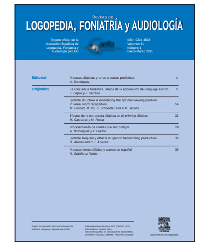
Revista de Logopedia, Foniatría y Audiología. 2011;**31(1):**33-38

Revista de
LOGOPEDIA, FONIATRÍA y AUDIOLOGÍA
www.elsevier.es/logopedia



ORIGINAL ARTICLE

Syllable frequency effects in Spanish handwriting production☆

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Received: 29-12-2010; accepted: 15-1-2011

KEYWORDS
Syllable frequency;
Phonics;
Handwriting

Abstract
This study was concerned with the nature of the sublexical units that are functional during the process of writing words in normal adults. Specifically, we focused on the role of syllables in Spanish handwriting. Participants were asked to write down trisyllabic words. In the experiment, a graphic tablet was used and the frequency of the second syllable was manipulated in the stimuli while controlling for bigram frequency. The latencies, letter durations and temporal intervals between letters were measured. The results showed an effect of syllable frequency on the interval between the first and second letter of the second syllable: the interval was shorter for high-frequency than for low-frequency syllables. An opposite effect was observed for the duration of the first letter of the critic syllable. No effect was found on the interval previous to the second syllable. These results confirm recent findings supporting the claim that syllables are involved during the handwriting production process and provide new information on the mechanisms underlying these syllabic effects.

PALABRAS CLAVE
Frecuencia silábica;
Fonología;
Escritura a mano

Efectos de la frecuencia silábica en la producción escrita del español

Resumen
Esta investigación se ocupa de la naturaleza de las unidades subléxicas funcionales durante el proceso de escritura en adultos normales. En concreto, se centra en el papel de las sílabas en el español escrito. Se pidió a los participantes que escribieran palabras trisilábicas a mano. Mediante una tableta gráfica, se manipuló la frecuencia de la segunda sílaba en los estímulos, mientras se controlaba por la frecuencia de bigramas. Se midieron las latencias, la duración de las letras y los intervalos temporales entre letras. Los resultados mostraron un efecto de frecuencia silábica en el intervalo entre la primera y la segunda letra de la segunda sílaba: fue más corto para las sílabas de frecuencia alta que para las de frecuencia baja. Se observó el

☆Este artículo está disponible en español en www.elsevier.es/logopedia
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efecto opuesto para la duración de la primera letra de la sílaba crítica. No se observó ningún efecto en el intervalo anterior a la segunda sílaba. Estos resultados confirman hallazgos recientes que respaldan la postura de que las sílabas están implicadas en el proceso de producción escrita y proporcionan nueva información acerca de los mecanismos que subyacen en estos efectos silábicos.

Introduction

In comparison with other fields of Psycholinguistics and until very recently, the experimental study of the cognitive processes underlying handwriting using on-line measures have been relatively neglected. Most of the evidence and models about these processes have come from neuropsychological studies with patients, using off-line measures such as errors (see for instance, Tainturier & Rapp, 2000 for a revision). Based on these studies, handwriting production had been typically assumed to involve, at least, two types of processing routes (Caramazza, 1988; Tainturier & Rapp, 2000). The lexical process would contain the orthographic word-forms (plus phonological and semantic relationship between words), and the sublexical process would include the appropriate correspondences between phonemes and graphemes. The former route would be especially effective in order to spell a well-known word, while the latter route would be useful to propose phonologically plausible orthographic forms for new words. Some evidence aims towards the existence of some kind of interaction between both routes during the handwriting process (Barry & de Bastiani, 1997; Barry & Seymour, 1988; Folk, Rapp & Goldrick, 2002; Hillis & Caramazza, 1991; Hillis, Rapp & Caramazza, 1999; Rapp, Epstein, & Tainturier, 2002). If this is the case, some sublexical units larger than letters could influence the spelling process of well-known words, leading to an effect in handwriting tasks. Although it was proposed that orthographic representations include only letter identity and serial order information (Caramazza, Miceli, Villa, & Romani, 1987), later on Caramazza and Miceli (1990) observed that writing errors preserved the orthographic consonant/vowel identity of the target letters supporting the claim that writing production processed involve more than the recovery of a simple string of letters, namely syllable-type units (see also Buchwald & Rapp, 2003).

