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Phonological Effects in Handwriting Production: Evidence From the Implicit Priming Paradigm

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In the present article, we report 3 experiments using the odd-man-out variant of the implicit priming paradigm, aimed at determining the role played by phonological information during the handwriting process. Participants were asked to write a small set of words learned in response to prompts. Within each block, response words could share initial segments (constant homogeneous) or not (heterogeneous). Also, 2 variable homogeneous blocks were created by including a response word that did not share orthographic onset with the other response (odd-man-out). This odd-man-out could be phonologically related to the targets or not. Experiment 1 showed a preparation effect in the constant homogeneous condition, which disappeared (spoil effect) in the variable condition not phonologically related. However, no spoil effect was found when the odd-man-out shared the phonological initial segment with the targets. In Experiment 2, we obtained a spoil effect in the variable phonologically related condition, but it was significantly smaller than in the variable not phonologically related condition. The effects observed in Experiment 2 vanished in Experiment 3 under articulatory suppression, suggesting that they originated at a sublexical level. These findings suggest that phonological sublexical information is used during handwriting and provide evidence that the implicit priming paradigm (and the odd-man-out version of this) is a suitable tool for handwriting production research.

Keywords: handwriting, implicit priming, phonology, articulatory suppression

The role played by phonological information during the writing production process is one of the more debated topics in this field of research. Early proposals in this area claimed that the recovery of an orthographic representation had to be unavoidably preceded by the retrieval of the phonological word form. From this point of view, the writing process would be completely subsidiary to the speech production process. This kind of theory mainly relied upon the results obtained from the analysis of slips-of-the-pen (Hotopf, 1980). Slips-of-the-pen are errors made by normal populations during handwriting and are thought to reflect a failure during the process of selection of the orthographic form. They are different from misspellings because in slips-of the-pen the writer actually knows what the correct form of the intended word is, so he or she would be able to recognize the error (Ellis, 1982). There are several types of slips-of-the-pen, but cases of homophonic substitution (e.g., writing *there* instead of *their*) have received the most attention (Aitchison & Todd, 1982). It has been argued that homophonic substitutions reflect the conflict generated by a phonological entry activating more than one orthographic (output) form. However, from this point of view, is not clear how a writer would be able to correctly select between both orthographic word forms in the case of heterographic homophonic items such as *there* and *their* if only phonological information is considered during the selection process.

This so-called *obligatory phonological mediation hypothesis* (see e.g., Rapp & Caramazza, 1994, 1997) has been challenged by findings from neuropsychological studies (Cuetos & Labos, 2001; Lhermitte & Dérouesné, 1974; Miceli, Benvegnù, Capasso, & Caramazza, 1997; Rapp, Benzing, & Caramazza, 1997; Tainturier & Rapp, 2002). It is not unusual to find patients who exhibit a better performance in written production compared with spoken production tasks (Caramazza & Hillis, 1990; Lhermitte & Dérouesné, 1974; Rapp et al., 1997). For example, Rapp et al. (1997) reported the case of PW, a patient who was often unable to produce the spoken name of an item although he was able to produce its written name. In addition, Miceli et al. (1997) observed that the patient WMA produced different semantic errors for the same picture in oral picture naming and in written picture naming. When faced with a picture representing peppers, WMA said "artichoke" but wrote the word *tomato*. How this kind of error can occur if the same phonological form underlies both modalities of response is a problematic issue for the obligatory mediation hypothesis. This evidence motivated the formulation of the *ortho-*

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graphic autonomy hypothesis (Miceli et al., 1997; Rapp & Caramazza, 1997; Rapp et al., 1997), which establishes that an orthographic word form could be directly accessed from the semantic system without any phonological involvement.

It is worth noting that the orthographic autonomy hypothesis does not preclude the possibility of phonological information affecting the spelling process, but this would occur through optional rather than obligatory links. Two versions of the orthographic autonomy hypothesis have been proposed on the basis of the level at which this optional influence is thought to take place (Bonin, Peereman, & Fayol, 2001). The *lexical version* proposes that the phonological output lexicon and the orthographic output lexicon are connected through nonobligatory links. In contrast, the *sublexical version* claims that phonological influence on the writing process could come from the application of phoneme-to-grapheme conversion patterns. Consider, for example, the Spanish word *vaca* (in English, "cow"). According to the lexical version, the phonological word form /baka/ is linked to the orthographic word form *vaca*. In contrast, the sublexical version states that the phonological form /baka/ activates its constitutive phonemes (/b/ + /a/ + /k/ + /a/), and these phonemes would send activation to the corresponding graphemes (*v* + *a* + *c* + *a*) through phoneme-to-grapheme conversion mechanisms. Therefore, in the two cases phonological information would be able to affect the handwriting performed by normal adults, but it need not be recovered, due to the existence of a direct link between the semantic system and the orthographic output lexicon.

Bonin et al. (2001) obtained evidence favoring the sublexical version of the orthographic autonomy hypothesis using a written picture naming task in French. In their study, the authors manipulated the consistency of the phono-orthographic mapping of the picture names at the lexical and at the sublexical level. At the lexical level, heterographic homophones (e.g., the picture of a *pool*, which is homophonic with *pull*) were compared with nonhomophonic picture names (e.g., *doll*). At the sublexical level, words containing sublexical units that have more than one plausible phonological spelling (e.g., the word *jeep* could be spelled *jeap*) were compared with consistent picture names (e.g., *map*). No effect of homophony was observed. Nevertheless, picture names that were inconsistent at the sublexical level showed longer written latencies than did consistent picture names. These results were interpreted by the authors as evidence of phonological information coming into play during the writing process at a sublexical level. Some studies using the priming technique have addressed this issue, but the results have been rather contradictory (Bonin & Fayol, 2000; Bonin, Fayol, & Gombert, 1997; Bonin, Fayol, & Peereman, 1998). For example, Bonin et al. (1998) failed to obtain a phonological masked priming effect in a written picture naming task, even when they obtained a reliable effect of orthographic priming. However, phonological priming effects have been found to affect written picture naming latencies when auditory distractors were used (Bonin et al., 2001).

