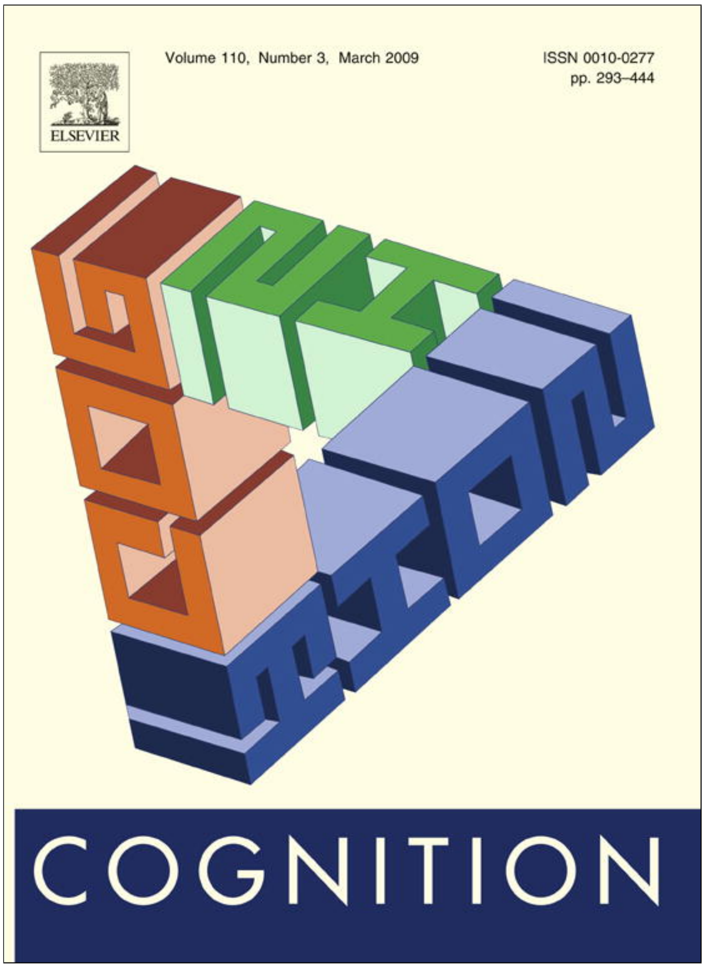
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Brief article

Orthographic vs. phonologic syllables in handwriting production

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ABSTRACT

French children program the words they write syllable by syllable. We examined whether the syllable the children use to segment words is determined phonologically (i.e., is derived from speech production processes) or orthographically. Third, 4th and 5th graders wrote on a digitiser words that were mono-syllables phonologically (e.g. *barque* = [baRk]) but bi-syllables orthographically (e.g. *barque* = *bar.que*). These words were matched to words that were bi-syllables both phonologically and orthographically (e.g. *balcon* = [bal.kõ] and *bal.-con*). The results on letter stroke duration and fluency yielded significant peaks at the syllable boundary for both types of words, indicating that the children use orthographic rather than phonological syllables as processing units to program the words they write.

1. Introduction

Handwriting proficiency requires that we group letters into chunks to optimise the recovery of spelling from memory and to program motor outputs efficiently. The present study investigated whether the activated chunks during handwriting derive from speech production processes or depend only on orthographic processes. Kandel and Valdois (2006a) observed that French 1st–5th graders chunk letters into syllable size units. They write words and pseudo-words syllable by syllable. The data indicate that they program the first syllable before starting to write. The child programs the second syllable on-line, as revealed by a systematic movement time peak at the syllable boundary. The authors suggested that the children used the syllable as a unit for chunking the letter string in a coherent – linguistically oriented – way. According to Van Galen's, (1991) model of handwriting production, the various representational levels are processed in parallel, and because processing capacities are limited, this produces increases in movement duration. The duration peak would therefore implicate the simultaneous processing of the spelling of the following syllable and the local parameters such as size and rotation direction of the current letter. In other words, in a bi-syllabic word, a duration peak at the syllable boundary indicates that although children prepare the gesture to produce the first syllable before movement initiation, they program the movement to execute the second syllable on-line, while writing its first letter. The syllable effect in handwriting production was confirmed in other developmental studies (Kandel, Soler, Valdois, & Gros, 2006; Kandel & Valdois, 2006b) as well as in adults (Kandel, Alvarez, & Vallée, 2006; Lambert, Kandel, Fayol, & Espéret, 2008). Although the syllable effect seems robust, there is scarce information on the kind of syllable the authors refer to. The present research aimed to show that the syllable we activate during handwriting production is essentially determined by orthographic patterns.

