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Syllables as functional units in a copying task

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This research used a copying task to study spelling acquisition from a perception and action perspective. First to fifth graders copied words and pseudo-words on a digitiser. Simultaneously, a camera registered the children's gaze lifts. First and second graders copied the first syllable and then produced a gaze lift to obtain information on the spelling of the second syllable. Words required fewer gaze lifts than pseudo-words. Third, fourth, and fifth graders copied the items as whole orthographic units and did not produce any gaze lifts. The analysis of movement duration revealed that, for all the children, the gesture to produce the first syllable was programmed before movement initiation. A systematic duration peak at the first letter of the items' second syllable was then observed. This indicates that the gesture to write the second syllable was programmed during the execution of its first letter. Thus, the younger children used syllables to articulate visual parsing and motor programming. The older children used whole word visual units but still organised their graphic production according to the syllable structure. Syllables therefore appear to act as functional units at both the visual and motor stages of processing during spelling acquisition.

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INTRODUCTION

Although many studies have investigated the cognitive mechanisms and processing units involved in written language acquisition, experiments using a copying task are quite rare. However, the copying activity is of particular interest because it allows one to study spelling acquisition from both a perception and action perspective. The copying task involves translating a visual input into a grapho-motor code. To copy a word, the child does a visual analysis of the input letter string. This process leads to the generation of an internal graphemic pattern that is maintained in the working memory and serves as a basis for programming handwriting gestures. The copying activity can thus provide an insight into the nature of the spelling units mediating perceptual processes and motor outputs. This study examines the role of the syllable during visual parsing and motor programming. The idea is that the syllable is used as a functional unit to articulate the perceptual and production aspects involved in spelling processes, especially at the beginning of the acquisition period.

Traditional stage models of reading/spelling development assume that children progress from an analytic stage -where processing relies on the relationships between letters and sounds- to the elaboration of word-specific knowledge (Ehri, 1986; Frith, 1985; Gentry, 1982; Marsh, Friedman, Welch, & Desberg, 1980). Other theorists conceive of reading/spelling development as a more continuous process where different strategies co-exist and develop together (Rittle-Johnson & Siegler, 1999; Share, 1995, 1999). According to this view, the children use sub-lexical processing units that represent phonological units within the input letter string. Later on during development, they use words as the predominant processing units. Although letters and graphemes are typically considered as the sub-lexical units involved in the reading process (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Patterson & Shewell, 1987), larger units may also mediate the parsing of the letter string. Another model of reading acquisition postulated that visual processing consists of the extraction and learning of visual units that progressively increase in size (Laberge & Samuels, 1974). Incoming information from the printed word is analysed by detectors specialised in processing visual features. The activation of several features -with the aid of visual attentional processes yields the construction of letter units. The co-activation of several letter units is necessary to synthesise spelling patterns, which are themselves involved in the formation of word-units when co-activated. Thus, higher order chunking processes will appear as the child gains more experience in reading. It is also assumed that syllable-size spelling patterns are activated during visual processing together with their phonological counterpart.

The idea underlying this investigation is that syllable-sized units play a major role in visual analysis and motor programming processes during the 'chunking' period at the beginning of spelling acquisition. In other words, after the letter-by-letter strategy and before the child can process a word as a whole unit, syllable-sized units coordinate visual inputs and motor outputs. This would be particularly important in French, while in other languages like English, other intermediate units like rhymes may play an important role (Goswami, Gombert, & Fraca de Barrera, 1998; Goswami, Ziegler, Dalton, & Schneider, 2003).

This hypothesis is supported by research showing that syllables are representational units in speech production (Dell, 1986; Garret, 1979; Levelt, 1989, 1992) and perception (Mehler, Dommergues, Frauenfelder, & Segui, 1981; Morais, Content, Cary, Mehler, & Segui, 1989), especially in French (Cutler, Mehler, Norris, & Segui, 1986). Other studies demonstrate the use of syllabic information in the visual perception of printed material (Carreiras, Alvarez, & de Vega, 1993; Rapp, 1992; Prinzmetal, Treiman, & Rho, 1986; Spoehr & Smith, 1975). Furthermore, the spelling performance of dysgraphic patients also indicates that syllabic information is specified in the representation of word forms (Caramazza & Miceli, 1990; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994; Tainturier & Caramazza, 1996). Caramazza and Miceli's (1990) case study of patient LB, who suffered cerebral damage resulting in a difficulty in keeping spelling information activated in the working memory, revealed that orthographic information is not merely coded as a letter string with information on letter identity and order (Caramazza, Miceli, Villa, & Romani, 1987). They observed that LB's spelling errors were constrained by rules that determine the combination of vowel and consonant graphemes into grapho-syllables (i.e., orthographic syllables). On this basis, they hypothesised that orthographic representations are multi-dimensional: the first dimension concerns the identity of the graphemes that constitute the spelling of the word (e.g., *baby* = B + A + B + Y), the second one stores information on the consonant/vowel status of graphemes (e.g., *baby* = C + V + C + V) and the third one refers to the syllable structure of the word (e.g., *baby* = CV + CV). An additional level distinguishes geminate from non-geminate consonant clusters. Words are thus stored in memory as a set of grapho-syllables, constituting the input for motor programming. Moreover, in handwriting production, analysis of movement duration and trajectory length of CV and CVC syllable initial Dutch words (e.g., *ga/lant* and *gas/lek*) suggests that adult handwriting production is programmed according to the syllable structure of the word (Bogaerts, Meulenbroek, & Thomassen, 1996). Both measures increased at the third letter of CV-words and at the fourth letter for the CVC-words (i.e., at the first letter of the second syllable). The motor system thus programs the movement to produce the second syllable while writing its first letter (cf. Van Galen, 1991). Note, however, that in French a syllable effect appeared in typing but not in handwriting (Zesiger, Orliaguet, Boë, & Mounoud, 1994).