Some authors have claimed that lexical information and phoneme-to-grapheme conversion patterns could integrate at a grapheme level (Bosse, Valdois, & Tainturier, 2003; Rapp, Epstein, & Tainturier, 2002; Tainturier & Rapp, 2002). Both processes (lexical and sublexical) would "vote for" a candidate graphemic element, so when both systems produce the same output (the same grapheme is activated), the selection would be reinforced. As a result, sublexical phonological information would influence the writing of well-known words at the level of grapheme selection. This means that orthographic lexical information can be accessed independently of the phonological information, but in normal writing conditions, phonology strengthens the activation of the graphemes constituting a word.

The first goal of the present study is to address whether phonological information actually comes into play during unimpaired handwriting production processes. Additionally, we try to explore the level of processing (lexical or sublexical) at which this influence may occur. To achieve this, we made use of the implicit priming paradigm (Alario, Perre, Castel, & Ziegler, 2007; Bi, Wei, Janssen, & Han, 2009; Chen, Chen, & Dell, 2002; Damian & Bowers, 2003; Meyer, 1990, 1991; Roelofs, 1996, 1998, 1999, 2006; Roelofs & Meyer, 1998). The implicit priming paradigm has been repeatedly used in the area of speech production research, and it is thought to be sensitive to the early stages of phonological encoding (like the classic priming paradigm), but it is also believed to tap into later stages at the interface of phonological and phonetic encoding (Cholin, Schiller, & Levelt, 2004). This paradigm has been recently adapted to the handwriting investigation (Damian & Stadthagen-Gonzalez, 2009). Here we use the odd-man-out version of the implicit priming paradigm in order to test whether phonological information can facilitate a written response independently from the orthographic information.

The Implicit Priming Paradigm

The Basic Paradigm

In the implicit priming paradigm (Meyer, 1990, 1991; Roelofs, 1996, 1999), participants have to produce the response words included in a small set of prompt–response pairs previously learned. During the learning phase, participants have to memorize a list of paired words in which the first word of the pair is the prompt and the second word is the response. During the test phase, the studied prompts are presented in random order, and for each prompt the participants have to produce the corresponding response word. In the basic version of the paradigm two types of lists are created. In one of them, called the *homogeneous* set, all the response words share a part of the sublexical units (e.g., the first syllable in *loner*, *local*, *lotus*; the first syllable in *major*, *maker*, *maple*; or the first syllable in *beacon*, *beadle*, *beaker*). In the *heterogeneous* set, response words are regrouped to create a list with nonrelated response words (e.g., *loner*, *major*, *beacon*). Thus, the same word is tested in both the homogeneous and the heterogeneous condition. The logic of the paradigm is the following: Because in the homogeneous blocks the first segment is shared by all the response words, participants are able to successfully anticipate it, so this information can be used to prepare the corresponding motor program. This is reflected in shorter response latencies (the time between the onset of the prompt and the onset of the response) in the homogeneous than in the heterogeneous condition.

It could be argued that memory mechanisms and not linguistic processes are responsible for this preparation effect. Nevertheless, this memory account has been ruled out in a wide range of studies, on the basis of converging evidence suggesting that preparation effect originates at the level of phonological planning. It has been observed that preparation effect is sensitive to abstract lexical

properties such as number of syllables (Roelofs & Meyer, 1998) or syllable structure (Meyer, 1991). This pattern of results was interpreted by the authors as showing that the preparation effect was due to neither articulatory nor memory processes but to partial phonological planning. Furthermore, Roelofs (1998) obtained a preparation effect for Dutch particle–verb combinations when the particle was shared, such as in "*op*zoeken," "*op*draaien," and "*op*geven"; however, there was no preparation effect when responses shared the verb, such as in "op*zoeken*," "af*zoeken*," and "uit*zoeken*." In a second experiment, the imperative forms of the same particle–verb combinations were used as response words. In the imperative form, the order is reversed (verb–particle). The results showed that in this case preparation was observed when the verb was shared but not when the particle was shared. This pattern of results is difficult to conciliate with an account of preparation in terms of memory processes, because the lexical item was the same in both experiments.

But probably the more striking evidence against the memory account is the fact that preparation effect has been obtained when pictures instead of associated pairs have been used to trigger a response (Alario et al., 2007; Roelofs, 1999; Santiago, 2000). This fact seems to confirm that the preparation effect is due to language production processes instead of memory processes. In Spanish, Santiago (2000) reported that the same size effect was observed whether associated pairs or pictures were used, but this effect reached significance only in the case of picture names serving as responses. This evidence suggests that the memory component of the associated pairs version of the paradigm introduces noise in the data, making the preparation effect more difficult to be statistically significant. This means that the use of prompt–response pairs to observe a reliable preparation effect would be detrimental (instead of beneficial).