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Most research on spelling acquisition supports the idea that written language is in fact the transcription of phonologically elaborated messages (Luria, 1970). According to this view, the processing units involved in the production of written language should be the same as in speech (e.g. syllables, rimes). An alternative approach suggests that written language production is relatively autonomous with respect to speech (Bonin, Peerman, & Fayol, 2001). It predicts that the processing units involved in written language production do not derive exclusively from oral language.

At the beginning of writing acquisition, the letter chunks are elaborated on the basis of phonological processes because the child is proficient in speech but has not mastered written language. Since syllable structure is a universal principle of organisation for phonological representation (Goldsmith, 1990) speech-like syllables would constitute the basis for letter chunking. These phonological syllables are governed by the principle of sonority (Clements, 1990) and are linked to the acoustic and/or articulatory characteristics of spoken language (Kenstowicz, 1994). At around eight or nine years old, along with the automatization of handwriting (Mojet, 1991) and repeated exposure to frequently associated letter groups which respect graphotactic constraints, the spelling units become independent from phonological ones. Accordingly, the syllable used in writing processes at this period would be constrained more by orthographic than phonological combination rules. For example, the French word *vase* is mono-syllabic phonologically [vaz] but bi-syllabic orthographically (*va.se*, the dot indicates the syllable boundary). Thus, to write *vase*, we activate *va.se* and not [vaz]. Neuropsychological data support this idea. Patients exhibiting a "graphemic buffer disorder" showed error patterns indicating that orthographic representations code the grapho-syllabic boundaries within the word; hence the name *grapho-syllable* or *ortho-syllable* (Caramazza & Miceli, 1990; Ward & Romani, 2000). Grapho-syllables obey the graphotactic constraints that define the combination of graphemic consonants and graphemic vowels (see Prinzmetal, Treiman, & Rho, 1986 for more details). Studies of written word picture naming suggest that access to representations during the spelling process is mediated more by orthographic rather than phonological codes (Bonin, Fayol, & Gombert, 1997, 1998). The issue is still under debate because later research by Bonin et al. (2001) suggests that the build-up of orthographic activation from pictures could in fact be phonologically constrained.

The present research exploited the French final e phenomenon – as in the *vase* example – to investigate whether children use orthographic or phonological syllables as processing units in handwriting production. Words ending in *e* are extremely useful for studying this question because the syllabification is not the same in speech and written language. The French language facilitates the study of syllabification because syllable breaks are highly predictable and clear (Noske, 1982). Third, 4th and 5th graders wrote words on a digitiser. Half of the words ended with an *e* and were mono-syllabic phonologically (*barque* = [baRk]) but bi-syllabic orthographically (e.g. *bar.que*, the "with e" condition henceforth). We matched them to words that were bi-syllables both phonologically and orthographically (e.g. *balcon* = [bal.kõ] and *bal.con*, the "without e" condition henceforth). We measured movement time and fluency, which interrogate the programming of the handwriting gesture by providing information on the distribution of duration and fluency for each letter within a word. As in Kandel and Valdois (2006a), we expected a clear syllabic effect in the «without e» condition for the three grade levels, with duration and fluency peaks at the first letter of the second syllable. If, as we hypothesize, writing mechanisms activate orthographic syllables, we should also observe duration and fluency peaks at the first letter of the second grapho-syllable in the "with e" condition, just as in the «without e» condition. Conversely, if the "with e" words are segmented according to phonological syllabification patterns, there should be no peaks at the orthographic syllable boundary. Since third grade children may still rely more on phonology than on orthography to organize the programming of handwriting movements, we expected lower or nonexistent duration or fluency peaks at the orthographic syllable boundary for the "with e" words.

2. Method

2.1. Participants

Fifty-four right-handed native French speaking children participated in this experiment. There were 14 third graders (age 8), 20 4th graders (age 9) and 20 5th graders (age 10).