The results of the pioneer experimental studies about the possible role of syllables in handwriting with normal population were rather contradictory (Bogaerts, Meulenbroek, & Thomassen, 1996; Zesiger, Orliaguet, Boë, & Mounoud, 1994). In a study using French words, Zesiger et al. (1994) reported no effect of syllabic structure in handwriting. However, in typing interkeypress intervals located at the syllable boundary (e.g., the interval between a and r in *pa.role*) were longer than the same interval within a syllable (e.g., *par.don*). Bogaerts et al. (1996) also failed in obtaining a syllabic structure effect in the lift durations in Dutch, but a post-hoc analysis revealed that mean stroke duration and trajectory length of the first letter was longer for CVC than for CV words. In recent years some on-line approaches have shown syllabic effects during the time course of the written response. Kandel, Álvarez and Vallée (2006) used a copy task in which subjects were asked to write visually— presented words in uppercase letters on a graphic tablet in French. The duration of the inter-letter intervals (the time between the last pen lift in a letter and the first pen down in the following letter: henceforth ILI) was the dependent variable. Longer ILIs were found when the interval was inter-syllabic than when the same ILI was intra-syllabic (e.g., the ILI between a and c in the French word tra.ceur was longer than the same interval in the word trac.tus. The dot marks the syllable boundary of the word) (see also Lambert, Kandel, Fayol, & Espéret, 2008). A similar pattern of results was observed in Spanish by Álvarez, Cottrell and Afonso (2009) using copy-to-dictation and written picture naming tasks. This fact suggested that syllable could play a role at the graphemic buffer level. The graphemic buffer is the processing stage in which orthographic representations are temporarily stored while more peripheral writing processes are planned, so it is thought to affect handwriting independently of the input modality (Caramazza, Miceli & Romani, 1987; Caramazza & Miceli, 1990).

Other studies have used the duration of the graphemes execution like an indicator of the processing cost during the written response. Kandel and Valdois (2006) found that 6- to 12-year-old children produced systematically bigger durations of the first grapheme of the second syllable if compared with other graphemes in bi-syllabic words. It seems that the movements involved in the writing of the second syllable were programmed during the execution of its first grapheme.

In spite of these recent findings, syllable frequency has not been manipulated in any experimental handwriting study so far. In speech production research, the observed facilitatory syllable-frequency effects have been interpreted as reflecting the existence of a repository of ready-made syllabic motor programs, at least for the most frequent syllables in a language (Cholin, Levelt, & Schiller, 2006). Following these authors, an abstract syllabic representation triggers the activation of pre-compiled gestural scores that are retrieved from this repository, so called mental syllabary. In handwriting production syllables are not overtly produced, but the results mentioned above showing syllabic boundaries effects suggest a syllabic segmentation also during the writing process. It is possible that at least the hand-movements corresponding to the most frequent syllables have been stored like pre-compiled motor programs. If this is the case, a syllabic frequency effect should be observed. In addition, if the representations in the graphemic buffer involve syllables, as we hypothesise based on recent evidence (Álvarez et al., 2009; Kandel et al., 2006), and because of the conceptualization of this buffer as a memory system, it should be sensitive to the frequency of the syllabic units. Moreover, the central processes related with the orthographic representations could be "cascaded" in the most peripheral moments. Unlike discrete processing, with cascade models the latter stages of information processing can begin operating before the completion of earlier information processing stages. It has been previously shown that the writing movements can be initiated before the orthographic processing has finished (Álvarez et al., 2009; Delattre, Bonin, & Barry, 2006). Thus, the frequency effects could be observed in the movement execution phase.