The implicit priming paradigm has been recently adapted to the handwriting investigation. Damian and Stadthagen-Gonzalez (2009) conducted an experiment (Experiment 1) using this paradigm in which participants were asked to write the response words. In the homogeneous blocks, response words shared a phonological and orthographic initial segment (e.g., *flow*, *flat*, *flip*, *flap*). The results showed a significant preparation effect in response latencies. These results suggest that implicit priming paradigm can be successfully used in handwriting research. However, it remains unsolved whether phonological information is able to induce a preparation effect in the absence of orthographic overlap. We address this issue by adapting a version of this paradigm in which an odd element (a so-called *odd-man-out*) is included in a homogeneous block.

The Paradigm With an Odd-Man-Out

The implicit priming paradigm with an odd-man-out (Bi et al., 2009; Cholin et al., 2004; Janssen, Roelofs, & Levelt, 2002; Roelofs, 2006) has been employed to assess which units are used by the participants to build up the oral response. In this variant of the paradigm an item that does not share some property with the rest of the response words is included in a homogeneous set. The homogeneous set of words with an odd-man-out is called a *variable set*. For example, Cholin et al. (2004) used this paradigm to test the involvement of the syllable during preparation of the speech production process. In the variable homogeneous set *beacon*, *beatnik*, *beaker*, the odd-man-out is the word *beatnik* because it differs from the other words in the first syllable (*beat* vs. *bea*), even though it shares with them an initial segment of the same length (*bea*). Cholin et al. reasoned that if syllabic information is used by the participants in order to produce a spoken word, then the introduction of this odd-man-out should spoil the preparation effect because of the impossibility of unambiguously predicting which syllabic program has to be prepared (*beat* or *bea* in our example).

In the present study we used this paradigm to test whether phonological information can affect written latencies. If phonology is retrieved to produce a written word, an odd-man-out phonologically related (although not orthographically related) to the other response words would not produce a spoil of the preparation effect (or a reduced spoil effect), because the initial phonological segment can still be prepared. This sort of odd-man-out could even activate all the phonologically plausible orthographic forms: the orthographic form included in the odd-man-out but also the alternative orthographic form included in the rest of the response words in the block. For example, in the variable set *banana*, *balada*, *vacuna*, the odd-man-out *vacuna* is phonologically related to the targets (in Spanish both "va" and "ba" are pronounced /bɑ/). This odd-man-out could not produce a spoil of the whole preparation effect because writing the word *vacuna* involves the activation of the phoneme /bɑ/ that would activate the orthographic segment "va" but also the orthographic segment "ba."

Our objective was to test whether the possibility of anticipating the phonological initial segment of a response word could lead to the absence of a spoil effect or at least to a reduced spoil effect compared with a condition in which the odd-man-out is not phonologically related to the target words. In contrast, if phonological information is irrelevant for the retrieval of the orthographic units, then a preparation effect should be observed only in the responses sharing the orthographic initial segment but not when a phonological relationship exists without an orthographic relationship. We chose the odd-man-out variant of the implicit priming paradigm for several reasons. First, this paradigm allowed us to manipulate the phonological relationship of an odd-man-out with the target words while keeping constant the orthographic overlap. Second, in the implicit priming paradigm the words serving as odd-man-out are actually produced differently from prime words in other priming paradigms used in handwriting research. This is important because, as mentioned earlier, these paradigms have not revealed consistent phonological effects in handwriting (Bonin & Fayol, 2000; Bonin et al., 1997, 1998). It might be possible that phonological influence occurs in a later stage of the spelling process. If phonological information comes into play at a later sublexical level (e.g., at the graphemic level), then a paradigm in which the primes (or context words) has to be processed at these later stages seems to be more suitable.

Experiment 1

In Experiment 1, we examined whether we could induce a preparation and spoil of the preparation effect. Longer written latencies are expected in the heterogeneous (*banana*, *mujer*, *periódico*, *recuerdo*) than in the homogeneous (*banana*, *balada*, *baraja*, *basura*) block, as previously reported by Damian and Stadthagen-Gonzalez (2009). In addition, the use of a variable set

in which the odd-man-out does not share the initial segment with the other response words (*banana*, *balada*, *baraja*, *camisa*) is expected to produce a spoil of the preparation effect resulting in written latencies similar to those in the heterogeneous set. More important, we created a second variable set in which the odd-man-out did not share the initial segments with the other responses (i.e., with the same orthographic overlap as in the former variable set) but did share the phonological initial segment (*banana*, *balada*, *baraja*, *vacuna*). We think that if phonological information is being used by the participants to prepare the written response, a phonologically related odd-man-out should be still able to induce some preparation effect. In contrast, if phonological information is not used when handwriting well-known words, then no differences should be observed between both variable sets.

Method

Participants. Eighteen students from introductory courses at the University of La Laguna took part in this experiment to fulfill a course credit requirement. All of them were native Spanish speakers who were right-handed and had no known motor or perceptive disorders.

