual information, and of the tendency to base recognition on local rather than global similarity.

1. Introduction

Despite the increasing use of computers at school, learning to write by hand remains one major acquisition children have to master during the first years of elementary education. Failure of this learning process leads often, if not inevitably, to poor school performance. A body of research has shown that when children experience difficulties in performing handwriting movements, they encounter difficulties in the process of expressing ideas (Jones & Christensen, 1999) or producing texts (Berninger, 1999; Graham, 1990; Graham, Harris, & Fink, 2000). Thus, studying the different processes that contribute to learning to write by hand in young children appears important.

Learning to write involves a perceptual component (learning the shape of the letter) and a motor component (learning the trajectory producing the letter's shape). From a developmental point of view, Lurçat (1974) is one of the rare authors to have studied the early phase of handwriting development, before school instructions occur. She showed that when children begin to copy letters, between 4 and 5 years, a conflict arises between the production of the letter's shape (mainly guided by visual information) and the production of the trajectory normally associated with this letter (guided by proprioceptive information). This conflict is first resolved to the benefit of the letter's shape, as it is more or less accurately reproduced even though the trajectory is wrong. Between 5 and 6 years, children learn to associate the correct trajectory with each specific letter's shape and the conflict appears fully resolved.

These two sensory components involved in handwriting, vision and proprioception, are so intimately entwined that strong relationships have been revealed between perceiving, reading and writing letters (e.g., Bartolomeo, Bachoud-Levi, Chokron, & Degos, 2002; Longcamp, Anton, Roth, & Velay, 2003). In preschool children, Longcamp, Zerbato-Poudou, and Velay (2005) demonstrated that handwriting training resulted in better letter recognition than typing training. A similar study conducted with adults learning artificial characters by writing or typing them also concluded that participants showed better memory of the characters following handwriting training, probably because motor commands and kinaesthetic feedback are closely linked to visual information, at a spatial and temporal level, in handwriting (Roll, Albert, Ribot-Ciscar, & Bergenheim, 2004), but not in typing (Longcamp, Boucard, Gilhodes, & Velay, 2006). Hulme (1979) has shown that in children aged 8–9 years, the very production of tracing movements aided visual recognition of unknown patterns in comparison to a condition where children simply looked at the forms. This literature leaves very little doubt that building accurate visual and proprioceptive or kinaesthetic representations of each cursive letter is extremely important, both in learning to write and, more generally, in all early literacy development.

However, to our knowledge, the current literature does not offer any data indicating whether young children, before they start handwriting learning, are able to visually or proprioceptively

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recognize the specific shapes of cursive letters. None of the very few studies that had explored letter recognition in children had used cursive shapes (Courrieu & de Falco, 1989; Gibson, Osser, Schiff, & Smith, 1963). The present two experiments deal with this question. Children were asked to identify a target letter from among two distracters, one very similar to the target, one moderately similar. This test of identification ability followed either visual inspection of the target for a short time (Experiment 1), or practice in tracing of the letter in a semi-passive guided condition, without being able to see the letter or the hand (Experiment 2).

Cursive letters are patterns that possess varying degrees of shape or trajectory similarity, making confusions between some of them more probable than between others. The recognition of a letter involves analyzing the shape, position and orientation or direction of each feature (processing of local features), in order to achieve a complete letter percept (coordination of wholistic properties and local features). Information is delivered simultaneously in the case of visual recognition, while it is necessarily delivered sequentially in the case of proprioceptive recognition. A further step of integration may therefore be needed in proprioceptive recognition, in order to build a global representation of the traced letter, as it occurs through haptic object exploration (Berger & Hatwell, 1996). Thus, processing information in a configural fashion, on the basis of global letter shape similarity, should be enhanced in the visual experiment as compared to the proprioceptive one, because young children's strong limits in working memory (e.g., Cowan, 1997) would prevent them from achieving accurate integration of sequentially delivered information. If, instead of sequentially integrating information in the proprioceptive condition, children progressively differentiated information (e.g., Gibson, 1969), the sequential nature of proprioceptive information should not hamper letter recognition because letter identification would progressively emerge during the course of the differentiation process, without requiring maintaining prior information in memory.

A body of research has reported that younger children have a greater tendency to process information in smaller and local parts than older children (e.g., Dukette & Stiles, 1996; Tada & Stiles, 1996; Vinter, 1999; Vinter & Marot, 2007). Carey and Diamond (1977), for instance, claimed that configurational visual processing evolves progressively during development, starting from a tendency to focus attention on local features. In a similarity judgment task, Kramer, Ellenberg, Leonard, and Share (1996) have shown that younger children privileged local similarities while older children tended to base their judgments on global similarities. In this perspective, we expect that in case of recognition errors, older children will select the most similar distracter more often than younger children, at least in the visual recognition task. However, if perception is initially structured around undifferentiated similarities (e.g., Garner, 1974; Gibson, 1969) and becomes more differentiated and selective as a function of experience, younger children may select the most similar distracter as often as the moderately similar distracter.

Beyond the role played by shape similarity in a letter recognition task, experiential factors surely also influence the ease with which children can recognize letters. The role of two exposure-related factors is worth investigating. Firstly, the repeated and frequent exposure to the letters comprising one's own first name should have an effect. Indeed, it has been shown that preschool children's letter knowledge is more developed for the letters forming their first names (e.g., Ferreiro & Teberovsky, 1982; Treiman & Broderick, 1998). A similar advantage for one's own first name letters could appear in our recognition task, though children aged between 3 and 5 years are, in general, less exposed to cursive than to printed letters. Secondly, in the visual experiment, a general effect linked to the frequency of letters in the children's written environment could also be expected, because a noticeable proportion of letters (c, d, e, i, n, m, o, q, t, u, v, w) retain a similar visual shape from printed to cursive writing. Letter naming performance, for instance, has been shown to be a function of letter frequency, with errors being produced more often for less common letters (Treiman, Kessler, & Pollo, 2006). It is likely that visual letter recognition is also a function of letter frequency. Therefore, visual recognition of frequent letters should be higher than that of less frequent letters. We did not expect to observe such a frequency effect in the proprioceptive experiment, because the frequency data we had at our disposal were extracted from children's reading textbooks, a source of information relevant for the question of visual letter recognition, but not, a priori, for proprioceptive letter recognition in young children.