If syllable structure constrains segmentation processes in speech production and perception, as well as in reading and handwriting, it may also determine the elaboration of spelling units. We used a copying task to investigate the role of the syllable in visual parsing and motor production during spelling acquisition. The few available studies using a copying task suggest that syllables could be used as visual processing units (Humblot, Fayol, & Lonchamp, 1994; Rieben, Meyer, & Perregaux, 1989; Rieben & Saada-Robert, 1991; Transler, Leybaert, & Gombert, 1999). Rieben et al. (1989) carried out a longitudinal study in which French-speaking 5- and 6-year-old children elaborated a story together with the teacher. This story was written on a large sheet of paper and displayed on the classroom wall. Then, they were asked to produce another text and they were told that they could use what was written in the first text as a model if they did not know how to write what they wanted to say. The results revealed that copying strategies differed among the children and that their orthographic representations of words were partial. However, most of the children's strategies evolved in the same way: at the beginning, words were written by copying isolated letters that the child did not know; the letters then became familiar and were easily 'transported'; and finally, chunks of letters were copied as a whole. The size of these chunks increased with age. According to the authors, the evolution from one phase to the other depends on the progressive acquisition of knowledge of the alphabetical code and working memory capacities.

In Humblot et al.'s study in French, 1st graders copied most words letter-by-letter. Second graders frequently copied words without any gaze lifts. There was, however, an intermediate phase in which children copied words by syllables or letter chunks. The use of one or the other strategy depended on the orthographic and lexical features of the word. First-grade children used syllable-sized units to copy frequent and regular words. Second-grade children copied most of these words as whole orthographic units. In contrast, infrequent and irregular words were still copied using syllables or letter chunks in 2nd grade. Therefore, all the children copied letter-by-letter, by chunks and whole-words, but the strategy they chose depended on the complexity and frequency of the word.

Finally, Transler et al. (1999) asked French normal and hearing-impaired children to copy words and pseudo-words varying in syllable boundary position, number of syllables, and orthographic similarity. The results revealed that all the children used syllables as visual copying units. However, when pseudo-words had different syllable boundaries but were similar orthographically (e.g., *ren$tala/re$nalat*), the deaf children no longer used the syllable systematically whereas the others continued using it. In English, a copying task was used to study the behaviour of dyslexic children (Martlew, 1992). This research did not examine the underlying processing units but rather handwriting quality and speed. To our knowledge, there are no studies that simultaneously investigate the visual and motor aspects involved in spelling acquisition. This is quite surprising because spelling processes (i) may be constrained by input and output mechanisms and (ii) may require the coordination of the visual and motor units that arise from inputs and outputs.

In the present paper, we used a copying task to investigate both the visual and motor aspects of spelling processes. The basic idea underlying the copying task is that the child produces a gaze lift because he/she does not have enough information on the spelling of the following letter-string. If the child needs more information it is either because he/she does not have the orthographic information available in memory or because the information he/she has is partial or underspecified (Perfetti, 1992). If the child produces a gaze lift at the syllable boundary, for instance, it means that he/she had enough information on the spelling of the first syllable but not on the second one. This implies that the child could obtain information on the spelling of the first syllable before movement initiation. Another possibility is that the child has seen the word before but the spelling information available in memory is insufficient. He/she still needs to produce a gaze lift at the syllable boundary to obtain information on the spelling of the second syllable. In both cases, the child segmented the letter-string according to the syllable structure – i.e., used the syllable as processing unit – because he/she could not copy it as a whole orthographic unit. In the present study, children from 1st–5th grade copied words and pseudo-words. Gaze lifts were recorded with a camera, as a measure for the visual parsing, and movement duration was registered with a digitiser to examine the units that regulate handwriting production. Movement time is used in most studies investigating linguistic effects on handwriting production (Bogaerts et al., 1996; Meulenbroek & Van Galen, 1986, 1988, 1989, 1990; Mojet, 1991; Orliaguet & Boë, 1993; Van Galen, 1991; Van Galen, Meulenbroek, & Hylkema, 1986; Zesiger, Mounoud, & Hauert, 1993; Zesiger et al., 1994). According to Van Galen's (1991) model, handwriting is the result of a series of modules organised in a hierarchical structure. The linguistic aspects of handwriting are higher in the hierarchy than the more local parameters like size, direction, and force. In this model, various modules can be active in parallel such that the linguistic modules process information related to the forthcoming parts of the word while producing a gesture. For instance, the pluralisation morpheme *s* of the French word *ver* (*worm*) is programmed while producing *v* and *e* (Orliaguet & Boë, 1993). Since the system has limited processing capacities, the result of parallel processing is an increase in duration. If syllable structure constrains motor programming, then movement duration increases should be observed at the syllable boundary of the letter-string. The copying task therefore provides information on how the child articulates the visual parsing of a letter string with the programming of the movement needed to write it down.

Method

Participants. One hundred right-handed elementary school children participated in this experiment. There were 20 children (10 boys and 10 girls) for each school level: the mean age for the 1st grade was 6;8 (ranging from 6;5 to 7;3), for the 2nd grade the mean age was 7;8 (7;2 to 8;3), for the 3rd grade the mean age was 8;10 (8;4 to 9;4), for the 4th grade the mean age was 9;8 (9;2 to 10;4), and for the 5th grade the mean age was 10;11 (10;6 to 11;5). None of the participants were repeating or skipping a grade and they were attending their grade at the regular age. They all had normal or corrected-to-normal vision and reported no hearing impairments. Their mother tongue was French and no learning disability, brain or behavioural problems were reported. School attendance was regular. They were all pupils of four schools of the Grenoble urban area and were tested towards the end of the school year (April).

