Article

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The effect of orthographic regularity on children's handwriting production

Résumé

Ce travail étudie comment l'irrégularité orthographique des mots influence la graphomotricité de l'écriture. Des enfants de CP et CE1 ont écrit des mots irréguliers sur une tablette digitalisante. L'irrégularité pouvait se trouver au début, au milieu ou à la fin des mots acquis tôt et tard. Les résultats montrent que les durées de production étaient plus importantes pour les mots irréguliers que pour les mots réguliers. Toutefois, les différences n'étaient significatives que pour les mots acquis tard. Les mots réguliers et irréguliers acquis tôt seraient donc activés directement du lexique orthographique. Les mots irréguliers acquis tard seraient traités par application de règles de recodage phonologique. L'écriture de mots irréguliers n'aurait que pour effet de rappeler l'orthographe du mot entier ainsi que le rappel de l'identité et de la localisation orthographique. Cette opération constituerait une surcharge cognitive réduisant la durée de production.

Abstract

This study investigated how orthographic irregularity affects handwriting production. First and second graders wrote regular and irregular words. The orthographic irregularity was located at the beginning, middle or end of early and late. The results revealed that movement duration was always higher for irregular than regular words. However, the differences only reached significance for words acquired late. Therefore, regular and irregular words acquired early are accessed from the orthographic lexicon. A different mechanism operates when writing unfamiliar irregular words. The child applies a phonological recoding operation that works successfully for regular words. When the child has to write an unfamiliar irregular word, memorize the spelling of the whole word and remember the identity and orthographic irregularity. This operation constitutes a supplementary cognitive load in an increase in processing time.

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Introduction

Handwriting is a linguistic motor task involving different stages. From the intention of writing to the actual movement execution, different processing levels such as semantic activation, syntax spelling recovery, allograph selection, size control and muscular adjustments (Van Galen, 1991). This study focuses on the spelling level. It examines the relationship between orthographic representations such as irregularity and the organisation of handwriting movements during acquisition.

Motor programming in handwriting does not merely involve the activation of letter strings at the spelling module (Teulings, Thom, & Van Galen, 1983; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989). It involves multi-dimensional orthographic representations that store information about the consonant and vowel status of letters and the syllabic structure (Caramazza & Miceli, 1990; Caramazza, Miceli, Villa, & Romani, 1987; Badecker, Goodman-Schulman, & Aliminosa, 1994; Wing & Badcock, 1983). Experimental studies also revealed that specific linguistic characteristics of orthographic representations require additional processing as cognitive load that affect the temporal and spatial features of production (Kandel, Alvarez, & Vallée, submitted; Orliaguet & Boë, 1993; Zesiger, Boë, & Mounoud, 1993; Wing, 1980). Zesiger, Mounoud (1993), for example, showed that adults' movement time and trajectory writing pseudo-words was systematically higher than when writing real words. The authors suggested that these increases translate an increase in time arising from the presence/absence of an orthographic representation and/or a more complicated search process in the case of non frequent words. The present experiment attempts to shed some light on whether orthographic irregularities in words affect handwriting production during acquisition.

Studies on children handwriting production support the linguistic characteristics of orthographic representations at the modulate movement execution. Søvik, Arntzen, Samuelstuen, & Valdois (in press), showed that 9 year old children produce lower movement duration when writing frequent words than less frequent words. In another research Valdois (in press), showed that French first to fifth graders handwriting movements according to their syllable structure. The children were very familiar words and pseudo-words on a digitiser. Movement analysis revealed that the children programmed the gesture to produce the words before starting to write. There was a systematic duration increase at the second syllable irrespective of lexical status, item length and
These duration increases were higher for pseudo-words than for pattern of results indicates that the children programmed the movement of second syllable during the production of its first letter. During production, there were concurrent processes - representation levels - that were active simultaneously (Van Galen, Meulenbroek, & Hylkema, 1986), resulting in duration increase. It be noted however, that the younger children, mostly first graders, wrote (in general pseudo-words) letter by letter.