2. Experiment 1

The first experiment deals with visual recognition of cursive letters' shapes in children. After a brief visual inspection of a letter, children had to recognize this target among two distracters, one with a high visual similarity and one with a moderate visual similarity. Classifications made by 20 college students, who were asked to sort the cursive shapes on the basis of their global visual similarity, were used. The matrix of percentages of association between letters thus obtained showed that some letters were systematically sorted into the same category (b, h, k, l in particular), whereas there was much less consistency between participants' classifications for letters like i, r, s or t. The most similar distracters corresponded to the letters that were most often sorted together into the same category by adults, i.e. letters that had the highest percentages of association with the target. The moderately similar distracters corresponded to those letters showing percentages of association with the target matching or approximating half of the value of the highest percentages. If some letters were systematically judged as most similar to a target (100% of association), we selected as moderately similar letters those associated in 50% of the cases (or in the closest percentage to 50%). Table 1 presents, for each letter, the corresponding most similar or moderately similar letters, together with their respective mean association percentage.

We may expect children to be better at recognizing letters possessing rather specific shapes (i, r, s, or t) than letters with more common shapes (b, h, k, l) because the closer the similarity, the more difficult the recognition task. However, if young children are more prone than older ones to focussing on local details, they may pay particular attention to salient local marks such as, for instance, the dot on i and j, selecting thus j (moderately similar distracter) instead of t (most similar distracter) when they have to recognize i. Similarly, this tendency to focus on local features (e.g., the small ascending final segment in letter o) may make a letter highly recognizable (in our example, letter o), whereas adults judged this letter highly similar to another one (in our example, to letter a).

2.1. Method

2.1.1. Participants

Sixty-two right-handed children (32 females and 30 males), aged between 3 and 5 years, participated in the experiment. They were divided into three age groups (3-year-olds: mean age = 3.1 years, n = 20, 11 females and 9 males, range = 2 years 11 months to 3 years 4 months; 4-year-olds: mean age = 4.1 years, n = 21, 10 females and 11 males, range = 3 years 10 months to 4 years 3 months; 5-year-olds: mean age = 5.1 years, n = 21, 11 females and 10 males, range = 4 years 10 months to 5 years 3 months). Each age group corresponded to one school level (5-year-olds: last

Table 1
Most visually similar distracters and moderately visually similar distracters associated to each letter target (in brackets, their respective mean percentage of association)

Target	Most similar distracter		Moderately similar distracter	
a	o	(90%)	q, s	(40%)
b	h, k, l	(100%)	f	(65%)
c	e, o	(65%)	s	(30%)
d	a, o	(65%)	e	(35%)
e	c, o	(65%)	d, s, x	(35%)
f	b, h, k, l	(65%)	j	(25%)
g	j, y, z	(65%)	a, d, f, o	(20%)
h	b, k, l	(100%)	f	(65%)
i	t, u	(40%)	j, p	(20%)
j	y, z	(70%)	f, i, q	(25%)
k	b, h, l	(100%)	f	(65%)
l	b, h, k	(100%)	f	(65%)
m	n	(100%)	v, w	(40%)
n	m	(100%)	v, w	(40%)
o	a	(90%)	s	(45%)
p	q	(55%)	j, y, z	(25%)
q	o	(55%)	c, z	(20%)
r	u	(30%)	a, o, p, v, w	(15%)
s	a, o	(40%)	r	(20%)
t	d, i	(40%)	b, h, k, l	(20%)
u	v, w	(65%)	i, r	(30%)
v	w	(95%)	m, n	(40%)
w	v	(95%)	m, n	(40%)
x	c	(50%)	d, v	(25%)
y	j, z	(75%)	p	(30%)
z	j, y	(70%)	p, r	(25%)

kindergarten level). A further group of children aged 6 on average (first elementary grade) was also tested, but it was removed from the analysis because of ceiling effects (all the responses were correct).

Handedness was assessed by means of simple tests drawn from Bryden (1977). Eight items were used, 4 were unimanual (drawing, throwing a ball, holding scissors and brushing one's teeth) and 4 were bimanual (tightening the lid on a bottle, hitting a nail with a hammer, lighting a match and wiping a plate with a cloth). Only children who obtained a score equal or superior to 6 were selected. None of these children was educationally advanced or retarded or had psychomotor deficits in drawing or handwriting. Their vision was normal or corrected to normal. Children were from middle SES families in 88% of the cases. They were all monolingual French-native speakers, born in France. They were observed individually in a quiet room inside their schools. The experiment was run early in the school year (between September and October). None of the children, even the oldest, had received at that time any systematic training in cursive handwriting. All children aged 4 and 5 knew how to write their first name in capital letters, at least partially; only a few children at 3 years possessed this ability. Around 40% of the children aged 5 also knew how to write their first name with lowercase script characters. Informed consent was obtained from the parents of each child participating in the study.

2.1.2. Materials

The materials included 26 white cards (format: 6 cm width, 10 cm length) on which cursive letters were printed (one letter per card), centred on the card. These shapes are illustrated in Fig. 1. The height of the letters was 1.5 cm for a, c, e, i, n, m, o, r, s, u, v, w and x, 3.5 cm for b, d, g, h, j, k, l, p, q, t, y, z and 6.5 cm for f. Because the same material was used in Experiment 2, the height of the letters was devised to enhance proprioceptive recognition at a better than chance level in the youngest children. A white opaque screen (30 cm × 21 cm) was used both to reveal the target letter for 3 s and to conceal it afterwards.

2.1.3. Procedure

Children were seated in front of a table on which the opaque screen had been placed approximately 15 cm away from them. They were told to examine very carefully the letter that was going to be revealed when the screen was removed because they would then be asked to recognize this letter from among two others. They were informed that the target letter would remain visible for only a short time. The experimenter ensured that the children had understood the instructions before starting the experiment. When the screen was removed, the target letter remained visible for 3 s, before the screen was lowered again. Out of sight of the children, the experimenter added two distracters (one most similar, one moderately similar) behind the screen. When more than one distracter was available (see Table 1), the experimenter selected alternately one letter or the other across children within each age group.