Material. The stimuli were 48 bi-syllabic words and pseudo-words (Appendix 1). The 24 selected words were regular from an orthographic point of view; i.e., straightforward spelling-to-sound correspondences. They all had a high lexical frequency (mean 12 057.17 pm) and bigram frequency (mean 6 458.14) in the LEXIQUE database for French words (New, Pallier, Ferrand, & Matos, 2001). The reason for choosing high frequency words was to make sure that all the children, including 1st graders, would be familiar with them. They were 4–7 letters long (6 words were 4 letters long, 6 words were 5 letters long, 4 words were 6 letters long, and 8 words were 7 letters long). The complexity of the letter forms was controlled as much as possible. In the 7-letter items, the initial syllable could either be 3 or 4 letters long, like in ***bou****cher (butcher)* and ***choi****sir (to choose)*, respectively. The 24 pseudo-words were derived from the words. One of the syllables in the word was kept, and the second one was changed, respecting vowel and consonant position (e.g., ***pou****ter* was derived from ***pou****let*). The changes respected as much as possible the grapho-motor demands of the letters in the word (e.g., ***per****ba* was derived from ***per****du* (lost): *b* and *d* have the same number of strokes and the only difference is the direction; *a* and *u* are produced in a similar manner but in *a* the loop is closed and in *u* it is open).

Procedure. Each stimulus was presented to the child on the centre of a card (21 × 15 cm) written in upper-case Times New Roman size 24. The card was put on the table, beside the left side of the digitiser (because all the participants were right-handed) so that the child only needed to lift the gaze, and not the whole head, to extract information on the letter-string. This is very important – and was not considered in other studies using the copying task (Humblot et al., 1994; Rieben et al., 1989) – because head movements can be tiring, especially for 1st graders, and constitute extra movements that need to be programmed and may thus interfere with the motor programming involved in handwriting production. The participants' task was to copy the item on a digitiser (Wacom Intuos 1218, sampling frequency 200 Hz, accuracy 0.02 mm) that was connected to a computer (Sony Vaio PCG-FX203K) that monitored the gesture the child executed. The children were asked to sit comfortably and copy the items as they did in class; i.e., in cursive handwriting. They had to write with a special pen (Intuos Inking Pen) on lined paper that was stuck to the digitiser. This paper was like the one they usually use to write when they are in school (the vertical limit is 8 mm and the horizontal limit is 17 cm). The children familiarised themselves with the pen and the digitiser by writing their names. No time limit or speed constraints were imposed. The chair and table belonged to the school and were adapted to the children's morphology.

The 48 items were divided into two sets to avoid exceeding the children's attention capacities. We divided the whole population into two equivalent groups (10 from each grade) so that each child had to copy a total of 24 items (12 words and 12 pseudo-words: Appendix 2). Each set of 24 items was divided into 4 subsets (2 × 6 words and 2 × 6 pseudo-words) so that the children could rest after 6 items. The items were randomised across participants and the order of the word and pseudo-word set was counter-balanced so that words and pseudo-words could be alternated. Before copying a set of items, the participants were informed of their lexical status. Pseudo-words were presented as a set of 'invented-words'. Two practice items (a word *route* and a pseudo-word *craspi*) preceded the experiment. The experiment lasted 20–30 minutes and the children were tested individually in a quiet room inside the school.

Data analysis

A video camera (Sony DCR-PC100E) registered the position at which the child lifted his/her gaze to pick up more information on the target. The idea was that if the child produced a gaze lift, it is because he/she needed more information on the spelling of the item. A gaze lift (GL) was counted as such when the child produced a gaze lift while producing a letter or immediately after producing it. For instance, if the participant lifted his/her gaze during the production of the *m* of *moto* (*motorcycle*), we counted a GL at the *m*. This procedure was adopted because if the child lifts his/her gaze while writing the *m*, he/she knows that an *m* has to be written (i.e., it is already programmed), so the GL is done to extract information on the identity of the following letters. If the child produced a gaze lift between the *m* and the *o* (before starting the production of the *o*), we also counted the GL at the *m* because the information to be extracted concerns the letters that follow the *m*. A GL at the last letter of the item was never counted because, if there was one, it could be for verification, but not for information extraction. By counting the number of GL within a word, the 'gaze lift coefficient' was calculated. It corresponded to the number of times the child lifted his/her gaze with respect to the total possible gaze lifts if he/she copied the item with a letter by letter analysis. For example, the word *voisin* (*neighbour*) has 6 letters, which would result in 5 possible GLs if the child copied letter by letter. If the child produced 2 GLs, then the GL coefficient is (2/5)*100, i.e., 40. In this manner, the gaze lifts for all the items in the experiment could be compared irrespectively of their length. We also analysed the gaze lift position within the item because it gives insight on when and where the child needed more information to finish copying it. That is, it provides information on the way the 'chunking' is done during the visual parsing of the item.