2.2. Material

The stimuli in the "with e" condition were 21 words ending by an *e* (see Appendix), which were mono-syllabic phonologically and bi-syllabic orthographically (e.g. *barque* = [baRk] and bar.que). These syllabification patterns appear in the Lexique French 3.5 data base (New, Pallier, Brysbaert, & Ferrand, 2004; <www.lexique.org>). They were matched to 21 words that were bi-syllabic both phonologically and orthographically (e.g. *balcon* = [bal.kõ] and bal.con, the «without e» condition). We made sure that the children syllabified the words according to these patterns by asking them to clap their hands each time there was a syllable. For the words in the «without e» condition they clapped their hands twice, whereas in the "with e" condition they only clapped once. The matched words shared at least the first two letters. They were also matched for lexical frequency (New, Pallier, Ferrand, & Matos, 2001): 21.12 pm for "with e" words and 23.06 pm for «without e» words, $t(20) = 0.85$, $p = .40$. The mean bigram frequencies at the orthographic syllable boundary were 405.04 for the "with e" words and 401.71 for the «without e» words (Content & Radeau, 1988), $t(20) = 0.97$, $p = .85$.

2.3. Procedure

The children were tested individually. They had to write the word they saw on the computer screen on the digitiser

(Wacom Intuos 2). The children wrote the words in cursive handwriting, with a special pen (Intuos Ink Pen), on lined notebook paper that was stuck to the digitiser. The words were randomised across participants.

2.4. Data analysis

The data were smoothed with a Finite impulse response filter (Rabiner & Gold, 1975) with a 12 Hz cut-off frequency. We segmented the words into letters according to curvature maxima in the trajectory and velocity minima in the velocity profile. Once the beginning and the end of each letter was defined, we obtained data on movement duration and fluency with *Ductus* -a semi-automatic handwriting analysis software recently developed in our laboratory (Guinet & Kandel, in preparation). Duration measured the time the children took to write each letter. Fluency discerned the number of absolute velocity peaks per letter (Meulenbroek & Van Galen, 1989). Smooth movements have few velocity peaks. When the cognitive system is overloaded, movement is less smooth – i.e. dysfluent – resulting in an increase in the number of velocity peaks. The simultaneous processing of subsequent syllable units and local parameters should overload the system and produce duration and fluency increases at specific locations.

Since the 42 words had the syllable boundary at different letter positions, we focused on the letter stroke duration and fluency values located at the orthographic syllable boundary (e.g. the *rqu* in *barque* and *lco* in *balcon*). As in Kandel and Valdois (2006a), Kandel and Valdois (2006b), the n position corresponded to the first letter of the second syllable (e.g. *q* in *barque* and *c* in *balcon*). The $n-1$ position is thus the last letter of the initial syllable (e.g. *r* in *barque* and *l* in *balcon*) and the $n+1$ position is the second letter of the second syllable (e.g. *u* in *barque* and *o* in *balcon*). To compare letters that are made up of a different number of strokes (e.g. for the n position, the *q* in *barque* has 3 strokes and the *c* of *balcon* has 2 strokes), we had to normalise the duration and fluency values with respect to the number of strokes per letter. The normalisation procedure was based on a letter segmentation analysis presented by Meulenbroek, and Van Galen, (1990). It is important to note that errors were rare (2%) because we instructed the children to avoid mistakes as much as possible. When words were copied with errors, we excluded them from the analysis.

3. Results

Mean stroke movement duration and fluency values were submitted to separate Analyses of Variance (ANOVA), analysed both by participants (F_1) and by items (F_2) with grade level (third, 4th, 5th), e condition («with e», «without e») and letter position at the syllable boundary ($n-1$, n, $n+1$) as factors.

3.1. Letter stroke duration

Table 1 presents the mean stroke duration at the syllable boundary for the "without e" and "with e" words for each grade level. The results revealed a main effect of grade level, F1(2,48) = 11.47, $p < .001$; F2(2,80) = 125.02, $p < .001$. The stroke durations for the "with e" words were longer than for the «without e» ones, F1(1,48) = 92.77, $p < .001$; F2(1,40) = .64, $p = .42$, ns. The letter position also yielded a significant effect, with a peak at the n position, F1(2,96) = 129.62, $p < .001$; F2(2,80) = 11.45, $p < .001$. There was a significant interaction between grade and letter position, F1(1,48) = 3.91, $p < .01$; F2(1,40) = 3.64, $p < .01$. This was mainly due to slightly lower peaks in 5th grade.

Table 1
Mean stoke duration (ms) for 3rd, 4th and 5th graders in the "with e" and "without e" conditions for the three letter positions at the syllable boundrary ($n-1$, n, $n+1$).