The three letters were arranged in a line, and the position of the target letter (left, middle, right) was random. The screen was removed again, and children had to point to the letter they had just seen before. There was no restriction on the time allowed to make a response, and it rarely exceeded 6–8 s. Their choice was recorded.

Fig. 1. The cursive letters used in the experiments.

The screen was lowered, the three letters removed, and the following target letter was put in place. This sequence was repeated 26 times so that children were exposed to the 26 cursive letters of the alphabet in a random order. The duration of 3 s for letter inspection time was determined empirically in a pilot study, in such a way that a percentage of correct recognition close to 50% was attained at 3 years. This duration was controlled directly by the experimenter, using a small clock.

2.2. Results

2.2.1. Accurate letter recognition scores

We calculated the number of correct letter recognition responses, assessed on the entire alphabet, on a set of letters reduced to those belonging to each child's own first name (considering all children, all of the letters in the alphabet were present in this set, though some were infrequent) and to those that possess a very similar shape in cursive and manuscript writing (c, d, e, o, i, q, t, u, v, w). Letters m and n were not included because the printed letter m is almost as similar to m as to n in French cursive handwriting. An ANOVA with Age (3) as a between-subjects factor was run on these dependent variables. We also computed the number of correct responses on the set of letters that were not included in each child's own first name (not-in-name letters) and on the set of letters that have different shapes in cursive and printed writing (a, b, f, g, h, j, k, l, p, r, s, x, y, z). *T*-tests were run to compare performance for in-name versus not-in-name letters, and for unchanged versus modified letters. Fig. 2 shows the percentages of correct letter recognition as a function of age for the entire alphabet, the in-name letters and the letters similar in cursive and printed writing.

Age was significant regardless of the set of letters considered - the entire alphabet, $F(2, 59) = 25.1$, $p < .001$, partial $\eta^2 = .46$, the letters belonging to the child's own first name, $F(2, 59) = 15.3$, $p < .001$, partial $\eta^2 = .34$ and the unchanged letters, $F(2, 59) = 21.2$, $p < .001$, partial $\eta^2 = .42$. Post hoc tests (Scheffé test) showed that the increase in letter recognition ability was significant between 3 and 4 years ($p < .05$) as well as between 4 and 5 years ($p < .01$). Performance reached 93% of success at 5 years, preventing any meaningful differences between types of letters. Regardless of the set of letters, recognition performance was systematically above chance (33.33%) at 3 years ($t_s(19) > 3$, $p < .01$), and of course at the older ages (p_s.01). An advantage for letters belonging to one's own first name (55.6%), as compared to not-in-name letters (42%), was significant at 3 years, $t(19) = 3.3$, $p < .05$, but not at 4 years ($p > .20$). Letter recognition scores were higher for unchanged letters (71.9%) than for those presenting different shapes in cursive and manuscript (57.7%) at 4 years, $t(20) = 4.1$, $p < .001$, but not at 3 years ($p > .20$).

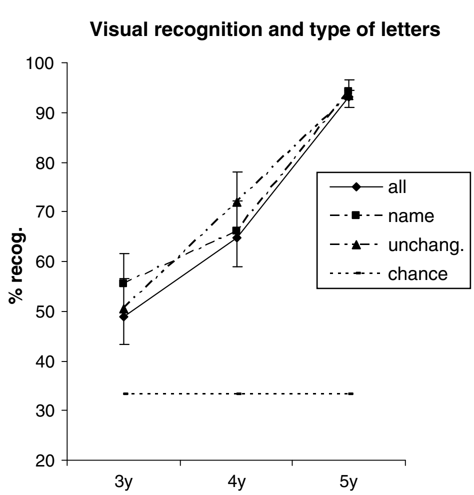

Fig. 2. Percentages of correct letter recognition as a function of age in Experiment 1 (all: for the entire alphabet; name: for in-name letters; unchanged: for letters with invariant shapes in cursive and printed handwriting). Error bars indicate standard-errors.

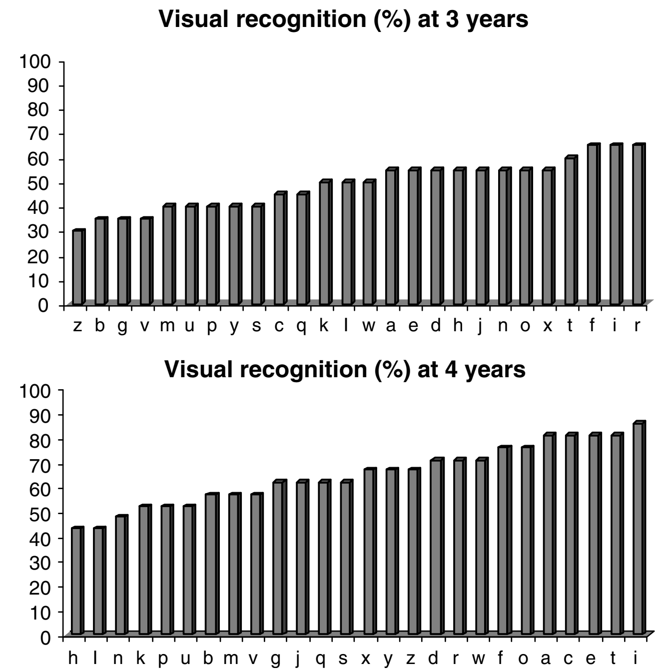

Fig. 3. Percentages of correct recognition for the entire alphabet letters (letters are ordered along the *x*-axis from the less frequently to the most frequently recognized letter) at 3 and at 4 years (Experiment 1: visual condition).

A more detailed look at the results can be obtained by analyzing letter recognition performance as a function of letters. Fig. 3 presents the recognition scores obtained for each letter at 3 and 4 years, the letters being arranged on the *x*-axis from the least to the best recognized. At 5 years, only 3 letters got a score below 85% of success (but above 75%, namely, u, w and y).