As with many studies on the linguistic aspects of handwriting production, we used duration as a measure to examine whether the items' syllable structure could constrain movement programming. We followed the standard procedure of movement analysis. First, the data were smoothed with a Finite Impulse Response filter (Rabiner & Gold, 1975) with a 12 Hz cut-off frequency. The trajectory and tangential velocity were then used to segment each word into its letter constituents, by using geometric (cuspids and curvature maxima) and kinematic (velocity minima) criteria. With this segmentation procedure we obtained the duration of each letter within an item. The duration measure concerned actual movement execution. The time the child took to produce a gaze lift or any other kind of pause were not considered in this measure. The duration of each letter was divided by the number of strokes it contained according to a segmentation procedure presented by Meulenbroek and Van Galen (1990). An *l*, for instance, has two strokes: an up-stroke and a down-stroke. If the duration of the *l* was 180 ms, then the mean stroke duration was 180/2 = 90 ms. This normalisation procedure allowed for comparisons among all letters, irrespective of the number of the strokes they contained. Then, for each letter, we calculated the ratio of the mean stroke duration to the sum of all the mean stroke durations of the word, and then, we converted it to percentages. Letter duration percentages reveal information on the global organisation of the handwriting gesture because they provide information on the distribution of the duration throughout the entire word. Duration increases at specific locations within the word arise from additional processing loads due to programming of following sequences (Van Galen, 1991; Van Galen et al., 1986). In addition, duration percentages allow comparisons among all participants, from very slow to very fast ones. For instance, the mean stroke duration of a given letter can be 100 ms for one child and 200 ms for another, but if the duration percentages for this letter for both children are around 17%, then both children organise their handwriting gesture in the same manner. This is very important in this study because the children's age varied from 6–10 years, which is a critical period of motor development. Indeed, many authors have shown that absolute movement duration decreases as the child grows up (Meulenbroek & Van Galen, 1986, 1988, 1989; Mojet, 1991; Zesiger et al., 1993).

RESULTS

The following section presents the results calculated from gaze lifts and movement duration. Analyses of variance (ANOVA) were conducted using both participants (F_1) and items (F_2) as random factors. The other factors concern lexicality (word, pseudo-word), school level (1st, 2nd, 3rd, 4th, 5th grade) and group (1, 2).

Gaze lift analysis

Gaze lift coefficient

Analysis of the gaze lift coefficient results (Figure 1) revealed a significant effect of school level, $F_1(4, 90) = 46.86$, $p < .001$; $F_2(4, 184) = 465.08$, $p < .001$: 1st graders' gaze lift coefficient was higher than 2nd graders', $F_1(1, 90) = 35.70$, $p < .001$; $F_2(1, 46) = 230.74$, $p < .001$; the latter had a higher GL coefficient than 3rd graders, $F_1(1, 90) = 19.49$, $p < .001$; $F_2(1, 46) = 192.75$, $p < .001$. The older children hardly did any gaze lifts: GL coefficients yield 10.00 for 3rd graders, 11.38 for 4th graders, and 3.44 for 5th graders. Therefore, in the following paragraphs, we will only consider 1st and 2nd graders' gaze lift coefficients to avoid ceiling effects. Analysis revealed no significant group effect.

Lexical status also yielded a significant effect, $F_1(1, 90) = 84.10$, $p < .001$; $F_2(1, 46) = 21.77$, $p < .001$: the gaze lift coefficient was higher when copying pseudo-words than when copying words, $F_1(1, 90) = 16.59$, $p < .001$; $F_2(1, 46) = 6.22$, $p < .01$ for 1st graders and $F_1(1, 90) = 26.48$, $p < .001$; $F_2(1, 46) = 9.55$, $p < .01$ for 2nd graders.

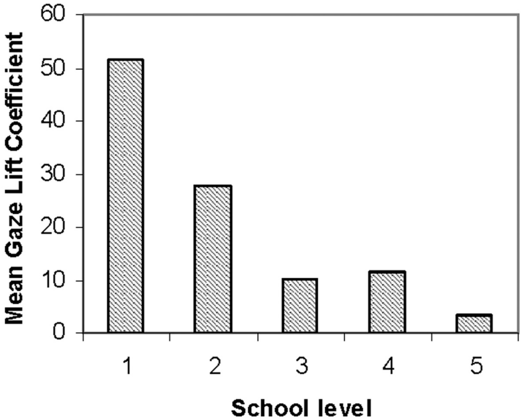

Figure 1. Mean gaze lift coefficient as a function of school level.

Gaze lift position within the item

We noted when and where within an item the child produced a gaze lift. This section presents a detailed analysis of 1st and 2nd graders' gaze lifts for words and pseudo-words. For all items, the results yield a systematic GL increase at the last letter of the initial syllable. In order to examine this effect observed at the syllable boundary – and for comparing the results among items of different lengths – gaze lifts at the *n*, *n-1*, and *n+1* positions were quantified (with *n* corresponding to the last letter of the first syllable; *n-1* corresponding to the previous letter and *n+1* corresponding to the first letter of the second syllable). For instance, for the word *poulet* (pou$let, *chicken*), *n* = u, *n-1* = o, and *n+1* = l.

As for the gaze lift coefficient, the results revealed significant effects of school level, $F_1(1, 36) = 15.58$, $p < .001$; $F_2(1, 46) = 10.95$, $p < .001$, and lexical status, $F_1(1, 36) = 17.84$, $p < .001$; $F_2(1, 46) = 24.76$, $p < .001$. No significant group effect was observed. The interesting part of this analysis was that the peak observed at the last letter of the first syllable (Figure 2) was significant, $F_1(2, 72) = 63.21$, $p < .001$; $F_2(2, 92) = 45.39$, $p < .001$. Indeed, $n\text{-}1 < n$: $F_1(1, 36) = 98.49$, $p < .001$; $F_2(1, 46) = 64.87$, $p < .001$, and $n > n+1$: $F_1(1, 36) = 44.26$, $p < .001$; $F_2(1, 46) = 63.75$, $p < .001$.