Materials. Nine words were selected as responses to create three different sets of three words each. Every set was constructed on the basis of a different first syllable ("ba-," "ve-" and "bo-"). We selected a further nine words, three for each set of words, to create the three homogeneous conditions (one constant and two variable conditions). Three additional words totally unrelated to the targets were included to generate the heterogeneous blocks (*mujer*, *periódico*, *recuerdo*). These unrelated words were common to all the sets. Altogether, the experiment consisted of 21 response words. For each set, four experimental conditions were created depending on the relationship between the response words: (1) the *constant homogeneous condition*, in which the response words were three target words and one filler word that shared the first syllable with the targets (e.g., *banana*, *baraja*, *balada*, *basura*); (2) the *variable homogeneous condition with a phonologically related odd-man-out*, consisting of the three target words and one odd-man-out sharing the first phonological syllable with the targets but not the first orthographic syllable (*banana*, *baraja*, *balada*, *vacuna*); (3) the *variable homogeneous block with a nonphonologically related odd-man-out,* in which the response words were the three target words and a word with a different phonological and orthographic first syllable and with the same orthographic overlap with the target words as the odd-man-out included in the second experimental condition (*banana*, *baraja*, *balada*, *camisa*); and (4) the *heterogeneous condition*, consisting of three different blocks, each block containing only one target response plus the three totally unrelated words (*banana*, *mujer*, *periódico*, *recuerdo*). Thus, the experiment included six different experimental blocks (one constant homogeneous, two variable homogeneous, and three heterogeneous). For a given set of words, the words used as odd-man-out were matched in word length, syllabic structure, number of syllables, word frequency, orthographic neighborhood, and stress pattern. Each response word was paired with a prompt word that was a synonym of the corresponding response word. We chose this procedure in order to make the relationship between the prompt and the response as similar as possible for all the pairs. Prompts and response words had no obvious orthographic or phonologic overlap. A full set of words is shown in Table 1 as an example. A complete list of the materials used in Experiment 1 is given in Appendix A. Two extra pairs were selected to be used as a practice block.

Design. Set of words was a between-subjects variable with three levels depending on the syllable used to create the target response words ("ba-," "ve-," "bo-"). The within-subject variable condition had four levels (constant homogeneous, variable homogeneous with a phonologically related odd-man-out, variable homogeneous with an odd-man-out not phonologically related, and heterogeneous). The between-subjects variable order had six levels depending on which of the six experimental blocks was the first being learned and tested. In the data analysis, only the latencies for the three target words were included.

Apparatus. The software SpellWrite II (Cottrell, 1999) was used for stimuli presentation and data collection. The experiment was run on an Apple PowerMac computer. A graphic tablet connected to the computer and an Intuos pen were used to register the participants' responses.

Procedure. The experiment was run individually in a soundproof cabin. For each experimental block, the procedure was as follows. In the study phase, participants were asked to learn a block made up of four prompt–response words that were presented on a screen. They were told not to pronounce the words aloud. This phase ended as soon as the participants believed that they could correctly spell the response word in answer to each prompt. During the test phase, the prompt presentation was preceded by an auditory signal. When the prompt word appeared, participants had to write as soon as possible in uppercase letters the associated response word on a lined sheet of paper placed over the graphic

Table 1
Response and Prompts Words Corresponding to Each Condition for the "Ba−" Set of Words

Homogeneous		Variable phonologically related		Variable phonologically unrelated		Heterogeneous	
Prompt	Response	Prompt	Response	Prompt	Response	Prompt	Response
poema	**BALADA**	poema	**BALADA**	poema	**BALADA**	poema	**BALADA**
naipes	**BARAJA**	naipes	**BARAJA**	naipes	**BARAJA**	señora	MUJER
plátano	**BANANA**	plátano	**BANANA**	plátano	**BANANA**	memoria	RECUERDO
suciedad	BASURA	inyección	VACUNA	inyección	CAMISA	diario	PERIÓDICO

Note. Prompt words are lowercased, and responses are uppercased. Experimental words appear in boldface.

tablet. Because a pen without ink was used and therefore no marks were left on the sheet, participants were told to always write each response word on the same line. The prompt word disappeared as soon as the written response started. After writing the word, participants had to press with their left hand a button labeled *Next*, which was set to the left of the workspace of the graphic tablet. By doing this, the next stimuli appeared on the screen. If they did not remember the response word, they were instructed to draw a horizontal line and then to press the *Next* button. Participants were instructed that between trials they should keep the pen above the line to be written on, without making contact. Each prompt word was presented three times in a pseudorandomized order, making sure that a given prompt did not appear more than once consecutively and that the odd-man-out was presented at least once before the last repetition of each target word appeared. The whole experiment lasted around 25 min.

Results

Only correct responses were included in the written latencies analysis. The responses registered during the practice block were not included in the analysis. Latencies above and below 2.5 standard deviations from the mean by participant and word were also excluded from the analysis (1.39% of the data). Responses containing misspellings and hesitations or those in which a recording error occurred were considered as errors and were also removed from the analysis (0.46%). Table 2 shows the mean and standard deviation for written latencies for each condition. An analysis of variance (ANOVA) by participants was conducted over correct responses with condition as a within-subject variable and set of words and order as between-subjects variables. Only the main effect of condition was significant, $F(3, 45) = 3.06$, $MSE = 42{,}416.72$, $p < .05$. In order to clarify which conditions were actually different, *t* tests were carried out. Significant differences were observed between the constant homogeneous and heterogeneous conditions, $t(17) = 2.45$, $p < .05$, reflecting the fact that target words were produced faster in the former than in the latter condition. In addition, the constant homogeneous condition was significantly faster than the variable homogeneous condition with a nonphonologically related odd-man-out, $t(17) = 2.93$, $p < .01$. Importantly, no differences were observed between the constant condition and the variable condition with a phonologically related odd-man-out ($F < 1$). The comparison between both variable conditions was marginally significant, $t(17) = 1.90$, $p = .074$, with shorter written latencies when the odd-man-out was phonologically related to the targets.