The letters that were best recognized at 3 years included i-t-r (letters with vertical strokes), and f (the bigger letter with both an ascending and descending loop). At age 4, t-i-f remained among the best recognized letters, to which a-o-c-e (round patterns) were added. The less well-recognized letters comprised z-g-b (descending or ascending loops) and v (humped letter) at 3 years, h-l (ascending loops) and m (humped letter) at 4 years. Thus, letters that were either easy or difficult to recognize tended to be, respectively, those that had high or low percentages of association with other letters in the sorting by similarity task given to college students. Indeed, the correlation between the mean recognition score for each letter at age 4 and its maximum percentage of association with other letters (see Table 1) was significant, $r = -.51$, $p < .001$. At 3 years, this correlation did not reach significance, $r = -.29$, $p = .14$, but was also negative. Data from the three age groups mixed, the correlation was high and significant, $r = -.52$, $p < .001$. This means that the higher the similarity between letters (as judged by adults), the worse the discrimination by these preschool and kindergarten children, though the trend was not significant at age 3.

Because letter recognition scores at 4 years were higher for those letters that did not undergo a change of shape from printed to cursive writing, it was likely that they correlated with some frequency index of alphabetical letters in written texts. We used a database (Appendix 1) compiled from texts found in French schoolbooks devoted to children attending first grade (Peereman, Lété, & Sprenger-Charolles, 2007). This database has the great advantage of having been calculated on child-directed texts. Correlations were computed between the mean recognition scores associated with each letter at 3 and 4 years (data grouped together) and the letter frequencies proposed in the Peereman et al. database. The correlation was significant, $r = .46$, $p < .05$. Looking at the results plotted in Fig. 3, it appears that the best recognized letters, namely, t, i, r, a, e, o, were indeed among those presented with the highest frequency.

Finally, we compared the impact of the frequency index and of the max-similarity index (maximum percentage of association of one letter with other letters, see Table 1) on the recognition scores obtained by each letter, averaging across ages 3 and 4 years, running a regression analysis using an ascending stepwise method. The first factor, that explained 24% of the scores' variance, was the max-similarity index ($p < .05$); the frequency index accounted for a supplementary 10.9% of the variance and was marginally significant ($p = .06$).

2.2.2. Errors in letter recognition

When errors in recognition occurred, we computed the number of responses in which children selected the most similar letters. Although they strongly diminished with age, errors were present in all children at 3 years, in 19 of 21 children at 4 years and in 15 of 21 children at 5 years. When they occurred, children selected the most similar letter in 48.9% of the cases at 3 years, 56.1% at 4 years and 82.8% at 5 years. This performance improved with Age, $F(2,\ 51) = 14.6$, $p < .001$, partial $\eta^2 = .36$, but it departed from chance (50%) only at 4 years, $t(18) = 2.1$, $p < .05$ and 5 years, $t(14) = 4.7$, $p < .01$. The most recurrent confusions, produced by more than 30% of the children (all ages mixed), were b with l or f, h with k or f, k with f, l with b or f, n with m or v, m with n or w, p with q or y, u with v, and w with u.

2.3. Discussion

Experiment 1 was designed to test young children's ability to recognize visually presented, isolated, cursive letters as a function of various factors: age, visual similarity, general letter frequency, and personal letter frequency as indicated by the letters included in the child's own first name. Time constraints were imposed in this experiment, with children inspecting the target letter for only 3 s.

The main results can be summarized as follows: They will be discussed in relation to the current literature in Section 4. Letter recognition improved rapidly between 3 years (48% correct) and 5 years (93% correct). It was a function of the "uniqueness" of letter shape. The best recognized letters at an age as early as 3 were those judged as less similar to other letters by adults required to sort letters on the basis of their visual shape similarity (i, r, t). The letter f, also well recognized, could be included in this family of letters characterized by specific shapes, this letter being the only one to have both an ascending and a descending loop, which makes it particularly tall. The complexity of letter shape also appeared influential: the set of letters well recognized from 4 years of age included a, c, e, o, i.e., simple, short, rounded patterns. Letter frequency accounted for these recognition scores as well, since the letters e, a, i, t, r are the most common letters according to the database we used. Finally, when children made a recognition error, it was in favor of the most similar letter at an above chance level at 4 and 5 years, but not at 3 years. Younger children selected the most similar letter as often as the moderately similar letter.

An advantage for the letters composing the first name was observed only at age 3, while an advantage for the letters keeping a similar shape through printed and cursive writing appeared at 4 years. Taking for granted that the in-name letters are the first letters to which young children are regularly exposed, and that a certain number of repetitions is needed to become familiar with specific shape letters, we can understand that developing a behavioral sensitivity to the whole set of letters present in children's writing environment takes time and necessarily appears after a sensitivity to the in-name letters. At 5 years, recognition scores attained ceiling values, preventing differential effects of types of letters from reaching significance.

To what extent are these results specific to the visual modality? For instance, the impact of letter frequency on recognition scores is likely to be restricted to the visual modality. Are the letters that are difficult to recognize visually (the humped letters for instance) also difficult to recognize proprioceptively? What are the relationships between spatial memory of shapes and spatial memory of trajectories at the beginning of handwriting learning? Lurçat's work (1974) suggests that the former precedes the latter. The second experiment was aimed at investigating young children's recognition of cursive letters on the basis of proprioceptive information. It was run on different children, because a pilot investigation revealed that although children as young as 3 years were able to perform in the visual condition, they were unable to participate in the proprioceptive condition. Furthermore, to ensure the best cooperation of children in this second experiment, we had to divide the alphabet into two equivalent sets of letters, and to present each half's age group with only one set, whereas even the 3-year-olds were able to be tested using the whole alphabet in the first experiment. These two points made it impossible to use a within-subjects design.

3. Experiment 2

In this experiment, children were required to identify a target letter among two distracters, one proprioceptively most similar, one moderately similar, while they were semi-passively tracing the letter three times without vision of the traced letter or of their hand. The three letters proposed as candidates were visible during the tracing task. This bimodal condition was supposed to facilitate recognition (Walsh, 1973). A pilot study showed that the youngest children who could be tested in such experiments should be aged 4. The experiment was therefore run with children aged 4–6. In order to make the visual and the proprioceptive recognition tasks as close as possible in terms of complexity, we used a pilot study to determine empirically the length of the letters to trace over and the number of repetitions of letter tracing so that a success rate of around 50% was attained by the youngest children.