This peak at the *n* position ($n\text{-}1 < n > n+1$) was significant for words, $F_1(1, 36) = 57.92$, $p < .001$; $F_2(1, 46) = 34.74$, $p < .001$, and $F_1(1, 36) = 23.98$, $p < .001$; $F_2(1, 46) = 25.61$, $p < .001$, respectively, and pseudo-words, $F_1(1, 36) = 69.48$, $p < .001$; $F_2(1, 46) = 56.18$, $p < .001$ and $F_1(1, 36) = 38.62$, $p < .001$; $F_2(1, 46) = 61.23$, $p < .001$, respectively. Pairwise comparisons indicated that GL for pseudo-words were more frequent than for words only at the *n* position, $F_1(1, 36) = 18.35$, $p < .001$; $F_2(1, 46) = 43.71$, $p < .01$.

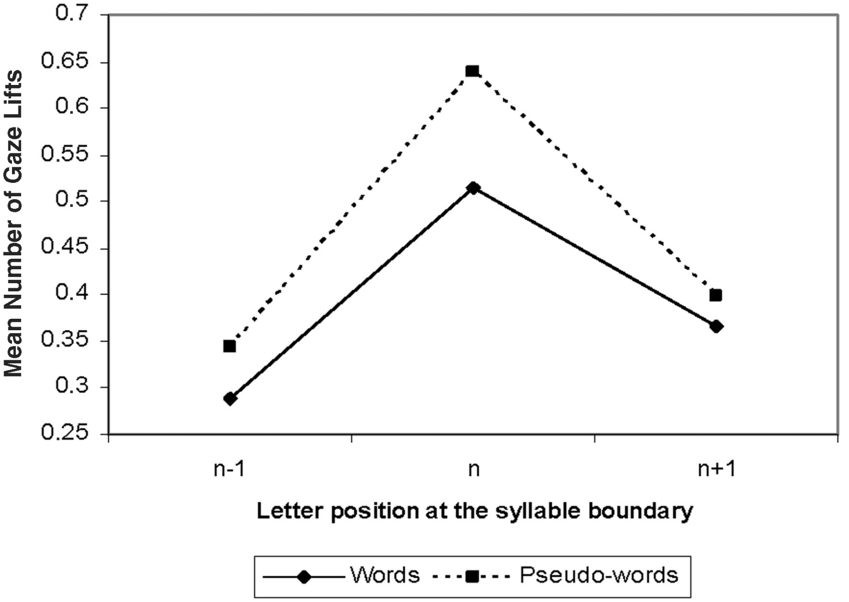

Figure 2. Mean number of gaze lifts at the syllable boundary for words and pseudo-words, in 1st and 2nd grade.

The following paragraph presents the analysis of the 7-letter items. The results for these items are of particular interest because they are equivalent in all aspects except for the position of the syllable boundary (Figure 3). The syllable boundary was either at position 3 (voi$ture, *car*) or 4 (jour$nal, *newspaper*).

When the initial syllable had 3 letters, there were fewer GLs for letter 2: $n\text{-}1 = 0.30$, than for letter 3: $n = 0.68$, $F_1(1, 36) = 114.89$, $p < .001$; $F_2(1, 14) = 64.87$, $p < .001$; GL scores for the latter were higher than for letter 4: $n+1 = 0.31$, $F_1(1, 36) = 72.43$, $p < .001$; $F_2(1, 14) = 45.62$, $p < .001$. When the initial syllable had 4 letters, there were fewer gaze lifts for letter 3 ($n\text{-}1 = 0.41$) than for letter 4: $n = 0.61$, $F_1(1, 36) = 12.88$, $p < .001$; $F_2(1, 14) = 11.65$, $p < .001$, and GL scores for the latter were higher than for letter 5: $n+1 = 0.49$, $F_1(1, 36) = 5.19$, $p < .05$; $F_2(1, 14) = 4.89$, $p < .05$. Thus, the significant GL increase was always observed at the last letter of the first syllable (position *n*), irrespective of the number of letters it contained.

Movement time analysis

Unlike data for GL, these results on mean stroke duration percentages only concern productions without errors, because when a child makes a mistake, movement time tends to increase and this could bias the global

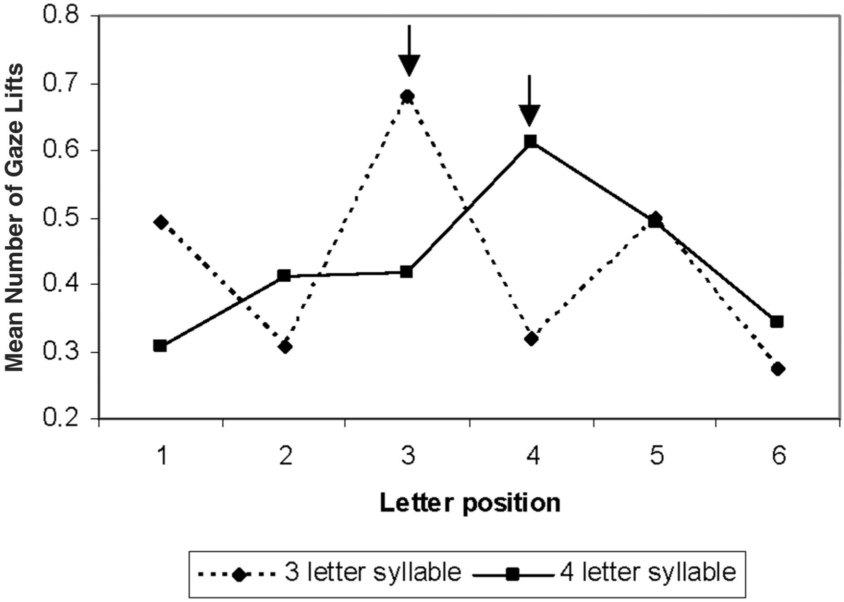

Figure 3. Mean gaze lifts for 7-letter items as a function of letter position, in 1st and 2nd grade. The arrows indicate the last letter of the initial syllable for 3- and 4-letter initial syllables.

results. It should be pointed out, however, that errors were so rare that they were not worth analysis. As for gaze lifts, an effect at the syllable boundary was observed for all the items, but with a peak shift towards the first letter of the second syllable. We thus performed calculations on the peak, the *n* position (first letter of the second syllable), *n-1* (last letter of the first syllable), and *n+1* (second letter of the second syllable) positions, so for the word *poulet* (pou$let), *n* = l, *n-1* = u, and *n+1* = e.