Table 2
Mean Written Latencies (in ms), Standard Deviations, and Preparation Effects (in ms) in Experiment 1

Condition	*M*	*SD*	Preparation effect
Homogeneous	1,167	283	101
Variable phonologically related	1,187	272	81
Variable phonologically unrelated	1,250	309	18
Heterogeneous	1,268	304	

Discussion

In Experiment 1 we obtained a preparation effect, indicating that participants were able to prepare their written responses on the basis of the shared segments of the words within a block. Furthermore, the preparation effect vanished when an odd-man-out not sharing the initial orthographic or phonological segment was included, suggesting that participants were no longer able to anticipate the initial segment of the response. These results indicate that this paradigm is indeed adequate for handwriting research: We were able to induce both a preparation effect and a spoil of the preparation effect. Crucially, no differences were observed between the constant homogeneous condition and the variable condition containing an odd-man-out phonologically related to the target words. The absence of a spoil effect when the odd-man-out shared with the target words the initial phonological segment points to the use of the phonological information during the writing process, benefiting the speed of the written response.

However, there could be alternative explanations for the absence of a spoil effect in the variable phonologically related homogeneous condition. It is possible that Experiment 1 was not powerful enough to capture differences between the constant homogeneous condition and the variable phonologically related condition. Our experimental design was rather complex, crossing three variables and resulting in a high number of conditions ($3 \times 4 \times 6 = 72$ levels). It is possible that the odd-man-out is in fact spoiling the preparation effect, but this cannot be observed with the present experimental power. To confirm or to rule out this hypothesis, a greater number of participants took part in Experiment 2.

Additionally, it could be that some characteristics of the stimuli affected the pattern of results. If the movements involved in the production of the first letter of the odd-man-out are more similar to the movements involved in the first letter of the targets in the phonologically related condition than in the phonologically unrelated condition, then faster latencies can be expected in the former condition purely due to an effect of practice. In Experiment 2 we replaced the words used as an odd-man-out in Experiment 1 by words starting with letters that had a similar first stroke in both variable conditions. For example, for the "vi−" set *bidón* and *pitón* were used as phonologically and not phonologically related odd-man-outs, respectively, because *b* and *p* are both letters with an initial down stroke. By doing this, we expected to avoid potential effects due to pure repetition of the hand movements. Moreover, in Experiment 2 we used four instead of three set of words to control for potential effects due to the identity of the target phonemes: Unlike in Experiment 1, in Experiment 2 two sets were generated on the basis of syllables starting with the grapheme *b* ("ba−," "bo−") and two sets were based on syllables starting with the grapheme *v* ("ve−," "vi−"). These modifications allowed us (a) to enhance the amount of trials performed in a particular condition, (b) to focus on just the size of the spoil effect, and (c) to make the new experimental conditions as comparable as possible.

Experiment 2

Experiment 2 tested the hypothesis that a real spoil effect due to the phonologically related odd-man-out was not detected in Experiment 1. For this reason, in Experiment 2 we focused on the comparison of the spoil effect produced by each variable condition

(odd-man-out phonologically vs. not phonologically related). Unlike in Experiment 1, here we generated four sets of words (beginning with "ba-," "bo-," "ve-," and "vi-") instead of three, and we replaced the words serving as odd-man-outs to make them as comparable as possible across conditions.

Method

Participants. Forty-eight students from introductory courses at the University of La Laguna took part in this experiment to fulfill a course credit requirement. All of them were native Spanish speakers who were right-handed and had no known motor or perceptive disorders. None of them had participated in Experiment 1.

Materials. The same stimuli as in Experiment 1 were used but with the previously mentioned modification. Furthermore, the pairs of words used to create the heterogeneous condition in Experiment 1 (*señora–mujer*, *diario–periódico*, *memoria–recuerdo*) were not included in Experiment 2. A full list of the materials used in Experiment 2 is shown in Appendix B.

Design. The experimental design was the same as in Experiment 1, but in this case each participant was asked to learn just three experimental blocks: (1) one constant homogeneous block, (2) one variable homogeneous block with a phonologically related odd-man-out, and (3) one variable homogeneous block with a nonphonologically related odd-man-out. Thus, the between-subjects variable order had three levels, depending on which block was presented first.

Apparatus and procedure. Apparatus and procedure were the same as those used in Experiment 1, but in this experiment each prompt word appeared four times per block instead of three times.

Results

An ANOVA was carried out on the written latencies, with condition (constant, variable phonologically related, and variable phonologically unrelated) as within-subject variables and order and set of words as between-subjects variables. The same exclusion criteria as in Experiment 1 were applied. This time 1.56% of the trials were extreme outliers, and 1.85% of the data were treated as errors. Mean written latencies and standard deviations for each condition are shown in Table 3. A main effect of condition was found, $F(2, 72) = 9.06$, $MSE = 63{,}037.37$, $p < .001$. To clarify which conditions were significantly different, t tests were carried out. Significant differences were observed between the constant homogeneous condition and the variable condition phonologically related, $t(47) = 2.32$, $p < .05$, and between the constant homogeneous condition and the variable condition without phonological relationship, $t(47) = 3.66$, $p < .01$, reflecting shorter written latencies in the constant condition than in both variable conditions. More important, the difference between the variable phonologically related condition and the variable condition not phonologically related was also significant, $t(47) = 2.30$, $p < .05$. Longer latencies were measured when the odd-man-out was not phonologically related to the target words. Besides, the variable set of words was significant, $F(3, 36) = 2.92$, $MSE = 418{,}483.93$, $p < .05$. A t test revealed that the set of "ve-" words was slower than the "ba−" set, $t(35) = 4.23$, $p < .01$; the "bo−" set, $t(35 = 3.76$, $p < .01$; and the "vi−" set, $t(35) = 6.16$, $p < .01$. No other differences were significant.