The present study examined how another linguistic clorthographic regularity- affects handwriting production during the writing skills. The effect of orthographic regularity has been well documented (Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003; Wat Seidenberg, 1985). Orthographic regularity refers to the way in which associates letters to sounds. To learn how to read and write, the child has to be aware of certain spelling peculiarities, e.g. the e pronounced /a/ (/fam/) instead of /e/. In the present study, we investigated the processing of these orthographic peculiarities constitutes a cost on handwriting production during written language acquisition. Bloemsaat and Meulenbroek (2003) have shown that orthographic irregularity performance when typewriting Dutch words. There was an increase in time and typing time. In line with this study, we hypothesized that when writing irregular words, orthographic irregularities constitute a supplementa load that results in an increase in movement time at the location of the irregularity. In our study, the orthographic irregularity was located at the beginning of words acquired early or late. If the child is familiar with the word, s/he can write it down by recovering information from the corresponding representations. In this case, the processing of irregular and regular words is the same and yield no duration differences for words acquired early or late. For example, the child has to write an unfamiliar irregular word, s/he has to spelling of the whole word and remember the identity and location of the orthographic irregularity. This operation constitutes a supplementary load that results in an increase in production time. We expected orthographic irregularity to affect first graders more than second graders. Second graders have been exposed to written language than first graders, so they should have information stored in memory and therefore recover the spelling of irregular words globally rather than analytically (Share, 1995, 1999).

Method
Participants

Fourty-four right-handed children participated in the experiment. There were 22 first graders (mean age 6;8 ranging from 6;1 to 7;3, standard deviation 3 months) and 22 second graders (mean age 7;7 ranging from 7;0 to 7;3, standard deviation 3 months). They were all pupils of two schools of the Greater Paris area and were tested throughout the month of March 2002. Their mother tongue was French. The teachers reported the reading global and phonological, since it also focused on grapheme-phoneme correspondences. None of the subjects were repeating nor skipping grades; they were attending their grade at the regular age. They all had normal or corrected-to-normal vision and reported no hearing impairments. No learning disabilities or behavioural problems were reported. School attendance was regular.

Material and procedure

The stimuli consisted of 24 six and seven letter French words (see Appendix). 12 words were orthographically regular and the other 12 were orthographically irregular. The irregularity of the words was situated in the beginning of the word (e.g. quatre), in the middle (e.g. cahier), and at the end (e.g. soldat). We used the Dubois-Buyse scale as a reference for age (Ters, Mayer, & Reichenbach, 1988). This scale distributes the French words for children in 43 sets of increasing familiarity. The words are learnt before the words in the last sets. In this experiment, the words could either be acquired early (sets 11 to 17) or acquired late (sets 18 to 28). The orthographically regular words were matched to the irregular words within the sets of age acquisition and number of letters.

The children saw each word on the centre of the screen (Sony Vaio PCG-FX203K) written in lowercase Times New Roman (presentation was preceded by an auditory signal and a fixation duration). The participants’ task was to copy the item on the digitizer (Intuos 1218, sampling frequency 200 Hz, accuracy 0.02 mm). The children had to write the word that was presented on the screen so that the correct word was available since the beginning until the end of the writing. The digitizer was connected to a computer that monitored the movement produced to write the word. The children copied the words as they were writing at school” (i.e. in cursive handwriting). There were no time constraints. They had to write (with an Intuos Inking Pen) on a lined sheet of paper stuck to the digitizer (the vertical limit was 0.8 cm and the horizontal limit was 16 cm). Once the child finished writing the word, the experimenter proceeded to the following one. Two practice items preceded the experiment.