A significant effect of school level was observed, $F_1(1, 76) = 5.52$, $p < .001$; $F_2(4, 184) = 8.35$, $p < .001$. It was essentially due to the fact that 1st graders' movement duration percentages were slightly higher than those of the other school levels: 1st graders (20.89%) > 2nd graders (20.04%), $F_1(1, 76) = 12.97$, $p < .001$; non significant by items, but 2nd, 3rd, 4th, and 5th graders' duration percentages were not significantly different (20.04%, 19.94%, 20.09%, 19.88%, respectively). No significant group effect was observed. More interesting was the significant effect of letter position, $F_1(1, 76) = 280.17$, $p < .001$; $F_2(2, 92) = 43.32$, $p < .001$: duration percentages were lower for letter *n-1* than for letter *n*, $F_1(1, 76) = 394.96$, $p < .001$; $F_2(1, 46) = 54.10$, $p < .001$, in turn, they were higher for letter *n* than for *n+1*, $F_1(1, 76) = 327.73$, $p < .001$; $F_2(1, 46) = 54.24$, $p < .001$.

This *n-1* < *n* > *n+1* effect (Figure 4) appeared in words, $F_1(1, 76) = 229.84$, $p < .001$; $F_2(1, 46) = 22.45$, $p < .001$ and $F_1(1, 76) = 203.41$, $p < .001$; $F_2(1, 46) = 21.85$, $p < .001$, respectively, and pseudo-words, $F_1(1, 76) = 277.49$, $p < .001$; $F_2(1, 46) = 32.07$, $p < .001$ and $F_1(1, 76) = 239.99$, $p < .001$; $F_2(1, 46) = 32.95$, $p < .001$, respectively. Lexical status was only significant in the by-participants analysis, $F_1(1, 76) = 24.83$, $p < .001$: the durations were again slightly higher when copying pseudo-words than when copying words. Lexicality effects were only observed at the *n* position, $F_1(1, 76) = 23.32$, $p < .001$; non-significant by items.

It is noteworthy that the interaction between school level and letter position was not significant, showing that the syllable boundary effect was equivalent at all school levels: *n-1* < *n* > *n+1*: $F_1(1, 76) = 69.78$, $p < .001$; $F_2(1, 46) = 35.33$, $p < .001$ and $F_1(1, 76) = 75.93$, $p < .001$; $F_2(1, 46) = 51.94$, $p < .001$ for 1st graders; $F_1(1, 76) = 72.42$, $p < .001$; $F_2(1, 46) = 45.88$, $p < .001$ and $F_1(1, 76) = 67.17$, $p < .001$; $F_2(1, 46) = 69.45$, $p < .001$ for 2nd graders; $F_1(1, 76) = 90.05$, $p < .001$; $F_2(1, 46) = 44.36$, $p < .001$ and $F_1(1, 76) = 45.72$, $p < .001$; $F_2(1, 46) = 23.17$, $p < .001$ for 3rd graders; $F_1(1, 76) = 84.01$, $p < .001$; $F_2(1, 46) = 48.46$, $p < .001$ and $F_1(1, 76) = 71.97$, $p < .001$, $F_2(1, 46) = 39.50$, $p < .001$ for 4th graders; $F_1(1, 76) =$

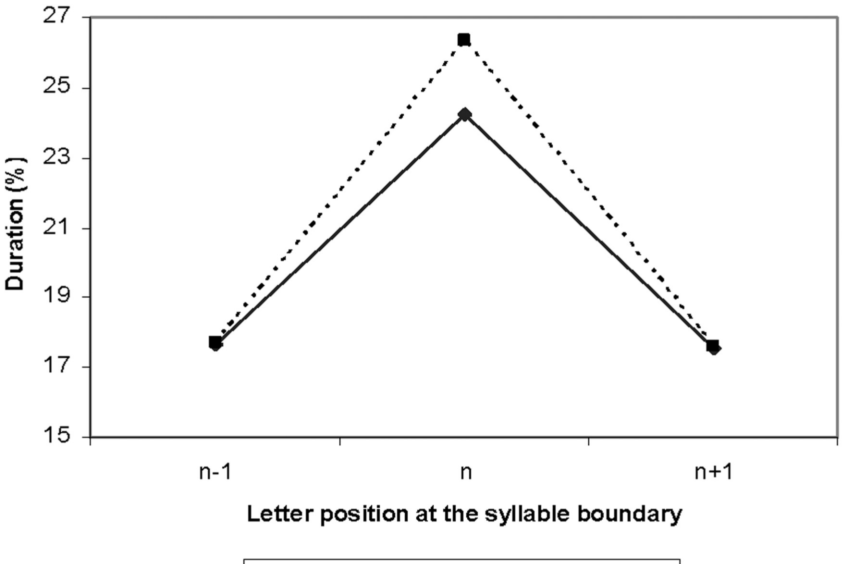

Figure 4. Mean duration percentages at the syllable boundary for words and pseudo-words, for all the school levels.