Normative data of proprioceptive similarity between letters were collected by asking 30 college students to sort the entire alphabet of cursive letters into categories according to the similarity of their writing trajectories, i.e. to their proprioceptive similarity. They were invited to enact the writing of each letter physically, and pay attention to how the movement felt, while making their similarity judgments. These results were used to match each letter with a highly or moderately similar distracter from a proprioceptive point of view. We expected children to be better at recognizing letters possessing rather specific trajectories than letters with more common trajectories.

However, it is reasonable to argue that children may considerably depart from adults in their capacity to establish proprioceptive similarity between letters, because proprioceptive information is delivered sequentially, as the movement progresses, thus requiring a final integrative step in order to form the entire proprioceptive image. Because of limits to their working memory (e.g., Cowan, 1997) and in their capacity to integrate sequential information (e.g., Hatwell, Streri, & Gentaz, 2003), young children may establish correspondences between the traced and the seen letters on the basis of partial segments only (e.g., the beginning, a salient shape, a salient movement like lifting up the pen). Children should be more inclined to select the most similar letter if they succeed in integrating the sequential proprioceptive information and match it with visual information, while the choice of a moderately similar letter may reveal a predominance of local processing, some details in letter shape being used as relevant cues for recognition. However, letter identification may rely on differentiation processes as well as on integration processes. Children may progressively rule out candidates on the basis of continuous matching between what they feel and what they see, leaving one letter standing alone in the span of attention at the end of the process. Children may therefore be more confused by two candidates sharing the same trajectory at the beginning of the movement than by two letters with different initial trajectories.

3.1. Method

3.1.1. Participants

Eighty right-handed children (43 females and 37 males), aged 4 to 6 years, participated in the experiment. They were divided into three age groups (Group 1: mean age = 4.2 years, $n = 28$ (14 children per letter set), 16 females and 12 males, range = 3 years 11 months to 4 years 4 months; Group 2: mean age = 5.1 years, $n = 28$ (14 children per letter set), 15 females and 13 males, range = 4 years 10 months to 5 years 3 months; Group 3: mean age = 6.1 years, $n = 24$ (12 children per letter set), 12 females and 12 males, range = 5 years 10 months to 6 years 3 months). The criteria of inclusion of children into the groups were exactly the same as those described in Experiment 1. The experiment was run early in the school year (between September and November). All children aged 4 and 5 knew how to write their first name in capital letters. Only the 6-year-olds had received systematic cursive writing training. None of these children had participated in the visual experiment.

3.1.2. Material

The material included the same 26 white cards (format: 6 cm width, 10 cm length) as used in the previous experiments (see Fig. 1). These letters were divided into two sets so that the different categories distinguished by college students in the pilot similarity judgment task were equally divided: (Set 1: a-d-e (round patterns), b-h-l (ascending loops), i-m-v (spike or humped patterns), g-r-x-z (descending loops or oblique segment start patterns); Set 2: c-o-q (round patterns), f-k (ascending loops), n-t-u-w (spike or humped patterns), j-p-s-y (descending loops or oblique segment start patterns)). Each set of letters was printed on a sheet of paper (format A4), 4 centred letters per line for the two first lines, 5 letters centred on a third line. This sheet was placed under a masking box which had an opening on the child's side and another on the experimenter's side (length: 40 cm; width: 45 cm; height: 20 cm). Children had to trace over the letters, with the help of the experimenter, and without seeing their hand and the letter. The cards used to identify the traced letters were placed on the top of the box. Remember that the height of the letters was 1.5 cm for a, c, e, i, n, m, o, r, s, u, v, w and x, 3.5 cm for b, d, g, h, j, k, l, p, q, t, y, z and 6.5 cm for f, that is around 3–4 times bigger than the sizes accepted by teachers in the first grade of elementary school.

3.1.3. Procedure

Children were seated at a table with the masking box located approximately 15 cm in front of them. They were given a blue ball-point pen and were told to put their right hand under the box, as if they were going to write on a sheet of paper placed in front of them, under the box. The experimenter was located to their right so that she was able to see under the box and to hold the child's right hand. They were asked to adopt the most comfortable writing position and were invited to write or to draw what they wanted on the non visible sheet of paper. While they traced, they were asked to concentrate on their hand movement and to "feel" their moving hand as much as possible in order to "get an idea" about the shape of the trace left on the paper, "how this trace would look like" if they could see it. This free active condition without vision lasted a few minutes, just the length of time needed to make children understand that focusing their attention on movement sensations allows them to recover the shape of the trajectory.

They were then informed that the experimenter would hold their right hand and help them to trace over letters. To give them an idea about the letters' shapes, they were shown the 13 letters printed on the cards for 10–15 s. The children were told that they were expected to trace three consecutive times over the non visible letter with their hand guided by the experimenter, while the three letter candidates were visible. The experimenter placed the three cards on the top of the box just before the tracing task began. She made sure that children had understood the instructions before starting with the experiment. A short pause of 1–2 s was introduced between each repetition of the tracing movement.