Data processing and analysis

As many studies on handwriting production, we use duration as an indicator of a supplementary processing load.
programming. We followed the standard procedure of movement analysis: the data were smoothed with a Finite Impulse Response filter (Rajna, 1975) with a 12 Hz cut-off frequency. To segment each word into individual letter constituents, we used geometric (cuspids and curvature maxima) and kinetic (velocity minima) criteria. With this segmentation procedure we measured the duration of each letter in the word. The duration measure considered movement execution (the time the child took to look at the word, or a word segment, with no pauses, were excluded). In order to compare the duration of letters across different spatial configurations, the duration of each letter was divided by the sum of all the mean stroke durations of that letter, then, converted to percentages. This normalization procedure provided a measure of the duration throughout the word. Mean stroke duration increases as the child grows older. Locations result from parallel processing of orthographic and motor characteristics. When one of these variables, like orthographic irregularity, requires additional processing, then duration percentages increase (Van Galen, 1991; Meulenbroek & Van Galen, 1992). In addition, mean stroke duration percentages allow comparison across all participants, from very slow to very fast writers. For instance, the duration of a given letter can be 100 ms for one child and 200 ms for another. The duration percentages for this letter for both children are around 10%, indicating that the children program their movement in the same manner. This is very important for the study because the children's age varied from six to eight, which is a critical period of motor development. Indeed, many authors have shown that absolute mean stroke duration decreases as the child grows up (Meulenbroek & Van Galen, 1989; Mojet, 1991; Zesiger et al., 1993). For the analysis of words with initial orthographic irregularity at the onset, we focused on the duration percentages of letters 1 and 2. For the words having the irregularity at the middle, we examined duration percentages of letters 3 and 4. For the words with the irregularity at the end, we analysed duration percentages of letters 5 and 6 for six-letter words and letters 6 and 7 for seven-letter words.

**Results**

For each irregularity position, we conducted an Analysis of Variance (ANOVA) with School level (1st, 2nd grade) as between-participants factor, orthographic characteristics of the word (irregular, regular) and age (early, late) were analysed as within-participants factors.

**Onset**

Figure 1 presents the mean stroke duration percentages acquired early and late at the Onset position. Analysis revealed...
differences in duration percentage between grades 1 and 2. Grade interact with any of the other factors. Mean duration percentages with irregular words than for regular words ($F(1, 42) = 16.65, p < .001$). Age of acquisition was also significant ($F(1, 42) = 16.08, p < .001$). The interaction between orthographic regularity and age of acquisition did not reach significance.

**Figure 1.** Mean stroke duration percentages for words early and late in the Onset condition as a function of the orthographic character of the word (irregular, regular).

**Middle**

Figure 2 presents mean stroke duration percentages for words early and late at the Middle position. Again, there was no grade factor did not interact with any of the other variables. Means percentages were higher for irregular words than regular ones ($F(1, 42) = 78.33, p < .001$) but the differences were significant only for the words acquired ($F(1, 42) = 23.92, p < .001$). Age of acquisition was also significant ($F(1, 42) = 23.92, p < .001$).
Figure 2. Mean stroke duration percentages for words early and late in the Middle condition as a function of the orthographic characteristic of the word (irregular, regular).

End

Figure 3 presents mean stroke duration percentages for words early and late at the End position. The ANOVA revealed no significant effect of grade level. It did not interact with any of the other factors. Regularity did not yield significant effects. Age of acquisition was significant ($F(1, 42) = 10.12, p = .002$). The interaction between the two factors was significant ($F(1, 42) = 17.74, p < .001$). For words acquired early, duration percentage for regular than irregular words ($F(1, 42) = 4.04, p = .05$). For words duration percentages were higher for irregular than for regular words ($F(1, 42) = 18.21, p < .001$).
Figure 3. Mean stroke duration percentages for words acquired early and late in the End condition as a function of the orthographic characteristics of the word (irregular, regular).

Discussion

This study investigated whether orthographic irregularity supplementary processing load in handwriting production during acquisition. We used movement duration as an indicator of cognitive orthographic irregularity was located at the beginning, middle or acquired early or late. The results revealed that mean stroke duration for irregular words were higher than for regular ones, both for first grade children. This pattern of results only reached significance for words acquired late.