Our specific objective was to analyze if syllable frequency can actually affect handwriting and to explore at which concrete temporal moment its influence occurs. We manipulated the frequency of the second syllable of trisyllabic words with a CV.CV.CV structure auditorily presented. The second rather than the first syllable was studied in order to avoid possible alternative interpretations based on a possible confounding with processes related to lexical access to the auditory input. Specifically, we decided to manipulate the second better than the first syllable because of the interpretative problems in case of an effect appearing in this position. If, for example, syllable frequency would influence the interval previous to the execution of critical graphemes, then this effect could be undistinguishable of effects related to input decoding processes. In other words, response latencies could be a deceitful indicator of the underneath sublexical processes. However, manipulating the frequency of the second syllable should enable us to easily detect potential differences in the interval previous to the execution of the critical syllable. In addition, we were mainly interested in analysing effects that take place when writing movements are being produced. Thus, in order to obtain a more complete view about the time course of the written response, we decided to measure not only the ILI before the critical syllable and the latencies (as in previous studies), but the first three ILIs and also the first four letter durations. Significant differences between words with high versus low syllabic frequencies were expected for the duration of the third letter (the first one of the second syllable), because of the results reported by Kandel and Valdois (2006). For the ILIs, a syllabic frequency effect is also expected for the ILI2 or for the ILI3, because differences in the writing movements' preparation between high and low frequency syllables should be reflected before the execution of one of the letters forming the syllable.

Method

Participants. Twenty-nine right-handed students from introductory psychology courses at the University of La Laguna took part in the experiment in exchange for partial fulfilment of a course requirement. All were native speakers of Spanish. They all had normal or corrected-to-normal vision and reported no hearing or motor impairments.

Materials. We selected 40 words of six letters and three syllables, with a CV.CV.CV structure, from the LEXESP Spanish corpus (Sebastián et al., 2000). In half of the stimuli, the second syllable had a high token syllable frequency (mean, 1080) and in the other half the second syllable was a low token frequency one (mean, 586). We chose the token syllable frequency instead of the type syllable frequency because the latter it does not reflect the number of times that a syllable actually appears in everyday language (Conrad, Carreiras, & Jacobs, 2008). Stimuli were chosen in pairs, each pair of words sharing all the letters except the first one of the second syllable (v.g. *ca.ni.lla* vs. *ca.pi.lla*). It is important to notice that this actual letter appeared in both conditions in order to avoid the influence of the letter identity; for example, the p grapheme is embedded in a high-frequency syllable in the stimuli *"do. pa.do"* and in a low-frequency syllable in the word *"ca. pi.lla"*. Both groups of words were matched for word frequency: M: 4.75 for words with high-frequency second syllable (HF condition) and mean: 6.1 for words with low-frequency second syllable (LF condition), orthographic neighbourhood density (means HF, 4.8 and mean LF, 5.35), frequency of the critical bigram (e.g., pi in *capilla* vs. ni in *canilla*. M: 272.89 and 238.92 respectively) and the frequency of the previous bigram (e.g., in *capilla,* the bigram ap; the bigram an in *canilla.* M: 351.93 and 388.92). T-tests showed no statistical differences between both conditions on any of these controlled variables, but they did it in the variables type frequency of the second syllable, $t1(19) = 4.25$, $P < .001$ and token frequency of the second syllable, $t1(19) = 6.12$, $P < .001$. Because of the high degree of similarity between each pair of words, 40 extra words served as fillers, which shared length and syllabic structure with the target words. Four words were used for the practice phase. All the auditory stimuli were recorded by a male Spanish speaker with SoundEdit on a Macintosh computer and they had an approximated duration of 1 second.

Procedure. Stimulus presentation and digital recording of the responses were controlled by Spellwrite II software (Cottrell, 1999) running on a Macintosh G4 computer. This program records the responses given by the subjects and provides information about the temporal moment after the stimulus onset in which a pen lift or a pen down was produced. The experimental task was a spell-to-dictation task and was conducted individually in a sound-proof room. Each trial started with an auditory word being presented via headphones which had to be written by the subject on a sheet of lined paper placed over the graphic tablet (Wacom Intuos GD-1218-u). They were asked to write the word in uppercase letters as soon as they recognized it using an Intuos Inking pen. The constriction about using uppercase letters was made in order to maximize the probability of producing a pause in an inter-letter interval as naturally as possible. If they did not recognize the word they had to sketch a horizontal line. The participants were instructed to press a button labelled next with the pen when they finished writing each word, leading to a new stimulus. The stimuli presentation was randomized for each participant. Each experimental session had a total duration of 20 minutes approximately. Auditory stimuli were presented through Labtec loudspeakers.