The experimenter guided children's writing movements so that they accurately traced over the letter as printed on the sheet. She also moved the model sheet between each change of letter so that children kept the same position all along the experimental session. Children had to trace over 13 letters, presented in a random order,

Table 2
Most proprioceptively similar distracters and moderately proprioceptively similar distracters associated to each letter target (in brackets, their respective mean percentage of association)

Target	Most similar distracter		Moderately similar distracter	
a	d, o	(83.3%)	g	(33%)
b	f, l	(86.7%)	e, t	(23.3%)
c	a, o	(76.7%)	q	(43.3%)
d	a	(83.3%)	e	(40%)
e	a, c	(66.7%)	q	(33.3%)
f	b, k, l	(80%)	e, j	(23.3%)
g	j, q	(60%)	o	(30%)
h	k	(90%)	e	(23.3%)
i	t, u	(56.7%)	v	(23.3%)
j	y, z	(66.7%)	f, q, s	(23.3%)
k	b, h	(83.3%)	e, y, z	(23.3%)
l	b, f, k	(80%)	e	(30%)
m	n	(100%)	v, w	(33.3%)
n	m	(100%)	v, w	(33.3%)
o	a, c	(76.7%)	g	(30%)
p	j	(53.3%)	q	(23.3%)
q	a, g	(60%)	e	(33.3%)
r	s	(43.3%)	v, w	(23.3%)
s	r	(43.3%)	j	(23.3%)
t	i	(60%)	u	(26.7%)
u	i, v	(56.7%)	t	(26.7%)
v	w	(86.7%)	m, n	(26.7%)
w	v	(86.7%)	m, n	(33.3%)
x	c	(30%)	o, r, w	(16.7%)
y	z	(86.7%)	g, p	(40%)
z	y	(86.7%)	g, p	(40%)

and a short pause of about 10 s was observed between each letter. The 3 cards put on the top of the box were arranged in a line, and the position of the target letter (left, middle, right) was random. The two letter distracters systematically included a closely (letters with the highest percentage of association) and a moderately (letters with half of the value of the highest percentage of association) proprioceptively similar letter. Table 2 displays, for each letter, the corresponding most or moderately similar letters together with their respective mean percentage of association, as obtained from the pilot experiment run with 30 college students.

3.2. Results

3.2.1. Accurate recognition scores

We computed the number of correct letter recognition responses, and first checked that the recognition scores did not vary as a function of the letter set children were confronted with. An ANOVA, with age (3) and letter set (2) as between-subjects factors, revealed that letter set was not significant, as a main effect or in interaction with Age, $F_s < 1$. We therefore ignored this factor in the following analyses. An ANOVA with age (3) was run on the mean percentages of accurate letter recognition computed across the whole set of letters children were exposed to. Unfortunately, the reduction in number of letters with which each child was confronted in the present experiment made it impossible to test an effect of first name letters because a large number of children (41 of 80) saw an insufficiently large subset of their own first name letters (less than 3). For the same reason, we could not test an effect of letters that maintain their shape across printed and cursive writing. Fig. 4 shows the percentages of correct letter recognition as a function of age.

Age was significant, $F(2, 77) = 49.2$, $p < .001$, partial $\eta^2 = .56$. The mean recognition scores increased from 48.3% at 4 years to 90.4% at 6 years. These scores differed from chance (33.33%) at all ages, from 4 years onwards, $t(27) = 5$, $p < .001$. At 6 years, performance was almost at ceiling level (remember, however, that we used large letter sizes).

Fig. 5 shows recognition performance as a function of letters at 4 and 5 years. Recognition scores varied between 30% and 70% at 4 years, 35% and 90% at 5 years. The global ordering of letters from the least to the best recognized established at 4 and 5 years share some features, as attested by a significant correlation, $r = .64$, $p < .01$. The letters that were best recognized included i-m-u (spike or humped patterns), z (descending loop) and q (round pattern with a descending stroke). The less well-recognized letters comprised l (ascending loop), a (round pattern) at both ages, f-k-y (ascending–descending loops) at 4 years, n (bridge-like pattern) and s (oblique segment start pattern) at 5 years. These results did not match very well adults' classification. Indeed, the correlation between the max. percentages of association of each letter with the others (see Table 2) and the recognition scores was not significant at 4 years, $r = -.17$, $p > .30$, nor at 5 years, $r = -.22$, $p > .25$. Thus, the classification made by adults on the basis of the letter's proprioceptive similarity did not fit well with the young children's capacities to recognize letters from their proprioceptive images. By contrast, this correlation was strong at 6 years, $r = -.54$, $p < .01$. The best recognized letters, at 6 years, were x-s-r-j-g and l-q, the five first letters showing the lowest mean percentage of association with other letters in adults' classification (see Table 2).

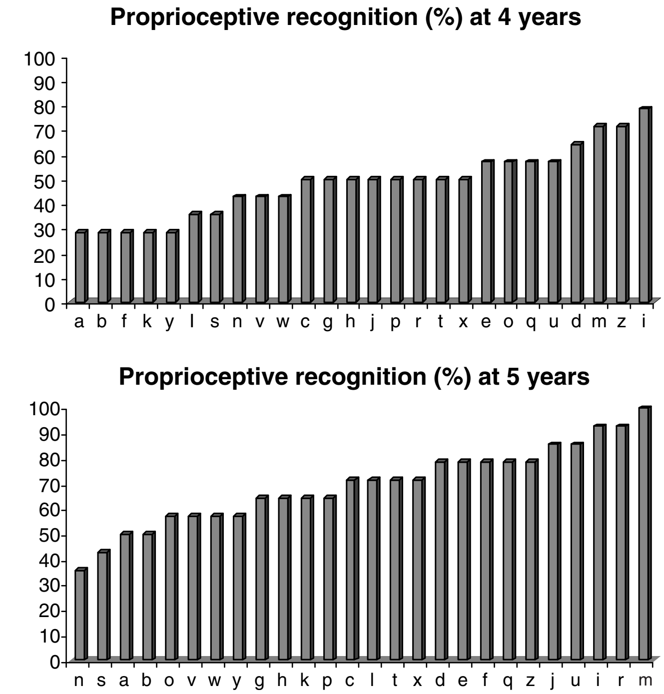

Fig. 5. Percentages of correct recognition for the entire alphabet letters (letters are ordered along the *x*-axis from the less frequently to the most frequently recognized letter) at 4 and at 5 years (Experiment 2: proprioceptive condition).

Finally, the correlations between the recognition scores associated with each letter and the letter frequencies computed by Peereman et al. (2007) were all non significant, whatever the age group (r values between .03 and .15, p values superior to .40).

3.2.2. Errors in letter recognition

Errors of recognition were present in all children at 4 years, 27 of 28 children at 5 years and in 15 of 24 children at 6 years. When they occurred, children selected the proprioceptively most similar letter in 53.1% of the cases at 4 years, 61.4% at 5 years and 79.2% at 6 years. This performance improved with age, $F(2, 68) = 5$, $p < .01$, though the size effect was low, partial $\eta^2 = .13$. It did not differ from chance (50%) at 4 years, $t < 1$, and it was marginally significant at 5 years, $t(27) = 1.95$, $p = .06$. Selecting the most similar letter was, however, established at 6 years, $t(14) = 4.4$, $p < .01$.