The fact that the relative duration of critical letter strokes in irregular than regular words indicates that orthographic irregularity supplementary processing load with respect to the processing of regular words. However, the differences did not reach significance for words acquired early. The results suggest that irregular words acquired early are already stored in the lexicon together with their orthographic characteristics and are accessible. There was no supplementary processing time because the children had the spelling from the lexicon, in the same fashion as for regular words that are unfamiliar, their corresponding orthographic representation becomes unavailable (Share, 1995) or underspecified (Perfetti, 1992). The child tends to apply phonological recoding rules. These rules work successfully when writing regular words (Share, 1995, 1999). The child reads the regular word, keeps its spelling in the graphemic buffer and programs the
write it down. When the child has to write an unfamiliar irregular word, the strategy they use to write the word without error is a) to process the identity and location of the letters related to the irregularity separately; or b) to write the word by applying grapheme-phoneme conversion rules and realise that the rules do not apply at certain positions. Kandel and Valdois (in press) used very familiar regular bi-syllabic words. The younger children program their handwriting movements according to the syllabic structure of the word. In other words, they anticipate the letter sequences further in advance. The results presented in this paper for irregular words acquired late indicate that there is a more letter by letter processing strategy that children adopt to write irregular words correctly. A possible reason for this difference is that orthographic syllabification of irregular words is not as straightforward as for regular words. For example, is the syllable boundary for the word *monsieur*? Phonologically, the syllable boundary is at the s between *mon* and *sieur*, but orthographically it is unclear to which syllable the *s* belongs because normally they represent the phoneme /õ/. So when the irregular word is unfamiliar, it is likely that the children apply a letter by letter processing strategy that does not even consider syllable boundaries. Finally, note that in the future, an analytic strategy can be applied when letter sequences are unfamiliar.

Furthermore, age of acquisition was significant at the third-grade level. For the onset position, the duration of critical letter strokes was longer for words acquired early than acquired late. This could be due to the fact that retrieval is done just before starting to write. Also, writing from an overlearned spelling dictionary is more efficient. For end positions, the duration of the critical letter strokes was globally higher for words acquired early than acquired late. It seems that the retrieval by first graders was more efficient during writing.

This study investigated the effect of orthographic regularity on children’s handwriting production from a developmental perspective. We hypothesized that orthographic irregularity affects first graders more than second graders. The results do not support this hypothesis. There was no grade effect in any of the conditions. This could be due to the fact that the words acquired late were equally unfamiliar to first graders.
graders. Another possibility is that second graders did have an orthographic representation of the irregular words acquired late, but information was underspecified or insufficient (Perfetti, 1992). It should be noted that Bloemsaat et al. (2003) found an irregularity effect in irregularity effect when writing unfamiliar words could therefore be adulthood and not evolve during spelling acquisition. Further research is needed to assess this issue.

Finally, this experiment provides further evidence that variables such as orthographic regularity (Bloemsaat et al., 2000), familiarity (Søvik et al., 1994) affect written language performance. Movement time increases supplementary cognitive loads that arise from the parallel processing: linguistic characteristics of the word and the lower levels of handwriting such as allograph selection, size control and muscular adjustments (1991; Van Galen et al., 1986).

## Appendix.

Irregular and regular words for early and late acquired orthographic irregularity appeared at the onset, middle and end of the words. Their orthographic irregularities of the irregular words are indicated in the table below.

<table>
<thead>
<tr>
<th>Irregular words</th>
<th>Regular</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquired early</strong></td>
<td><strong>Acquired late</strong></td>
</tr>
<tr>
<td><strong>Onset</strong></td>
<td></td>
</tr>
<tr>
<td>quatre</td>
<td>hurler</td>
</tr>
<tr>
<td>horloge</td>
<td>mystère</td>
</tr>
<tr>
<td><strong>Middle</strong></td>
<td></td>
</tr>
<tr>
<td>cahier</td>
<td>façade</td>
</tr>
<tr>
<td>bonheur</td>
<td>méthode</td>
</tr>
<tr>
<td><strong>End</strong></td>
<td></td>
</tr>
<tr>
<td>soldat</td>
<td>désert</td>
</tr>
<tr>
<td>cadenas</td>
<td>paletot</td>
</tr>
</tbody>
</table>

## References


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