In order to compare both experimental conditions, we recorded the following measures: *a)* response latencies, defined as the time between the auditory stimuli onset and the first pen down in the first grapheme; *b)* the durations of the first three inter-letters intervals in a word (ILI1, ILI2 and

ILI3), defined as the time between the last pen lift in the first letter of the bigram and the first pen down for the second letter of the bigram, and *c)* the duration of the first four letters of the word (LD1, LD2, LD3 and LD4), defined as the time between the first pen down for a letter and the last pen lift for that letter. For example, for the Spanish word *ba.ti.do,* LD1 is the duration of the b, LD2 represents the duration of the a, LD3 is the duration of the t and LD4 is the duration of the letter i; ILI1, ILI2 and ILI3 correspond to the interval between b and a, a and t and t and i, respectively.

Results

Response latencies, letter durations and ILI durations more than 3 standard deviations above or below the mean for each participant, condition and measure were excluded from the analyses, as well as responses containing misspellings and those items in which no pause was produced in an inter-letter interval. In total, 11.85% of the data were removed. Stimuli considered as errors for more than a half of the subjects (*"cosido"* and *"nevada"* in the high syllabic frequency condition and *"balido"* and *"casada"* in the low syllabic frequency condition) were excluded from the analyses, as well as their counterparts in the other condition (*"batido"* and *"camada"; "cogido"* and *"negada"*). Mean duration and standard deviations for latencies, grapheme 3 and inter-letters intervals are shown in Table 1.

Analyses of variance, both by participants and by items, were conducted over response latencies, inter-letter intervals, and letter durations with the frequency of the second syllable of the word (high vs. low: HF and LF, respectively) as the only factor. A significant difference between both conditions was obtained in the analysis of the ILI3 (e.g. the interval between t and i in batido), $F1(1,28) = 9.55$, $P < .005$; $F2(1,30) = 4.2$, $P < .05$, being this ILI shorter in the HF condition (Mean: 105 ms, SD: 27) than in the LF condition (M: 112 ms, SD: 30). Also a reverse effect was found in the LD3 (e.g. the duration of t in batido), being the difference between HF (M: 352 ms, SD: 44) and LF (M: 302 ms, SD: 49) significant but only by participants, $F1(1,28) = 65.7$, $P < .001$, but not in the analysis by items, $F2(1,30) = 1.22$, $P = .278$. No significant differences were found for the rest of the collected measures.

Table 1 Mean duration (in ms) and standard deviations (in parentheses) for latencies, the third grapheme (LD3) and the first, second and third inter-letters interval in a word (ILI1, ILI2 and ILI3, respectively), as a function of syllable frequency

	High syllable frequency	Low syllable frequency
Latencies	1086 (248.44)	1051 (243.6)
ILI1	110 (36.55)	114 (46.08)
ILI2	128 (53.9)	123 (41.58)
ILI3	105 (27.32)	112 (30.72)
LD3	352 (44.12)	302 (48.53)

Discussion

The goal of this study was to gather new information about the time course and locus of the sublexical processes involving syllables in the hand-movements when normal participants write Spanish words. Our main objective was to test if syllable frequency affected the letter and lift durations. A syllable frequency effect was found in the inter-letter interval (ILI) between the two letters that form the critical syllable (*ba.t_i.do*), being shorter when the syllable was a high frequency one (HF). In addition, a reversed effect appeared in the duration of the first letter of the critical syllable (e.g., t in *ba.ti.do*), being shorter when the syllables were of low frequency (LF).

This pattern of results provides novel knowledge and clarifies the previous evidence about the role of syllables in handwriting. The effect detected here in the ILI3 (within the critical syllable) shows that the letters forming frequent syllables are easier and more quickly linked than those within less frequent syllables, even when the actual syllable is being produced. These outcomes illustrate that it is possible to obtain syllabic effects based on the frequency of syllables (not explained by the frequency of single letters clusters) in even later and peripheral moments than other studies have shown. They, therefore, make clearer the argument for a strong cascade mechanism.