The most frequent confusions between letters are again worth mentioning: a with g-d, l with e, f with l, k with l-h, n with v-w, s with r, v with w-n, and y with g. Except in the last example (y with g), in all the other cases the confusion may come from the similarity of the trajectory in the beginning of the writing movement. The difference in letter size did not prevent frequent confusion of a with d.

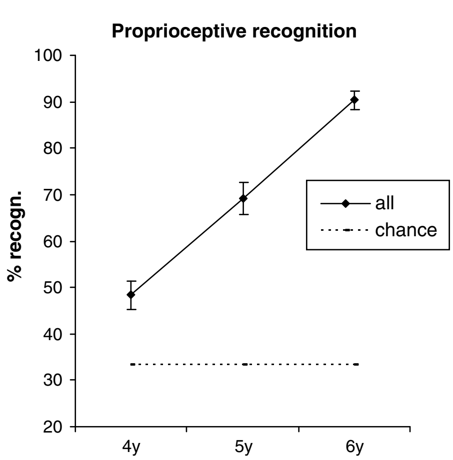

Fig. 4. Percentages of correct letter recognition as a function of age in Experiment 2. Error bars indicate standard-errors.

3.3. Discussion

Children as young as 4 years of age were able to proprioceptively recognize approximately 50% of the letters to which they were exposed. This ability increased rapidly between 4 and 5 years, as well as between 5 and 6 years to attain a high level of 90% correct letter identification. Letters u, m and i were the best recognized at all ages. When they failed to recognize the correct letter, children did not select the most similar one before 5/6 years. Thus, preschool children's ability to identify letters from their proprioceptive images did not depend on the strong or weak proprioceptive similarity between letters, as judged by adults. It was only at 6 years that a convergence of adults' judgments and children's recognition scores was observed. As expected, proprioceptive recognition of cursive letters was not a function of the quantity of exposure to written material, as expressed by letter frequency. Finally, the main errors made by children in this proprioceptive task revealed that young children tended to focus more on the beginning than on the end of the tracing, and tended to have difficulties in processing the size of the movement, i.e. more difficulty discriminating letters with similar shapes but of short (a) or high size (g-d).

4. General discussion

What are the capacities of young children to recognize cursive letters visually and proprioceptively? What factors influence this recognition ability in both modalities? Are there congruencies between children's recognition choices and adults' judgments of similarity between letters in both modalities? The studies presented here aimed at investigating these questions.

The results of Experiment 1 indicated a rapid increase, between 3 and 5 years, in visual recognition of cursive letters, while Experiment 2 showed that a similar fast evolution of proprioceptive recognition occurs between 4 and 6 years. These data, revealing a delay of around 1 year between visual and proprioceptive recognition of cursive letters, provide strong support to the view developed years ago by Lurçat (1974), who showed that the letter's shape is learned approximately 1 year before learning the correct trajectory of the movement in the beginning of handwriting learning. However, in our experiment, small letters like a, e or c were 1.5 cm high, i.e. around 4 times larger than the sizes accepted by teachers in the first grade of elementary school. Children no doubt would perform worse with smaller letter's sizes, as could be suggested from Laszlo and Bairstow (1985), who highlighted the difficulties children younger than 7 years encounter in handwriting acquisition because of insufficiently mature proprioceptive processing. Be that as it may, our results clearly demonstrate that preschool and kindergarten children are able to recover the shape of letters from their proprioceptive "signature" (Roll et al., 2004). This ability surely accounts in part for the results reported by Longcamp et al. (2005), who established that the very act of writing letters led to better letter recognition in preschool children.

It could be argued that our guided proprioceptive task underestimates children's ability to process proprioceptive information. A body of research has shown that better performance is obtained when participants, deprived of visual information, can move their limbs actively rather than passively (e.g., Féry, Magnac, & Israël, 2004; Wexler & Klam, 2001). Indeed, the efference copy of the movement can be used to monitor movements in an active condition, but not in a passive condition, and an active condition increases attentional processes, thus leading to better sensory processing (Yardley, Gardner, Lavie, & Gresty, 1999). However, this is a controversial issue, and the opposite view, that passive-guided perception can be at least as good as active perception, if not better (e.g., Magee & Kennedy, 1980), has been proposed. For instance, no difference in performance on active and passive tasks was found in adults who participated in tactile tasks of letter recognition (Vega-Bermudez, Johnson, & Hsiao, 1991). The developmental delay between visual and proprioceptive recognition shown in our experiments may not be dependent on our choice of a semi-passive guided condition.

By contrast, the bimodal condition in which children could look at the letter candidates while tracing the target probably boosted recognition. Indeed, a recent study demonstrated that adults who failed to haptically identify a stimulus from a raised line drawing become able to do so after they have depicted on paper what they had felt during tactile exploration of the raised line drawing (Wijntjes, van Lienen, Verstijnen, & Kappers, 2008). Visual information was needed to help identification.

Visual and proprioceptive recognitions of cursive letters were partly a function of the same factors. There was quite a good correspondence between older children's recognition scores and adults' judgments of similarity between letters. The more letters were judged as similar to each other by adults, the less older children were able to recognize them. Conversely, these children performed best on letters possessing shapes that were rather specific – those that adults did not sort into a category with other letters. However, these correspondences were stronger in the visual than in the proprioceptive experiment. When they used a perceptual modality that provides immediate access to global letter's shape information, such as vision, children converged more easily toward adults' ratings than when they had to process sequential information in order to recover the letter's shape, as in the proprioceptive experiment. This finding provides more support to the view that young children have difficulties in integrating sequential information over time, because of limits in their working memory (Cowan, 1997) as opposed to the differentiation view that does not expect the sequential nature of proprioceptive information to be necessarily detrimental to performance.