	Without e words			With e words		
	$n-1$	n	$n+1$	$n-1$	n	$n+1$
3rd grade	229.46	294.00	230.20	257.62	329.77	284.64
4th grade	193.46	248.62	193.14	224.80	298.35	227.06
5th grade	144.42	187.71	167.63	174.49	228.06	189.92
Mean	189.11	243.45	196.99	218.97	285.39	233.87

There were significant peaks at the syllable boundary for both word types: for the «with e» words $n-1 < n$, F1(1,48) = 91.42, $p < .001$; F2(1,40) = 11.72, $p < .001$ and $n > n+1$, F1(1,48) = 101.66, $p < .001$; F2(1,40) = 6.17, $p = .01$; for the «without e» words: $n-1 < n$, F1(1,48) = 173.55, $p < .001$; F2(1,40) = 6.19, $p = .01$ and $n > n+1$, F1(1,48) = 99.97, $p < .001$; F2(1,40) = 4.63, $p = .03$. The letter stroke durations for the "with e" words were higher than for the «without e» ones at all three letter positions but these differences did not reach significance in the by-items analysis: for $n-1$, F1(1,48) = 23.71, $p < .001$; F2 < 1; for n, F1(1,48) = 55.07, $p < .001$; F2 < 1; for $n+1$, F1(1,48) = 78.24, $p < .001$; F2(1,40) = 1.15, $p = .27$. The reason for this item variability seems to be due to the fact that 8 out of 21 of the "with e" words contained two-letter graphemes at the syllable boundary (e.g., for the *casque–castor* pair, there is a complex grapheme in *casque* because *qu* = /k/ whereas the *t* in *castor* is a simple grapheme because *t* = /t/). Kandel et al. (2006) provided evidence with 1st and 2nd graders indicating that the letter stroke duration and dysfluency of a given letter can vary when it is embedded in a complex grapheme because the complex grapheme is programmed as a single unit. This issue should be studied with more detail in further research.

3.2. Letter stroke fluency

Table 2 presents the mean letter stroke fluency values for the "without e" and "with e" words at the syllable boundary for each grade level. The results revealed a main grade effect, F1(2,51) = 6.82, $p < .005$; F2(2,80) = 148.82, $p < .001$. The «with e» words yielded more dysfluency than the «without e» words, F1(1,51) = 112.10, $p < .001$; F2(1,40) = 7.80, $p = .007$. Letter position was also significant, with a peak at the n position, F1(2,102) = 53.92, $p < .001$; F2(2,80) = 20.01, $p < .001$. The interaction between word type and letter position only reached significance in

Table 2
Mean fluency values (number of velocity peaks) for 3rd, 4th and 5th graders in the "with e" and "without e" conditions for the three letter positions at the syllable boundary ($n-1$, n, $n+1$).

	Without e words			With e words		
	$n-1$	n	$n+1$	$n-1$	n	$n+1$
3rd grade	1.34	1.63	1.56	1.55	1.87	1.58
4th grade	1.16	1.47	1.35	1.37	1.63	1.48
5th grade	1.00	1.20	1.18	1.15	1.32	1.32
Mean	1.17	1.43	1.36	1.36	1.61	1.46

the by-participants analysis, $F1(1,48) = 3.28$, $p < .05$; $F2(1,40) < 1$.

There were significant peaks at the syllable boundary for both word types: for the «with e» words $n-1 < n$, $F1(1,51) = 79.15$, $p < .001$; $F2(1,40) = 10.54$, $p = .002$ and $n > n+1$, $F1(1,51) = 16.13$, $p < .001$; $F2 < 1$; for the words «without e» $n-1 < n$, $F1(1,51) = 41.20$, $p < .001$; $F2(1,40) = 9.48$, $p = .003$ and $n > n+1$, $F1(1,51) = 12.75$, $p < .001$; $F2(1,40) = 2.34$, $p = .13$. Note however, that the decrease from the n to the $n+1$ position did not reach significance in the by-items analysis. The item variability could be due to the presence of complex graphemes at the n and $n+1$ positions for the "with e" words, as for letter stroke duration, but also because of an important dysfluency decrease in 4th and 5th grade. The fluency values for the «with e» words were higher at all three letter positions at the syllable boundary, although the differences were not significant in the by-items analysis for the n and n+1 positions: for $n-1$, $F1(1,51) = 92.97$, $p < .001$; $F2(1,40) = 5.94$, $p = .01$; for n, $F1(1,51) = 41.69$, $p < .001$; $F2(1,40) = 2.55$, $p = .11$; for $n+1$, $F1(1,51) = 9.95$, $p = .002$; $F2(1,40) = 2.00$, $p = .16$. Again, the item variability could be due to the presence of complex graphemes for the "with e" words at the syllable boundary, like in *bal**c**on-bar**qu**e*, *cas**t**or-cas**qu**e*, *cou**s**in-cou**ch**e*.