9.19, $p < .01$; $F_2(1, 46) = 29.98$, $p < .001$ and $F_1(1, 76) = 12.54$, $p < .001$; $F_2(1, 46) = 19.02$, $p < .001$ for 5th graders.

Duration percentages for the 7-letter items always increased at the first letter of the second syllable (position n), irrespective of the number of letters it contained (Figure 5).

When the initial syllable had 3 letters, duration percentages were lower for letter 3 ($n\text{-}1 = 12.97\%$) than for letter 4 ($n = 19.00\%$), $F_1(1, 79) = 79.80$, $p < .001$; $F_2(1, 14) = 18.48$, $p < .001$; and duration percentages for the latter were higher than for letter 5 ($n+1 = 15.62\%$), $F_1(1, 79) = 24.03$, $p < .001$; $F_2(1, 14) = 4.69$, $p < .05$. When the initial syllable had 4 letters, duration percentages for letter 4 ($n\text{-}1 = 13.61\%$) were lower than for letter 5 ($n = 20.47\%$), $F_1(1, 79) = 69.39$, $p < .001$; $F_2(1, 14) = 12.41$, $p < .01$, and differences between the latter and letter 6 were significant as well ($n+1 = 14.12\%$), $F_1(1, 79) = 69.65$, $p < .001$; $F_2(1, 14) = 6.67$, $p < .05$.

DISCUSSION

This research used a copying task to study spelling acquisition from a perception and action perspective. The analysis of gaze lift coefficients revealed that 1st and 2nd graders lifted their gaze frequently (51% and

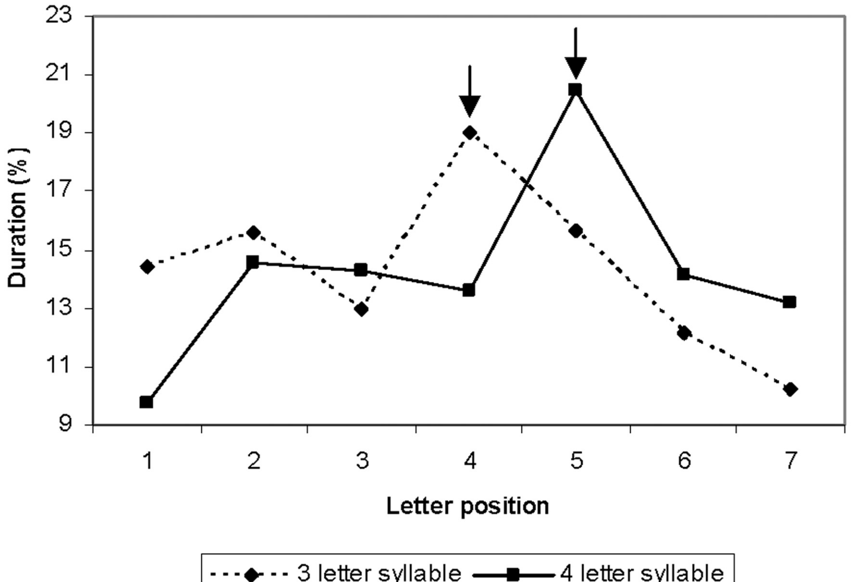

Figure 5. Mean duration percentages for 7-letter items as a function of letter position, for all the school levels. The arrows indicate the first letter of the second syllable for 3- and 4-letter initial syllables.

27% respectively), whereas 3rd, 4th and 5th graders copied the items as a whole unit, without any gaze lift. This indicates that the younger children not did not have enough orthographic information available to copy the items as a whole spelling unit and therefore decomposed them into sub-lexical units. Words required fewer gaze lifts than pseudo-words, suggesting that sub-lexical processing is more frequent for unfamiliar items.

The analyses of gaze lift position within the item were conducted in order to assess whether the syllable mediated visual parsing. The results for 1st and 2nd graders revealed that gaze lifts were much more frequent at the last letter of the first syllable than at any other position within the item. After this peak, GLs decreased significantly and were almost non-existent at the end of the word. This means that the children decomposed the items into their syllable constituents. In other words, the child extracted information on the first syllable before movement initiation, and then produced a GL at the end of the first syllable for obtaining information on the spelling of the second syllable. The fact that this increase was also observed for different syllable lengths in the 7-letter items reinforces this idea. It should be noted, however, that the children may use units smaller than the syllable, as suggested by Humblot et al. (1994). Further research is needed to determine which letter strings are parsed into smaller units (Laberge & Samuels, 1974), especially during the 1st grade.

The analysis of movement time revealed systematic duration increases at the first letter of the second syllable, at all school levels and item lengths, and regardless of lexical status. After this peak, duration decreased progressively until the end of the word. This distribution of movement duration suggests that the gesture to produce the first syllable is programmed before movement initiation (or maybe letter-by-letter during the production of the first syllable). The duration peak at the first letter of the second syllable and the duration decrease towards the end of the item indicate that the motor system programs the movement to write the second syllable while writing the first letter (Van Galen, 1991). Thus, word syllable structure constrains motor programming. The fact that this pattern was also observed for different syllable lengths in the 7-letter items confirms this idea. In addition, a similar result was observed with Dutch adults: mean stroke duration increased at the first letter of the second syllable both in CV and CVC syllable initial words (Bogaerts et al., 1996). In sum, the results strongly suggest that the motor programming system stores syllables as spelling units (Caramazza & Miceli, 1990). The implications of this finding are that (i) word forms are stored as sets of grapho-syllables in the spelling module and (ii) words are written by activating syllable-sized motor units. In addition, durations were higher when copying pseudo-words than when copying words only at the syllable boundary. This indicates that the lack of familiarity of the item constitutes a supplementary processing load that delays the programming of the next syllable. This is consistent with previous reports on adults which show that lexical status affects handwriting performance (Zesiger et al., 1993).