However, other findings show that the differentiation theory offers an appropriate account of some results. The correspondence between children's recognition scores and adults' similarity judgments of letters was not observed in the younger children. When they made an error of recognition, only older children tended to systematically select the most (visually or proprioceptively) similar letter. This may indicate that perception is still quite undifferentiated, with young children, for example, in the visual experiment, perceiving letters "with loops" (and consequently, l can be confused with b as well as with f), letters "with waves" (letter m can be confused with n as well as with w) or letters with "descending segments" (letter p can be confused with q as well as with y). As a function of experience, children would then progressively differentiate between ascending and descending loops for instance, and consequently would tend to select preferentially the most similar distracters than the moderately similar distracters. At the beginning of this differentiation process, a complete undifferentiated level would correspond to the confusion between letters and scribbles, followed by a level where letters are differentiated. However, the same pattern of results can be used to show that young children focus their attention on local features alone (loops for instance, or waves) without considering how these features are combined with others to form a unique specific configuration. Finally, it could also be argued that the improvement of recognition performance with age is at least partly due to an increase in short-term memory capacity (e.g., Cowan, 1997). This hypothesis is very likely correct, and does not exclude the other theoretical accounts in terms of differentiation of features or of a move from a focus on salient local features to an integrated configural percept.

The difficulties children encountered in distinguishing between letters, as indicated by their errors of recognition, seem partially modality-specific. In the visual experiment, as claimed by Garner (1979), the simplicity of the physical (geometrical) properties of the letter configuration itself can account for the fact that some letters are easy, others difficult to recognize. In a study using uppercase letters, he has shown that the letters that were most rapidly identified were those with single vertical lines, simple curvature (T-P-B-O for instance), while the slowest were those with diagonal lines (M-K-V-W for instance). We also observed that the best recognized letters were those with simple patterns (i, t, o, c for instance) while the most poorly recognized letters were those combining complex changes in direction and loops (z, b, h, g for instance). Note that the confusions between the letters n and v or the letters m and w may also be due partly to the perceptual confounding of patterns with their own mirror-images, a phenomenon well documented by Deregowski and collaborators (e.g., De Kuijer, Deregowski, & McGeorge, 2004; Deregowski & Ellis, 1974), although the symmetry, in these cases, is not perfect.

The role of such geometrical factors is less evident in the proprioceptive experiment, where we observed that most confusions between letters revealed that children paid more attention to the beginning of the tracing movement than to the end, as they do in haptic exploration of objects (Berger & Hatwell, 1996), probably because of limits in their attentional processing. This may explain why the letter n is confused with the letter v, and v with n. Repetition of the same movement unit (motor redundancy) seems, by contrast, to facilitate letter recognition in the proprioceptive study, since children were very good at recognizing the letter m and u, whatever their age. Interestingly, that children confuse letters sharing the same trajectory at the beginning of the movement may provide support to the claim that children progressively differentiate information, excluding candidates (those with a different trajectory from the beginning) in the course of the tracing movement, as well as to the view that children can integrate sequential information only over a short-time period.

Finally, similarity between letters did not appear to be the sole determinant of cursive letter recognition in the visual condition. Letter frequency accounted for children's recognition scores to a significant level. The more frequent the letter, the better it was recognized by children in the visual condition. A more personal frequency effect tended to affect recognition performance at 3 years, with an advantage for in-name letters over not-in-name letters. These results appear to be highly congruent with a growing body of empirical evidence establishing the importance of statistical factors in different learning processes (in language, e.g., Saffran, Aslin, & Newport, 2004; in visual perception, e.g., Fiser & Aslin, 2005). This literature shows that the more frequently a pattern is encountered in the environment, the better it is learned. It could be argued that the written environment of young children (at school, at home, in shops, etc.) probably contains more printed than cursive letters, implying that preschool children may not be confronted very often with cursive letters. This dominance of printed letters may account for the fact that children aged 4 years showed a recognition advantage with respect to those letters that keep their shape across the writing types.

However, it should also be noted that it is common practice in French pre-elementary schools to write the child's first name above her coat rack and her personal locker in both cursive and manuscript. This practice may be sufficient to provoke the in-name letters advantage observed at 3 years, probably because children's attention is most enhanced towards the letters forming their first name than towards letters in general. Then, with developing practice and repeated experience, their attention may be more widely oriented, giving rise to the letter frequency effect and shape-stable letter advantage. The negative result obtained in the proprioceptive experiment with regard to the relationship between letter frequencies and children's recognition scores was expected for two reasons. First, there is no empirical evidence that the letter frequencies computed on the basis of children's books could be pertinent to children's writing activity, and second, children under 6 years have too little cursive writing practice to allow for statistical learning effects. However, the very good proprioceptive recognition of letter m may partly result from similar learning effects, drawing waves constituting a very frequent exercise in kindergarten school.

In conclusion, these results show that visual as well as proprioceptive recognition of cursive shapes improve rapidly between 3 and 6 years, making children at around 6 years certainly ready to learn cursive handwriting. Visual letter recognition seems to be a complex function of the degree of "uniqueness" of letter shape (degree of similarity with other letters), of the simplicity of letter shape and of experience-related factors, either personal (first name letters) or general (frequency of letters in the children's written environment). Our results would seem to indicate that the factors determining proprioceptive recognition are more complex to define. Further investigation is needed, comparing an active to a semi-passive exploration condition, comparing a condition where the letters candidates are shown after the tracing movements have been completed to a condition where they are present during tracing.

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Appendix 1

The Peereman et al. (2007) database was constructed from a corpus of 1.9 million words taken from 54 readers used in French primary schools between the 1st and 5th grades. For each grade, the authors extracted a wordform lexicon (10861 entries for the 1st elementary grade) and computed a series of lexical and infralexical statistics. We used here the data concerning the occurrences of each letter in this children-directed written language. The occurrences obtained for each alphabetical letter are reproduced in the following table.

a	6 274	n	5 317
b	1 148	o	4 483
c	3 054	p	2 370
d	1 644	q	373
e	12 805	r	6 717
f	1 027	s	5 440
g	1 398	t	5 453
h	1 053	u	3 625
i	5 790	v	1 175
j	202	w	14
k	60	x	276
l	3 502	y	229
m	2 140	z	253

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