4. Discussion

French children program the words they write syllable by syllable (Kandel & Valdois, 2006a). This research examined whether the syllable the children use to segment words is determined phonologically (i.e., derives from speech production processes) or orthographically (i.e., obeys graphotactic constraints). Third, 4th and 5th graders wrote words that were bi-syllables both phonologically and orthographically («without e» words) as well as words that were mono-syllables phonologically but bi-syllables orthographically («with e» words). The results on letter stroke duration and fluency indicate that all the children used orthographic syllables rather than phonological syllables as processing units in handwriting production.

Mean letter stroke duration and movement fluency values revealed significant peaks at the syllable boundary for both types of words. There was a significant increase in both duration and number of velocity peaks at the first letter of the second syllable, confirming Kandel and colleagues' studies with French-speaking children (Kandel & Valdois, 2006a). This indicates that the children prepared the movement to produce the first syllable before starting to write. They programmed the movement to produce the second syllable on-line, while writing its first letter. More interesting for the purpose of this study was the fact that the «with e» words followed the same segmentation pattern as the «without e» words. This implies that even if the words are mono-syllables in speech, they are processed as bi-syllables when they have to be written. This data therefore support the idea that the segmentation processes of written words are relatively autonomous with respect to spoken language very early in the acquisition period.

The results also revealed a significant grade level effect. Third graders took more time to write and produced more dysfluent movements than 4th graders. In turn, the latter's results were lower than those observed for 5th graders. This is not surprising since several studies have shown that duration and dysfluency decrease as the children grow up (cf. Zesiger, Mounoud, & Hauert, 1993). The pattern of syllabic segmentation is orthographic already in third grade and remains orthographic during the automatization of handwriting in 4th and 5th grade. Martinet, Valdois, and Fayol (2004) showed that at the beginning of reading/writing acquisition, children give priority to phonologic strategies but also use orthographic information. This might be the reason why our third grade children used an orthographic pattern of syllabic segmentation. Futher studies with 1st and 2nd graders should be conducted to determine the age in which the handwriting programming systems shifts from phonological to orthographic syllable activation.

Another interesting and unexpected result was that the durations and fluency values for the «with e» words were higher than for the «without e» words. This implies that the children took longer and produced more dysfluent movements when they had to write the «with e» words than «without e» words. Movement duration and dysfluency increases implicate a supplementary cognitive load. It seems that words sharing the same phonological and orthographic syllable boundaries –the «without e» words- were easier to segment during writing than words that have different phonological and orthographic segmentation boundaries (the «with e» words). However, further research must be done to confirm this interpretation because the item variability was important. A detailed look at the by-items analysis suggests that the presence of complex graphemes at the syllable boundary could explain this variability.

In summary, this study revealed that French children not only program writing movements syllable by syllable, but that the syllable they use is different from the phonological patterns that are explicitly taught at the beginning of the reading/writing acquisition period. They chunk letters into grapho-syllables rather than phonological syllables.

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Appendix

Words used in the experiment, together with their corresponding word frequency (pm) and the bigram frequency at the orthographic syllable boundary.

«with e» words			«without e» words		
	Word frequency	Bigram frequency		Word frequency	Bigram frequency
Barque	16.81	62	Balcon	17.29	11
Boucle	9.1	221	Boulot	17.23	428
Casque	12.03	158	Castor	1.39	618
Charme	33.9	287	Chargé	48	119
Couche	39.06	221	Cousin	22	460
Dingue	9.58	271	Diesel	7.87	613
Douche	10.39	221	Doudou	3.52	117
Flaque	5.13	75	Flacon	6.87	335
Hanche	5.97	842	Hangar	6.97	271
Manche	29.84	842	Manqué	19.74	60
Manque	66.32	60	Manger	78.26	271
Marbre	27.1	51	Marqué	24.03	62
Menthe	5.32	1154	Mental	8.94	1154
Moufle	0.48	59	Mouton	11.1	593
Perche	5.65	229	Persil	3.19	154
Plante	19.97	1154	Planté	13.84	1154
Poivre	6.65	216	Poison	6.71	1028
Preuve	48.06	623	Profit	47.58	47
Prince	55.42	842	Projet	56.87	10
Trèfle	2.97	48	Trésor	22.13	613
Viande	33.84	870	Vivant	60.84	318
Mean	21.12	405.04		23.06	401.71

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