Table 3
Mean Written Latencies (in ms), Standard Deviations, and Spoil Effects (in ms) in Experiment 2

Condition	*M*	*SD*	Spoil effect
Homogeneous	913	222	
Variable phonologically related	947	226	34
Variable phonologically unrelated	985	233	72

Discussion

The results obtained in Experiment 2 are similar to those observed in Experiment 1, but in this case a spoil effect in the variable phonologically related condition was also observed. The improvements in the materials and the design introduced in Experiment 2 allowed us to detect an advantage of the constant homogeneous blocks over both variable blocks, indicating that the preparation effect is stronger when all the words within a block share the orthographic onset. Critically, participants were faster when the odd-man-out was phonologically related to the target words than when there was no phonological relationship, even though orthographic overlap with the targets was the same in both variable groups. These data support the idea of phonological information being used when generating a written response.

The results obtained in Experiments 1 and 2 suggest that phonology is used by the participants during the writing process. Written latencies were benefited when participants were able to prepare the initial phonological segment of a response word in advance. It seems that sublexical phonological information is retrieved during handwriting, so the constant homogeneous blocks and the variable blocks with a phonologically related odd-man-out allow the anticipation of the phonological unit to be produced. However, it is possible to propose a lexical explanation for our findings. It could be the case that the phonological lexical form of the phonologically related odd-man-out *vacuna* (/bɑkuna/) activates other lexical entries related to it in the phonological lexicon (e.g., /bɑka/, /bɑliente/, /bɑnana/, /bɑraja/). These phonological word forms would in turn activate the corresponding orthographic word forms (e.g., *vaca*, *valiente*, *banana*, *baraja*) through links between the phonological lexicon and the orthographic lexicon (Bonin et al., 2001). This kind of process would offer a lexical account of the results obtained in Experiments 1 and 2. To confirm or overrule this account, we conducted a third experiment, in which we used articulatory suppression to selectively interfere with the sublexical processes. Articulatory suppression involves making a participant repeatedly produce an irrelevant word or sublexical unit. This procedure has proved successful in selectively disrupting the sublexical process in written spelling by interrupting the subvocal rehearsal. For example, the patient MMD studied by Folk, Rapp, and Goldrick (2002) produced more form-related substitutions with articulatory suppression than without articulatory suppression. In addition, MMD made more errors on words containing low-frequency phoneme-to-grapheme segments than on words with high-frequency phoneme-to-grapheme segments when spelling in normal conditions. However, this difference disap-

peared under articulatory suppression. This pattern suggests that articulatory suppression affected sublexical processing but spared the lexical processing. This ability of articulatory suppression to "disconnect" phonological sublexical processing offers a unique opportunity to test whether the phonological preparation effect originates at the lexical or at the sublexical level.

Experiment 3

In Experiment 3 the participants performed the same task as in Experiment 2 but in this case under articulatory suppression. If the effects observed in Experiment 2 originated at a sublexical level, they should disappear in Experiment 3. Conversely, if the lexical account is correct, the preparation effect and the spoil effect should be equivalent to those obtained in Experiment 2.

Method

Participants. Forty-eight students from introductory courses at the University of La Laguna took part in this experiment to fulfill a course credit requirement. All of them were native Spanish speakers who were right-handed and had no known motor or perceptive disorders. None of them had participated in Experiments 1 or 2.

Materials and design. The same materials and design as in Experiment 2 were used.

Procedure. The procedure was the same as in Experiment 2, but in this case participants had to repeat the meaningless syllable /lu/ during all of the test phase. We chose this syllable because it was not present in any of the response words used in the experiment. During the practice block they were instructed to produce this syllable in a systematic manner, with an equivalent time interval between repetitions. During the test phase they had to start producing it as soon as they saw the first fixation point.

Results

An ANOVA was carried out on the written latencies from Experiments 2 and 3, with condition (constant, variable phonologically related, variable phonologically unrelated) as a within-subject variable and order and set of words as between-subjects variables. Extreme outliers (1.62%) and errors (1.86%) were excluded from the analysis following the same criteria as in Experiments 1 and 2. Mean written latencies and standard deviations obtained for each condition in Experiment 3 are shown in Table 4. None of the included variables reached significance ($F < 1$). Constant homogeneous blocks were not faster than the variable blocks, and the variable blocks did not differ from each other. Another ANOVA was conducted over the latencies of Experiments 2 and 3, including condition as a within-subject variable and order, set of words, and experiment (Experiment 2, Experiment 3) as between-subjects variables. We wanted to know whether the introduction of articulatory suppression reliably changed the pattern of results. The analysis showed that the two-way interaction Experiment $\times$ Condition was significant, $F(2, 144) = 4.31$, $MSE = 20{,}732.53$, $p < .05$, showing that the effects observed in Experiment 2 were absent in Experiment 3.

Table 4
Mean Written Latencies (in ms), Standard Deviations, and Spoil Effects (in ms) in Experiment 3

Condition	*M*	*SD*	Spoil effect
Homogeneous	966	221	
Variable phonologically related	989	218	23
Variable phonologically unrelated	985	230	21

Discussion

In Experiment 3 we failed to obtain preparation effects. Participants did not benefit from the shared segments of the response words. These results suggest a sublexical nature of the effects observed using the implicit priming paradigm in Experiments 1 and 2. It seems that participants were unable to use the information about the shared initial segments when the sublexical pathway was engaged in processing a different sublexical unit. This indicates that the preparation effect was attributable to anticipation of the shared initial segments of the response words and not due to an advantage coming from the activation of related words in the phonological lexicon.