Lexical status affected the children's performance in both the visual and motor domains. The younger children decomposed pseudo-words into syllable-size units. In contrast, many words could be copied as whole orthographic units. Thus, before global processing is possible, the syllable plays a major role in determining the way the letter strings will be decomposed into chunks. This is in line with the item-based theory of reading/spelling acquisition (Share 1995, 1999), in which analytic processing applies to unfamiliar words and, simultaneously, a child can read globally other words which are more familiar.

Taken together, these results support the idea that 1st and 2nd graders organise their copying behaviour according to the syllable structure of the item, both for the visual and motor aspects of spelling processes. The child extracts information on the spelling of the first syllable before starting to write. This means that the syllable determines the way the item is segmented into sub-lexical chunks. The spelling of the first syllable constitutes the input to the motor system. A GL is then produced at the last letter of the first syllable, or once the letter has been finished, to obtain information on the spelling of the second syllable. The spelling of the second syllable constitutes the input to the motor system. The movement to produce the second syllable is programmed while writing its first letter. This is why there is a duration increase at the first letter and a progressive decrease towards the end. The syllable is thus the common functional unit that allows the child to articulate visual inputs and motor outputs.

This articulation of inputs and outputs through a common unit is of particular importance for spelling acquisition because there is coherence between perceptual parsing and motor programming. The child does not have to deal with different kinds of chunks at the same time. According to the *psycholinguistic grain size* hypothesis, English children learning to read have to rely on psycholinguistic units of different sizes (Goswami, Ziegler, Dalton, & Schneider, 2001; Ziegler, Perry, Jacobs, & Braun, 2001). They use grapheme-phoneme correspondences but also word phonology and rhymes, and this is not because of the teaching method (Landerl, 2000). Having to deal with units of different sizes delays the acquisition process with respect to children learning to read languages with shallow orthographies (e.g., in German the children only rely on grapho-phonological correspondences). Our results suggest that in French – a more shallow language than English but a deeper language than German (Seymour, Aro, & Erskine, 2003) – the syllable serves as a unique functional unit in visual and motor processing. The syllable is used to segment letter strings into familiar psycholinguistic units during perceptual processing. For instance, the syllable *ta* in the word *ta/xi* is likely to be familiar to the child because it also belongs to words that he/she already knows, like *ta/ble*. The syllable *ta* therefore facilitates the representation of the input even if the child is capable of encoding more letters: *ta* is easier to keep in the buffer than *tax* because it can be matched to a *ta* already present in memory. Since the motor system relies on orthographic representations that are stored as chains of grapho-syllables (Caramazza & Miceli, 1990) it is also likely that *ta* rather than *tax* is used to recall the spelling of the letter string and constitute the input for motor programming. The syllable is used for online visual processing and motor programming, but also as a common unit that facilitates the articulation of inputs and outputs.

The results for 3rd, 4th, and 5th graders further indicate that word syllable structure still determines the organisation of handwriting even when the syllable is no longer used for visual parsing. The children have to coordinate word-like visual inputs with syllable-sized motor outputs. This does not seem to be problematic for them. This means that the syllable-sized units used during visual parsing and motor programming at the beginning of the acquisition process may determine the internal structure of the graphemic patterns which serve as the basis for handwriting production later on. Further research is needed to assess this issue. A copying task seems to be a precious research and pedagogical instrument to investigate the links between perceptual and action mechanisms underlying spelling processes.

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Appendix 1

Words and pseudo-words. The space indicates the syllable boundary. The translation of the word in English is in parentheses. The 7-letter items are presented at the bottom of the table (the bold characters indicate the 3- and 4-letter syllables)

Words	*Pseudo-words*
Ta xi (*taxi*)	Ta do
Mi di (*noon*)	Mi bu
Au to (*car*)	Au ba
Mo to (*motorcycle*)	Na to
De mi (*half*)	Li mi
Tu er (*to kill*)	Lu er
Ai gle (*eagle*)	Ai pli
Mer ci (*thanks*)	Mer ta
Per du (*lost*)	Per ba
Jou et (*toy*)	Pau et
Hi ver (*winter*)	Lu ver
Su per (*super*)	Ca per
Pou let (*chicken*)	Pou ter
Voi sin (*neighbour*)	Voi rou
Cou per (*to cut*)	Roi per
Che veu (*hair*)	Cli veu
Bou cher (*butcher*)	**Loi** cher
Tri cher (*to cheat*)	**Lar** chon
Doc teur (*physician*)	**Bal** teur
Voi ture (*car*)	**Mai** ture
Choi sir (*to choose*)	**Choi** rel
Chau ffe (*heats*)	**Chau** tte
Tour ner (*to turn*)	**Tour** nau
Jour nal (*newspaper*)	**Jour** tel

Appendix 2

Items for participants in Group 1		*Items for participants in Group 2*	
Words	*Pseudo-Words*	*Words*	*Pseudo-Words*
taxi	tado	midi	mibu
auto	auba	demi	limi
moto	nato	aigle	aipli
tuer	luer	jouet	pauet
merci	merta	perdu	perba
hiver	luver	super	caper
poulet	pouter	voisin	voirou
couper	roiper	cheveu	cliveu
boucher	loicher	tricher	larchon
docteur	balteur	voiture	maiture
choisir	choirel	chauffe	chautte
tourner	tournau	journal	jourtel