Regarding the reverse effect on the letter duration of the first letter of the syllable (not significant by items), it could suggest that for HF syllables the execution of that first grapheme is affected by the fact that a bigger unit (namely, the whole syllable) is being produced. Congruently, the ILI following this letter is shorter for HF syllables. Thus, during ILI3, the spelling of the second letter of the syllable would be recovered in LF syllables, but when writing HF syllables the spelling of the entire syllable has been already processed during the execution of the first letter. However, if the syllable is LF, it could be the case that the syllabic unit is not pre-compiled. For example, consider the examples cadera (HF) and rodado (LF). The letter d is more slowly produced in the former case because the subsequent hand-movements related with the performance of letter e are being partially recovered too. This preparation leads to a shorter pause between both letters (as commented). However, in the LF-condition word rodado, the hand-movements corresponding to each grapheme are independently retrieved, because a pre-compiled motor for the whole syllable is not available. This result is in agreement with those from Bogaerts et al. (1996), who reported an increase in stroke durations at the first letter of the second syllable in Dutch adults, and with the findings of Kandel and Valdois (2006). These last authors obtained a systematic duration peak in the first letter of the items' second syllable. They concluded that the second syllable was programmed when its first letter is being produced. Our data suggest that this may be the case only for HF syllables, programmed as a whole unit, while LF would be processed letter by letter as previously commented.

In speech production research, it has been generally assumed that frequency effects reflect the existence of some kind of store. Following this principle, the present results can be explained postulating a repository which would include the most frequent syllables of a language, at least in Spanish. This explanation is very similar to the mechanism proposed by Levelt and Wheeldon (1994) for the syllabic frequency effects obtained in the speech production studies. In this model, a mental syllabary which would contain the "articulatory scores for at least the high frequency syllables of the language" is proposed. It is possible to claim a similar repository which would contain the motor programs associated to the most frequent syllables in a language. Nevertheless, in the present study the question about the specific nature of the representations stored in this mental syllabary (phonological or orthographic) remains outstanding. More investigations are necessary in order to clarify this issue.

In sum, the present findings show that writing a word is a process sensitive to the frequency of the constitutive syllables in the execution phase. Syllable frequency effects have been also reported in Spanish, both in reading words (e.g., Álvarez et al., 2001) and in naming pseudowords (Carreiras & Perea, 2004). As it was mentioned, in speech production research it has been assumed that syllable frequency effects reflect the existence of some kind of store or a sort of repository with the most frequent articulatory routines, at least by some models (Levelt, Roelofs, & Meyer, 1999; Levelt & Wheeldon, 1994; but see Dell, 1986, for a different position). Because learning to write usually relies on phonological knowledge in shallow languages such as Spanish, it is possible that the handwriting movements have been acquired by chunking them in a syllabic-size unit at least for the syllables more frequently produced. The observed syllable-frequency effect would reflect the difference between HF and LF syllables with regard to the activation of hand-movements pattern needed to produce the intended graphemes. HF syllables would trigger the activation of a more complex and bigger pattern in which all the letters of the syllable would be included, whereas LF syllables would lack such a hand-movement program for the whole-syllable — its letters being executed as independent units.

An interesting methodological conclusion can be drawn from our data: We obtained an inhibitory effect of syllable frequency followed by a facilitatory effect. An obvious consequence of this double effect is that, if we had measured only the duration of the whole word, probably these effects would have cancelled each other out, so we would have been unable to observe the reported differences between both groups. A detailed analysis of graphemes and ILIs duration seems to be necessary in order to observe sublexical effects in further investigations. Moreover, this procedure allows for obtaining a more detailed picture of the time course of the handwriting process.

Finally, we want to highlight the necessity of a more basic investigation of the handwriting production process in order to formulate a suitable model of the spelling process. Even when handwriting might seem an old fashioned activity compared to typewriting, there are several studies suggesting that learning to write a grapheme by hand improves the recognition of this grapheme relative to learning to type it in a keyboard (Longcamp, Zerbato-Poudou, & Velay, 2005). It is important to know what units are used during handwriting in order to understand how handwriting production relates to or might influence the development of language processing in general. The present study can help to determine how the language production system works, and in which manner can be easier for a novel writer to learn to produce new orthographic forms. Additionally and undoubtedly, the psycholinguistic knowledge about the precise mechanisms underlying writing will produce better and more accurate instruments to evaluate and treat the writing problems, such as dysgraphia, mirroring the progress that has been made in the field of reading disabilities.

Acknowledgements

Preparation of this article was supported by the grant SEJ2007-66860/PSIC (Spanish Ministry of Science and Technology) to the second author. Correspondence concerning this article should be addressed to Olivia Afonso. BCBL. Paseo Mikeletegi 69, 2nd Floor. 20009 DONOSTIA (Spain). EMAIL: o.afonso@bcbl.eu

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