General Discussion

We reported three experiments investigating the role of phonology during the writing process. We used the odd-man-out variant of the implicit priming paradigm to determine whether phonological information was used by the participants to prepare the written response. In this paradigm, participants produced a previously learned list of words that could share or not share the initial segment. In Experiment 1 we observed shorter response latencies when the target words were embedded in constant homogeneous blocks (all the response words shared the initial segment) rather than in heterogeneous blocks (none of the responses shared the initial segment). This indicates that participants used the information about the shared segments of the response words to prepare the forthcoming written response. However, when an odd-man-out completely unrelated to the target response words was included, the participants were no longer able to anticipate the initial segment of the response, which led to a spoil effect. Crucially, we failed to obtain a spoil effect in Experiment 1 when the odd-man-out was phonologically related (but not orthographically related) to the target words. In addition, we found differences between both groups of odd-man-outs (phonologically related vs. not phonologically related). In Experiment 2, with improved materials and design, we obtained a spoil effect due to the phonologically related odd-man-out, but this was significantly smaller than that observed in the nonphonologically related condition. This pattern of results suggests that participants' written responses profited from the phonological information provided by the phonologically related odd-man-out. Experiment 3 showed that the preparation effect vanished under articulatory suppression. We interpret these results as evidence supporting the involvement of the phonological information during handwriting at a sublexical level.

Our findings fit with a functional architecture in which lexical and sublexical processes integrate information at a grapheme level (Folk et al., 2002; Houghton & Zorzi, 1998, 2003; Rapp et al., 2002), so the activation of the same graphemic element from both

processes would strengthen the correct selection of the initial segment. If such a mechanism is assumed, a strong preparation effect is expected for the constant homogeneous condition, because the lexical orthographic information is reinforced by the constant activation of an orthographic element through the sublexical system. When performing a variable block, an initial segment different from the target one is introduced by the odd-man-out, so participants cannot unambiguously select the correct initial segment in advance. However, when the odd-man-out is phonologically related to the target responses, the target initial phonological segment can still be prepared, even before response selection (Roelofs, 2008). It is also possible that the initial phonological segment of the phonologically related odd-man-out activates all the orthographic forms linked to it, including the orthographic form present in the target response words. This process would produce an advantage of the variable phonologically related condition over the nonphonologically related condition.

For example, in the variable phonologically related block constituted by the response words *baraja*, *balada*, *banana*, and *vacuna*, the written performance of the initial segment of the odd-man-out *vacuna* ("va−") implies the retrieval of the sublexical phonological unit /bɑ/, which is in fact shared by all the response words of the block. Even when the participants cannot anticipate the actual initial grapheme (the next response word can start with either the letter *b* or the letter *v*), they are still able to predict the initial phonological segment of the next response. It is possible that this phonological segment activated both the grapheme *b* and the grapheme *v*. Conversely, when the odd-man-out is neither phonologically nor orthographically related to the targets, such as *tarima* in our example, target words cannot profit from either the orthographic or the phonological sublexical information. In consequence, spoiling of the whole preparation effect is observed because the initial segment of the target response is not consistently activated by all the trials within a block.

If a sublexical account of the observed effects is correct, then both orthographic and phonological preparation should disappear when the sublexical process is disconnected, because only lexical information would be available to perform the task. In Experiment 3 we tested this prediction by using articulatory suppression. It is generally assumed that the continual repetition of a meaningless syllable selectively disrupts the sublexical process by interrupting the subvocal rehearsal, and indeed we did not obtain a preparation effect when participants performed the writing task under articulatory suppression. It seems that participants were not able to use the information about the segments shared by the response words when sublexical processes were engaged in a different task (in our experiment, producing the syllable /lu/). This suggests that the preparation effects observed in Experiments 1 and 2 originated at a sublexical level.

Although we cannot discard the obligatory phonological mediation hypothesis on the basis of the results obtained in the present study, this kind of theory has been progressively disregarded due to a large amount of experimental and neuropsychological data that it cannot account for. As mentioned earlier, from the obligatory mediation point of view it is difficult to explain not only the performance of several neuropsychological patients (Lhermitte & Dérouesné, 1974; Miceli et al., 1997; Rapp et al., 1997) but also the normal writing process in an opaque language (Hotopf, 1980). Therefore, we consider that the sublexical version of the orthographic autonomy hypothesis represents the optimum perspective to account for the pattern of results obtained in the literature concerning the spelling process, including the evidence reported here. Nevertheless, more investigation is necessary to determine in which precise conditions the phonological information affects the written response and what is the extent of the phonological contribution in normal handwriting situations.

We think that our data provide strong evidence for the involvement of phonological information in the unimpaired handwriting production process through sublexical mechanisms. It seems that the sublexical process would strengthen the correct selection of the constitutive graphemes of words. Some particularities of our experimental design allow us to rule out several alternative explanations for the phonological preparation effect reported here. First, it is worth noting that both odd-man-outs had the same orthographic overlap with the target words, so this cannot be the cause of the reduced spoil effect observed in the variable phonologically related blocks. Furthermore, this effect cannot be attributed to the influence of the visual information given by previous responses, because the ink of the pen was removed so participants could not see what they wrote. Likewise, the reduced spoil effect cannot be explained by differences in latency between the words used as odd-man-outs, because only the target words (which were the same across all the conditions) were considered for the analysis. Finally, it is unlikely that general memory retrieval processes were responsible for the present results. Studies using immediate serial recall tasks report slower response times when the items have a phonological relation (Baddeley, 1997; Cholin et al., 2004), whereas we observed faster written latencies when the odd-man-out was phonologically related to the targets. Moreover, preparation effects have been obtained even when the memory component of the task was absent (Alario et al., 2007; Roelofs, 1999; Santiago, 2000).

Using the odd-man-out variant of the implicit priming paradigm, we succeeded in finding both preparation (Experiment 1) and spoil effect (Experiments 1 and 2) in a handwriting task. Moreover, we were able to reduce the size of the spoil effect by manipulating the phonological properties of the odd-man-out. Our study confirms that the odd-man-out variant of the implicit priming paradigm can be used to determine which units are functional in the preparation process of a written response. Obviously, spelling-to-dictation, copy, and written picture naming tasks have vastly contributed to our knowledge of the processes involved in normal handwriting production, but some characteristics of these paradigms make them not always ideal for approaching some empirical questions. For instance, this kind of paradigm often compares different groups of words per condition. This fact is particularly relevant for handwriting production tasks because slight differences in letter shape can lead to huge variations in hand movements. In implicit priming, the effect of the relationship between the words within a block is tested over the same small set of target words. Also, it would be recommendable to have at one's disposal a paradigm involving the actual production of the primes. This particularity of implicit priming could be especially important when one wants to tap into later stages of the production process. Finally, the odd-man-out variant of the paradigm permits the manipulation of one property of the words included in a block while another property is kept constant. Thus, the influence of a wide range of sublexical units during handwriting could be tested.

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Appendix A

Prompt and Response Words Used in Experiment 1

Table A1

Syllable for set of words	Constant homogeneous	Variable phonologically related	Variable phonologically unrelated	Heterogeneous		
"Ba−"	poema–**BALADA** plátano–**BANANA** naipes–**BARAJA** suciedad–BASURA	poema–**BALADA** plátano–**BANANA** naipes–**BARAJA** inyección–VACUNA	blusa–CAMISA poema–**BALADA** plátano–**BANANA** naipes–**BARAJA**	poema–**BALADA** señora–MUJER diario–PERIÓDICO memoria–RECUERDO	plátano–**BANANA** señora–MUJER diario–PERIÓDICO memoria–RECUERDO	naipes–**BARAJA** señora–MUJER diario–PERIÓDICO memoria–RECUERDO
"Ve−"	próximo–**VECINO** reunión–**VELADA** poción–**VENENO** calor–VERANO	hermosura–BELLEZA próximo–**VECINO** reunión–**VELADA** poción–**VENENO**	llegada–REGRESO próximo–**VECINO** reunión–**VELADA** poción–**VENENO**	señora–MUJER diario–PERIÓDICO memoria–RECUERDO próximo–**VECINO**	señora–MUJER diario–PERIÓDICO memoria–RECUERDO reunión–**VELADA**	señora–MUJER diario–PERIÓDICO memoria–RECUERDO poción–**VENENO**
"Bo−"	claxon–**BOCINA** entrada–**BOLETO** farmacia–**BOTICA** cúpula–BÓVEDA	claxon–**BOCINA** entrada–**BOLETO** farmacia–**BOTICA** náusea–VÓMITO	claxon–**BOCINA** entrada–**BOLETO** farmacia–**BOTICA** dolor–CÓLICO	claxon–**BOCINA** señora–MUJER diario–PERIÓDICO memoria–RECUERDO	entrada–**BOLETO** señora–MUJER diario–PERIÓDICO memoria–RECUERDO	farmacia–**BOTICA** señora–MUJER diario–PERIÓDICO memoria–RECUERDO

Note. Prompt words are lowercased, and responses are uppercased. Experimental words appear in boldface.

Appendix B

Prompt and Response Words Used in Experiments 2 and 3

Table B1

Syllable for set of words	Constant homogeneous	Variable phonologically related	Variable phonologically unrelated
"Ba−"	poema–**BALADA** plátano–**BANANA** naipes–**BARAJA** descenso–BAJADA	poema–**BALADA** plátano–**BANANA** naipes–**BARAJA** jarrón–VASIJA	poema–**BALADA** plátano–**BANANA** naipes–**BARAJA** plataforma–TARIMA
"Bo−"	claxon–**BOCINA** entrada–**BOLETO** farmacia–**BOTICA** cúpula–BÓVEDA	claxon–**BOCINA** entrada–**BOLETO** farmacia–**BOTICA** náusea–VÓMITO	claxon–**BOCINA** entrada–**BOLETO** farmacia–**BOTICA** dañino–TÓXICO
"Ve−"	próximo–**VECINO** reunión–**VELADA** poción–**VENENO** calor–VERANO	hermosura–BELLEZA próximo–**VECINO** reunión–**VELADA** poción–**VENENO**	parcela–TERRENO próximo–**VECINO** reunión–**VELADA** poción–**VENENO**
"Vi−"	existencia–**VIDA** poste–**VIGA** tinto–**VINO** abrigo–VISÓN	barril–BIDÓN existencia–**VIDA** poste–**VIGA** tinto–**VINO**	serpiente–PITÓN existencia–**VIDA** poste–**VIGA** tinto–**VINO**

Note. Prompt words are lowercased, and responses are uppercased. Experimental words appear in boldface.

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